AN INVESTIGATION OF CONTAMINANT IMPACTS TO THE WATERCRESS DARTER, ETHEOSTOMA NUCHALE, AND ITS HABITAT AT ROEBUCK SPRINGS, THOMAS' SPRING, AND GLENN SPRINGS, JEFFERSON COUNTY ALABAMA

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INTRODUCTION

The watercress darter, Etheostoma nuchale, is an endangered species known to occur naturally only in three springs in Jefferson County, Alabama; Glenn Springs, Thomas' Spring, and Roebuck Springs. In 1988 the species was successfully transplanted in Tapawingo Plunge Spring, also located in Jefferson County.

In 1985, the U.S. Fish and Wildlife Service funded a contract with Dr. Mike Howell to conduct a 5-year population status and trends study of the watercress darter in the three springs in which the species historically occurs (Howell 1989). The Thomas' Spring population was determined to have remained relatively constant from 1985 through 1988, ranging between 5,888 and 6,850. However, the 1989 study estimated the population to have decreased to 3,484. In 1986 the number of darters estimated to inhabit Glenn Springs fell to 737, one half of the numbers reported for the previous year. The following year the population increased to near the 1,985 level and has remained between 1,110 and 1,312 since.

Of the known localities where watercress darters exist, the Roebuck Springs site has historically contained the greatest number of individuals. The habitat is much more extensive here in terms of area extending downstream from the spring basin for 625 yards. For this reason the Howell study divided the area into two sites: Roebuck Springs basin and Hawkins Park spring run. During the first three years of the investigation, 1985 - 1987, the population in the basin area was estimated to have increased from 16,786 to 37,872. A major decline appeared to have occurred during the remaining two years with the 1989 population estimated at 5,782. The largest population of darters projected anywhere, 58,905, was found in the Hawkins Park run in 1985. From that time the species began a drastic decline with only one individual taken from the ten collection stations in 1988 for a computed population of 468. In 1989 the population underwent a modest increase to an estimated number of 4,675.

Although population levels in Glenn and Thomas' Springs have been erratic, the most dramatic impacts have occurred in Roebuck Springs where 1989 numbers were 13% of the 1985 estimate. It was suggested in Dr. Howell's report that the problem could possibly be linked to a water pollution source affecting the springs.

In order to ascertain if contaminants could be impacting the darter and/or its habitat, the Fish and Wildlife Enhancement Office, Daphne, Alabama initiated an investigation. This document is a summary of interim reports submitted during the study as well as the final survey data and conclusions.

METHODS AND MATERIALS

It was determined that the initial effort should be conducted where the greatest impacts had been observed, namely in Roebuck Springs. This would be followed by an investigation of Thomas' and Glenn Springs. Two matrices were chosen for chemical analysis; sediment and snails. Sediment has the ability to assimilate and concentrate a wide range of contaminants particularly the less soluble constituents. Sediment also provides a historical record of inputs into a system. The watercress darter being a rather sedentary species spends much of its time resting on the bottom in direct contact with the stream sediments. Therefore, the darter would, potentially, have the opportunity to directly uptake contaminants occupying these sediments.

An important factor in the interpretation of sediment data is the bioavailability of the chemical constituents and the capacity for biomagnification through the food chain. This assessment is frequently done by conducting tissue residue analyses of organisms in primary contact with these sediments. It is of particular value if that organism happened to occupy a position in the food chain that constituted a significant part of the diet of the organism undergoing the risk assessment. A snail was found in each of the three springs that fulfilled these criteria and, with few exceptions, was available for collection at all stations.

An inspection of the areas around the springs was conducted to assess potential contaminant sources and the appropriate analytical parameters. All the springs were located in close proximity to heavily traveled streets and roadways and their associated runoff. A large diameter storm drainage pipe was observed discharging into the upper end of Roebuck Springs near the spring basin. A reconnaissance of the area revealed that this drainage network collected runoff from a car dealership as well as a number of other commercial businesses. To assess these impacts metals and polycyclic aromatic hydrocarbons (PAH's) were incorporated into the analytical parameter list for all stations. The land use survey concluded that Roebuck Springs had a possibility of being impacted by pesticides, as a result of activities associated with the management of the park. To address these concerns a chlorinated hydrocarbon pesticide/PCB scan for 33 compounds was run on all samples analyzed from the initial Roebuck Springs investigation.

There were no observed commercial or municipal point source discharges into any of the three springs. A potential for groundwater contamination existed but was a difficult concern to address since the recharge areas were poorly defined thus making it nearly impossible to accurately delineate potential contaminants. It was concluded that the basic analyses being conducted were adequate to address ground water related pollutants anticipated in the study areas.

All sediment samples were composited, consisting of from three to six subsamples, the number of subsamples being dependent on the size of the area being investigated. In shallow water, less than 1 foot, the subsamples were collected with a large stainless spoon or scooped into a small glass jar. At deeper water stations a stainless steel Petite Ponar Grab Sampler was used.

Only highly organic or clay sediments were taken. Samples containing sand, gravel, or rocks were discarded and not included in the composite. Collection sites were chosen in areas of deposition rather than scoured areas where available. The subsamples were placed in a large aluminum pan for blending, after which the necessary aliquotes were taken. It was understood that use of the aluminum pan would contaminate the samples for that analysis. However, there was no indication that aluminum was a metal of concern in this study.

Snail samples were collected individually by hand. Where possible snails were taken randomly throughout the station site. A certain degree of spacial bias was unavoidable since they tended to concentrate on hard substrates (gravel and rocks) near the waters edge.

The samples for chemical analysis were stored in commercially acid/solvent cleaned glass jars with teflon lined lids. After collection the jars were tagged and immediately placed on wet or dry ice. Within 48 hours they were transferred to the Daphne Field Office and stored in a freezer prior to shipment for analysis. All samples were shipped in ice chests containing adequate dry ice to maintain the frozen condition.

Sediments for Microtox bioassay evaluation were collected as aliquotes in conjunction with the samples for chemical analysis. The sediments were placed in one gallon clean glass jars and preserved on wet ice. Within 6 hours of collection the pore waters had been removed using the Winger Extraction Method (personal communication) and submitted for the Microtox toxicity evaluation.

1988 Survey:

The first study was initiated at Roebuck Springs on November 10, 1988. Composite duplicate sediment samples were collected at three sites; the spring basin, the area of the storm drain discharge into the spring run, and downstream adjacent to the Roebuck Recreation Center, figure 5. Composite duplicate snail samples were collected in the spring basin and the downstream run adjacent to the Roebuck Recreation Center. An unsuccessful attempt was made to find snails at the storm drain discharge station. Metals, PAH's, and chlorinated hydrocarbon/PCB analyses were conducted on the sediment and snail samples collected from the station adjacent to the Roebuck Recreation Center. It was reasoned that this site would reflect upstream impacts. The remaining samples were held for future analysis.

1989 Survey:

On June 15, 1989, a follow-up survey was conducted at Roebuck Springs to expand the data base and to confirm the elevated PAH concentrations reported from the initial study. The sampling effort was expanded to seven stations, extending from the spring basin downstream to an area below the known range of the darter, a total distance of approximately 1.0 miles, figure 6. Composite snail and sediment samples were collected at all stations with the exception of the most downstream station at which snails were unavailable. Because the pesticide data from the initial survey were below the detection limit, 0.05 ppm, these analyses were deleted from this subsequent investigation. Although pesticides were known to have been used on the park golf course the runoff into the spring run was at the lower extremity of the darters range. As a result this downstream discharge was not determined to be a potential contributing factor in the decline of the darter population. To assess the possibility of histopathological aberrations, watercress darters were collected and submitted to the U. S. Fish and Wildlife Fish Service Technology Center in Bozeman, Montana, for examination.

1990 Survey:

On July 25, 1990, a third survey was conducted at Roebuck Springs. PAH and Microtox bioassay analyses were run on sediment samples collected from four stations, figure 7. Three of these stations had been previously sampled for chemical analyses; the spring basin, the storm water discharge site, and the run downstream of the tennis courts. The forth location, the mouth of an unnamed tributary entering the spring run near the lower reach of the darters range, had not been sampled. This tributary was suspected of being a source of PAH's and poor water quality primarily in the form of copper sulfate introduced upstream for algae control. Snails were collected for PAH analysis at all stations with the exception of the storm water drain area where they were not available.

During this survey the investigation was expanded to include Thomas' and Glenn Springs. PAH and metal analyses were conducted on all sediment and snail samples. A land use survey indicated that pesticides were not used in areas subject to runoff into the springs and were, therefore, not included in the parameter list.

In Thomas' Spring, composite samples were taken at two sites; the original spring and a manmade pond adjacent to and receiving runoff from the spring, figure 8. The spring was divided into east and west sampling sections. A composite sample consisting of three subsamples was collected from each sampling section. An additional composite sediment sample was taken in the east section for Microtox bioassay analysis. Snails were not found to be as common as in Roebuck Spring. After much effort, the minimum sample size was obtained in the east section but not in the west section.

The manmade pond was created in 1987 to provide additional watercress darter habitat. A single composite sediment sample was taken consisting of two subsamples from near the dam and two samples at the point where the spring water enters the pond. The sample was split for chemical and Microtox bioassay analyses. Snails were much more common here than in the spring. Two composite snail samples were collected, one on the north shoreline and another on the south shoreline.

Sampling stations were established at two sites in Glenn Springs; the main spring run between the spring basin and the highway and in a small tributary to the run that parallels the highway, figure 9. Composite sediment and snail samples were collected at the main spring run station with the sediment split for chemical and Microtox bioassay analyses. A composite snail sample was randomly collected at the tributary station for PAH and metal analyses. A sediment sample was not collected at this station since the bottom material consisted of sand and gravel. Snails were found to be quite common and widespread throughout Glenn Spring.

RESULTS

ROEBUCK SPRINGS

1988 Survey:

The initial Roebuck Springs investigation conducted on November 10, 1988 sampled three stations. The spring basin station was selected as a background and to assess contaminant input from groundwater sources exclusive of surface water impacts. The stormwater discharge site would determine contaminant loading from a major surface water runoff source. The Roebuck Recreation Center station would provide an estimate of the total loading to the system downstream of the major suspected contaminant sources but was still located within important darter habitat.

Since this investigation was established as a screening survey, only the Roebuck Recreation Center station samples were submitted for analysis. Chlorinated hydrocarbon pesticides, metals, and PAH's were run on the sediment as well as the snail samples. It was decided that if elevated contaminant levels were found the remaining frozen samples would be analyzed to better pinpoint the source and delineate the extent of contamination.

Because of a laboratory error in reporting the data all PAH values were inaccurately reported a thousand fold greater than the actual concentrations. Nevertheless, the corrected data were still in excess of that found in unpolluted streams. Total PAH's in sediments collected below the recreation center averaged 10.17 ppm, table 1. A total PAH concentration of 0.34 ppm found in the snails indicated that these contaminants were indeed bioavailable. Individual PAH compounds in Roebuck Springs sediments ranged from 0.006 ppm for acenaphthylene to 1.4 ppm for fluoranthene. Benzo(a)pyrene, a compound with particular carcinogenic implications was found in sediments at 0.715 ppm and in the adjacent snails at 0.016 ppm. The highest value for a PAH in sediments was phenanthrene at 1.447 ppm. This was also the compound with the highest level reported in snails, 0.46 ppm.

The sediment and snail samples were analyzed for 23 metals, table 7. Based on sediment data, boron (38.9 ug/l), zinc (262 ug/l), mercury

(0.14 ug/l), magnesium (10,100 ug/l), cadmium (2.76 ug/l) and lead (209 ug/l) were all above the concentrations expected in unpolluted areas. In the snail samples mercury and cadmium were below detection levels with the remaining metals occurring at or slightly above concentrations expected in unpolluted areas.

A chlorinated hydrocarbon pesticide/PCB scan was conducted on both sediment and snail samples for 33 compounds. There were no values reported above the analytical detection limit of 0.05 ppm. These compounds are extremely persistent and any relatively recent contamination should have been detected.

Aliphatic hydrocarbon analyses were conducted on snail and sediment samples for pristane and phytane as well as the n-alkanes within the 12 to 20 carbon number chains, table 8. As with PAH,s these compounds may result from man-made or natural sources. However, they tend to be less toxic with no evidence of being carcinogenic. Frequently, organism synthesized alkanes result in a predominance of odd carbon number chains whereas anthropogenic sources result in increased numbers of even carbon number chains. However, there are enough exceptions to negate any clearcut assessment of the source based on carbon chains. Concentrations in Roebuck Springs were somewhat above background conditions.

<u>1989 Survey:</u>

The second survey at Roebuck Springs on June 15, 1989 expanded the effort to seven stations in an attempt to determine the source of the PAH contamination and the extent of the impacts. Of particular interest was a determination of the PAH contamination at the storm water drain site. Sampling was initiated in the spring basin and continued downstream for approximately one mile, table 1. In addition, watercress darters were collected at two stations, in the spring basin and immediately below the tennis courts, and submitted to the Fish and Wildlife Service Fish Technology Center, Bozeman, Montana for histopathological examination.

As suspected, the highest total PAH sediment concentrations reported, 27.88 ppm, were found in the area of the storm water discharge. The lowest, 0.8 ppm, occurred in a sample collected in the spring basin, the most upstream station. In the spring run downstream of the storm water discharge values in the sediments were in the range of 3.22 - 6.73 ppm until reaching a point immediately downstream from the mouth of a unnamed tributary which receives runoff from several bridge/roadway crossings. At this site total PAH sediment concentrations increased to 16.06 ppm. Further downstream at the last station in the study area, levels had once again decreased to a concentration of 6.59 ppm.

Similar to total PAH's, the maximum concentrations for individual compounds were also found at the storm water discharge. The highest being benzo(b)fluoranthene at 3.59 ppm followed by chrysene at 3.54 ppm and fluoranthene at 2.90 ppm. Benzo(a)pyrene, one of the more carcinogenic PAH's, was found here at 2.41 ppm.

Below the unnamed tributary the maximum individual concentration found was fluoranthene at 2.77 ppm and pyrene at 2.15 ppm. Benzo(a)pyrene was also elevated in sediments at this station, 1.16 ppm.

Watercress darters collected for histopathological examination showed no evidence of neoplasia yet there were a number of abnormalities that could have been related to the presence of PAH's in their environment. Two of the fish showed megalocytic hepatocytes which have been found to be precursors of neoplasia in sole in Puget Sound.

<u>1990 Survey:</u>

The third survey on July 25, 1990 incorporated Thomas and Glenn Springs into the investigation and utilized the Microtox bioassay to assess sediment pore water toxicity. The analysis for PAH consisted of 12 fewer compounds used in determining the total PAH value than was used in the previous studies. Therefore, total PAH concentrations can only be compared between stations sampled during this survey and not data from previous investigations. However, the values of the 14 individual compounds that were analyzed are comparable with the data for these compounds reported during the previous studies.

Four stations in Roebuck Springs were selected for PAH analysis; the spring basin, the storm water drain site, below the tennis courts, and the mouth of the unnamed tributary. Again, the highest total PAH concentrations in sediments, 12.88 ppm, were found in the storm water drainage area being three times that reported for any other Roebuck Springs station, table 1. At the following downstream station, below the tennis courts, the second highest levels, 4.32 ppm were reported. As expected PAH's were the lowest, 0.38 ppm, in the spring basin.

The station in the mouth of the unnamed tributary was found with slightly lower total PAH's, 3.44 ppm, than in the upstream station at the tennis courts. These lower values were somewhat surprising as it had been suspected that this creek was a PAH source into the spring system since the station immediately below the streams discharge had previously been found with the second highest values reported during that survey period.

It was unfortunate that snails were not available for analysis at the storm drain station since those sediments had the highest reported total PAH's. In the remaining three stations snail residues correlated well with sediment loads. In the spring basin where total PAH levels in the sediments were the lowest reported snail residues were below the detection limit of 0.01 ppm. Conversely, the highest reported residues, 0.23 ppm, occurred downstream of the tennis courts where some of the highest sediment loading was found.

The highest reported sediment concentration for a particular PAH compound was fluoranthene(3.2 ppm) followed by benzo(b)fluoranthene (1.7 ppm), phenanthrene (1.6 ppm), benzo(e)pyrene (1.4 ppm), and chyrsene (1.2 ppm), all reported from the storm water drainage station.

All other compounds throughout the spring run were less than 1.0 ppm.

The highest values for individual compounds in snails were from the station below the tennis courts: benzo(b)fluoranthene (0.64 ppm), pyrene (0.59 ppm), fluoranthene (0.57 ppm), benzo(a)pyrene (0.53 ppm), and benzo(e)pyrene (0.49 ppm). However, it should be noted that snails were not collected from the storm water drainage site.

With the exception of the storm water discharge site all other stations reported levels of PAH compounds relatively similar to those found during previous surveys. The levels at the storm water discharge for many of the compounds were considerably less than found during the 1989 investigation. This could have been the result of a decrease in the PAH input or stratification in the uptake of the station sediments. Sediments discharging via the storm water drain into the spring run have created a broad delta resulting in a number of individual inflow channels. Because of these numerous discharge points it is difficult to conduct a sampling scheme that adequately characterizes the pollutant loading. Therefore, it is possible that this reported decrease in PAH concentrations could be the result of a sampling error caused by a complex stratification in sediment loading.

All samples collected in Roebuck Spring were found to be non toxic to the Microtox test organisms with an EC50 value greater than 100% of the test water. Even the storm water discharge site that was found with elevated PAH values in both sediment and snail samples failed to exhibit any degree of sediment pore water toxicity. For confirmation, a second assay was run at the station with similar results.

THOMAS' SPRING

PAH analyses were run on composite sediment and snail samples collected from both the spring and the adjacent manmade pond, table 2. In the man made pond total PAH sediment values were found at 0.21 ppm while the maximum found in the spring was 0.33 ppm from sediments collected on the east side. These values are comparable with the concentrations in the spring basin at Roebuck Spring. Pyrene and benzo (e)pyrene were reported with a concentration of 0.06 ppm, the highest of the individual compounds. The maximum total concentration for snails on the east side was 0.05 ppm with phenanthrene being the highest at 0.02 ppm. The total PAH levels in sediments on the west side of the spring, 0.24 ppm, were similar to those found on the east side.

Metals analyses were conducted on sediment and snail samples from the spring and the man made pond. The only metals that appeared to be elevated was manganese (3730 ppm) in a snail sample collected in the manmade pond, table 5.

An EC50 of 75.76 % was reported from the Microtox bioassay conducted on sediment pore water collected on the east side of the spring. This is indicative of a slight degree of toxicity; however, statistically the confidence range is so broad as to severely compromise the accuracy of the value. The sample from the manmade pond was found non toxic with an EC50 value greater than 100 % of the test water.

GLENN SPRING

Total PAH values in the sediments were found to be 0.62 ppm, slightly higher than in Thomas's Spring and the spring basin at Roebuck Spring, table 3. The greatest concentration reported for an individual compound was benzo(e)pyrene at 0.19 ppm. Total PAH in the snail sample was 0.53 ppm, almost as much as in the sediments, with the highest compound being benzo(e)pyrene at 0.10 ppm. A second snail sample collected in the tributary near the road was considerably less at 0.03 ppm.

Cadmium (0.5 ppm) and lead (93 ppm) were slightly elevated in sediment samples collected from the main spring run, table 6.

A Microtox bioassay was run on pore water extracted from a composite sediment sample taken along the main spring run between the spring source and the highway. The EC 50 for both the 5 minute and 15 minute assays was found to be greater than 100% of the test water, indicative of negative toxicity.

DISCUSSION

With the exception of snail collections from the manmade pond at Thomas' Spring and the spring basin in Roebuck Springs, PAH's were detected in all sediment and snail samples analyzed. It is not uncommon to find widespread low concentrations since PAH's are naturally biosynthesized by plants and microorganisms. They are also known to occur naturally as minerals particularly the relatively rare minerals curtisite, idrialite, and pendletonite. Another naturally occurring source of PAH are volcanic activity and forest fires. Forest fires and other open fires especially can be important in establishing background levels. Sediments are excellent indicators of PAH impacts since a significant portion of the aquatic input is incorporated into the bottom sediments of the receiving waters. In the absence of light or under anaerobic conditions they can remain in a stable condition for long periods of time.

By far the largest concentrations of PAH's are produced from anthropogenic sources such as coke production in the iron and steel industry, catalytic cracking in the petroleum industry, the manufacture of carbon black, coal tar pitch and asphalt, heating and power generation, open burning, emissions from internal combustion engines, storm water runoff, and, of course, oil spills. High levels have been reported in wastewater treatment plant discharges, particularly after a rainfall when surface runoff has been allowed to enter the wastewater collection system.

In water, PAHs may either evaporate, disperse into the water column, become incorporated into the bottom sediments, concentrate in aquatic biota, or experience chemical oxidation and biodegradation. The most important degradative process for PAHs in aquatic systems are photo-oxidation, chemical oxidation, and biological transformation by bacteria and animals. Most PAHs in the aquatic system are associated with particulate matter. In the water column they degrade rapidly, particularly with elevated temperatures, oxygen, and solar radiation. In sediments, PAHs degrade slowly in the absence of penetrating radiation and oxygen and may persist indefinitely in oxygen-poor basins or in anoxic sediments.

The primary objective of this investigation was to determine if contaminants existed at levels of concern in the three springs native to the watercress darter and, if possible, the source and extent of the contamination. Based on the analysis of sediment and snail samples Roebuck Springs was found to be significantly polluted, being impacted by a wide range of PAH compounds at levels documented to be detrimental to aquatic life. The highest concentrations were found adjacent to the stormwater discharge in the upper reach of the spring run, fig. 1,2. The second highest levels were found downstream of the confluence of an unnamed creek below the Roebuck Recreation Center parking lot. The evidence appears conclusive that the stormwater drain and possibly the creek are major avenues of PAH introduction into the spring system. Both of these sources appear to receive the same general type of urban runoff, i.e. streets, highways, parking lots, various types of light industry, and business, etc.

Although considerably lower than the concentrations found at the other stations in the drainage, the PAHs occurring in the spring basin are also indicative of some degree of hydrocarbon pollution since it is not uncommon for pristine unaffected aquatic environments to report PAHs below the level of detection, usually 0.01 ppm. These modest levels could possibly be the result of backwater from the stormdrain discharge, runoff from the adjacent land, or even contaminated groundwater.

Residue concentrations in resident snails in Roebuck Springs generally coincided with sediment values with the two highest total PAH levels, 1.4 and 0.12 ppm, occurring at stations with the maximum sediment levels, and the lowest value, 0.01 ppm, found in the spring basin where the lowest PAH values were found. However, the ratio of tissue to sediment concentrations was somewhat variable. This could be the result of stratification of contaminants within the sediment in which case a single composite sample may not be representative of the overall sediment loading in an area. This may account for the results of sediment samples taken below the tennis courts in which the November 10, 1988, collection reported 12.0 ppm and the June 15, 1989, sample found 4.46 ppm.

Snails tend to prefer a hard substrate to browse algae and periphyton and are frequently not in direct contact with sediments which could also compromise to some extent a direct correlation. The higher ratio of tissue to sediment levels at the storm water drain could be explained by the fact that these snails were collected directly from the bottom and many of those at the other stations were taken from substrates off the bottom.

During two of the collection periods, 1988 and 1990, adequate numbers of snails for chemical analysis were not found at the storm water discharge site. The minimum was obtained in 1989 only after a great deal of effort. This scarcity of snails could possibly have been the result of contaminants in the storm water discharge or a reflection of the variation of this habitat from the remainder of the spring run. The drain discharge has created a mini swamp environment characterized by a soft mud substrate. The spring run tends to consist of a hard bottom overlain with rocks and gravel, more supportive of the periphyton related feeding habitats of the snails.

Because of the limited geographic scope of the study it was not possible to determine the absolute lateral extent of PAH contamination in the spring run. At the farthest downstream station, approximately 1 mile below the spring basin, elevated values still existed. This could be the result of instream transport from the upstream sources or the effects of a continuous reintroduction from nonpoint sources adjacent to the stream. It is possible that, because of the numerous nonpoint sources, instream PAH concentrations may not appreciably fall below these levels throughout the Birmingham metropolitan area.

An additional objective of this investigation was to ascertain, if possible, the source of the individual PAH compounds occurring at elevated concentrations in the spring. The PAH group contains a large number and complex array of hydrocarbon compounds. To some extent the origin can be determined by the molecular weight of the compound. However, environmental conditions and the media being examined frequently alter the original compound confounding the assessment. For example, used crankcase oil shows a relatively high concentration of naphthalenes and benzothiophenes. An EPA study of stormwater particulates concluded that, after only 14 days of weathering, these two compounds can be significantly reduced and in some cases absent from the sample. Also, these compounds have a lower molecular weight and are therefore more water soluble. This characteristic makes them more available to the water column and less likely to be found in sediments. Photodegradation and biodegradation can be factors affecting the transformation of PAHs under natural conditions. A number of studies have documented the biodegradation of low molecular weight PAHs such as naphthalene, acenaphthene, and acenaphthylene at rates as great as 90% within 7 days. PAH's of higher molecular weights, such as fluoranthene, benzo(a)anthracene, chrysene, and benzo(a)pyrene, however, are much more resistant to biodegradation.

In evaluating the individual PAH's in the Roebuck Spring sediments it was found that the higher molecular weight compounds such as phenanthrene, fluoranthene, pyrene, benz(a)anthracene, chrysene, benzo(b)fluoranthene, and benzo(a)pyrene occurred in the greatest concentrations. Pyrene, fluoranthene, and benzo(a)pyrene have been particularly linked with used motor oils. An additional compound associated with used motor oil, naphthalene, was only found in trace amounts in the sediments. However, based on the solubility and weathering ability it may not be expected to significantly accumulate in sediments. Another compound prevalent in Roebuck Spring sediments, phenanthrene, has been found at high levels in gasoline, crude oil, and wood preservative waste. A study conducted in Rhode Island evaluating urban runoff found that the majority of chrysene and a high percentage of the fluoranthene and benz(a)anthracene reported was generated from highway runoff.

A determination of the impacts of the elevated concentrations of PAHs found in Roebuck Spring on the watercress darter population must include an assessment of the acute and chronic toxicity, sublethal effects, and carcinogenicity on the population as well as the associated environment. Historically PAHs have not been considered acutely toxic to aquatic life because the solubilities were less than the toxicity levels reported from laboratory bioassay tests. Recent studies conducted under more ecologically relevant conditions of simulated natural sunlight have found acute toxicities to increase dramatically. This photoinduced toxicity has increased the sensitivity of bluegills to anthracene 400 times more than that previously reported. Under these conditions a mortality of 100% occurred in less than 9 hours with an exposure level of .012 ppm. Preliminary screening has indicated that benzo(a)pyrene is even more toxic than anthracene. Benzo(a)pyrene was found in Roebuck Spring sediments at a level of 2.41 ppm. Although it is not possible to directly correlate sediment concentrations with anticipated water column concentrations, the sediment levels do indicate a cause for concern. A closer relationship has usually been found between sediments and the benthic or more sedentary organisms. This bioavailability is evident by 0.11 ppm benzo(a)pyrene in snails collected from this same site. The watercress darter is also an organism that spends much of its time on or in close proximity with bottom sediments.

The phototoxicity of PAH is dependent in part on the amount of solar radiation of the active wavelength penetrating the water. Although unimportant for aquatic systems with high particulate loads or significantly colored waters, this phenomenon becomes quite effective in clear waters such as Roebuck Springs where solar radiation can penetrate to ecologically significant depths.

The only assessment of acute or chronic toxicity conducted during this investigation was the Microtox bioassay conducted on sediment pore waters. The sediment pore water was assayed because it represents one of the most mobile mediums within the sediment matrix for the transport of contaminants into the aquatic biota. The Microtox protocol utilizes an extremely sensitive bioluminescent bacteria as the test organism.

The Microtox bioassay on pore water extracted from sediments collected at all three springs did not indicate any significant level of toxicity. However, there are limitations in this procedure that should not be overlooked. The test uses only one organism, a bacteria, to evaluate toxicity. Although it has been found to be one of the more sensitive test organisms, it still only represents one species and may or may not equate with the sensitivity of the watercress darter, particularly during critical life stages. Also the test did not factor in an assessment of photoinduced toxicity which has been determined to significantly increase the effects of many of these compounds.

Although PAH's were detected in Thomas' and Glenn Springs they were not found at concentration expected to be particularly harmful to aquatic life, fig. 3,4.

The manmade pond at Thomas' Spring had PAH's a bit lower than the other study sites. This could have been a result of its recent origin and distance from expected contaminant sources. Having only been in existence for a few years it would have a limited period of exposure to natural and man created PAH's. The location is also the most remote of all the study areas to roads and highways.

The U.S. Fish and Wildlife Service (Eisler 1987) has tabulated body burden levels of total PAHs for a number of mollusks, a group of organisms known for their ability to concentrate high levels of PAHs. The maximum value reported was 0.986 ppm in bay mussels near an industrialized area in Oregon. This concentration is less than the 1.4 ppm found in snails at the storm drain in Roebuck Spring.

Since 1984 the National Oceanic and Atmospheric Administration (NOAA) has been analyzing sediment samples from 200 coastal and estuarine sites throughout the United States (Long and Morgan 1990). Only two areas, Boston Harbor, MA (58.0 ppm) and the Hudson/Raritan Estuary, NY (34.0 ppm), reported total PAH,s greater than found in Roebuck Springs. While the NOAA study was not designed to evaluate the most polluted coastal areas, it does provide a good cross section of existing sediment PAH levels which include some of the more widely acknowledged polluted harbors.

During 1987-88, the U.S. Fish and Wildlife Service (Service) collected sediment samples from unconfined and confined disposal areas along the Houston Ship Channel (Cain 1989). The maximum total PAH concentration found was 0.268 ppm. at Atkinson Island. Although the Ship Channel is generally considered one of the more polluted areas in the country, particularly from petrochemical dischargers, PAHs were less than found at any of the stations in Roebuck Springs.

Sediment samples were collected from three recreational marinas, areas of traditionally high PAH levels, along the South Carolina coast. The maximum total PAHs were found to be 4.1 ppm. With the exception of the spring itself and one downstream site, all of the Roebuck Springs stations reported higher sediment concentrations than those found in the marinas.

Sediments in unaffected environments would be expected to have total PAH values of less than one ppm and are frequently reported as "non detected." Louisiana State University investigated sediment PAH levels at the site of an abandoned creosote wood treatment operation (Catallo and Gambrell 1987). This is a major hazardous waste site and has been placed on the National Priority List by EPA as a "Superfund Site." Although samples taken near the contaminant source contained PAHs as high as 49,207 ppm the nearby reference station could not confirm its presence.

Analyses on sediments and snails were run for a wide range of heavy metals at each of the springs. Although the results indicated elevated levels in sediments for a few of the metals there was no indication of significant uptake by the springs biota. Pesticides analyses of snail and sediment samples in Roebuck Springs did not exhibit any measurable level of contamination. This was the spring judged to have the best opportunity for pesticide impacts from area land use and related activities.

CONCLUSIONS

1. Roebuck Springs was the only site found with contaminant loading with PAH's at levels suspected of being harmful to the watercress darter. Residue levels in snail tissue were considerably less than found in sediments indicating a modest level of biotic uptake.

2. The primary source of PAH's into Roebuck Springs was a large diameter stormwater drainage pipe discharging into the upper reach

of the spring run. Elevated levels were also found in the spring run immediately below the mouth of an unnamed tributary indicating this as a secondary source. The parking lot below the tennis courts is another suspected secondary source.

3. Chlorinated hydrocarbon pesticides were not found above analytical detection limits in Roebuck Springs which was the spring suspected of having the greatest potential for pesticide impacts.

4. Microtox bioassays of sediment pore water samples did not indicate any appreciable level of toxicity. However, this should be interpreted as a limited assessment and not a conclusive toxicity evaluation.

5. Histopathological examinations of watercress darters collected from Roebuck Springs did not indicate any evidence of tumor formation. However, two of the fish were found with megalocytic hepatocytes which have been found to be precursors of neoplasia in other species of fish.

6. Cadmium and lead levels were elevated in Roebuck Springs sediments, yet low to non detectable concentrations in snail tissue indicated minimum bioavailability.

7. There were no observed commercial or municipal point source discharges into any of the three springs.

RECOMMENDATIONS

The storm drain discharging into the upper reach of Roebuck Springs should be removed and redirected into another drainage or at least to a point in the spring run well below the current and anticipated recovery range of the watercress darter.

A further investigation should be conducted on the unnamed tributary and the park parking lot in Roebuck Springs to assess their PAH contribution.

A water quality monitoring program should be developed in the three springs to establish a data base and historical record of the basic parameters, ie. pH, temperature, DO, etc.

A more indepth bioassay should be conducted using Roebuck Spring water on a battery of test organisms to evaluate chronic effects with particular emphasis on photoinduced toxicity.

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TABLES

TABLE 1. PAH Analysis of Sediment and Snail Samples Collected in Roebuck Springs During Three Surveys; November 10, 1988, June 15, 1989, and July 25, 1990. PPM, Wet Wt. S = sediment, B = biota (snails).

LOCATION	Spring Basin				Storm Water Discharge			
STATION #	89-4-1/2		01-08		89-4-3/4		01-09	
SAMPLE PERIOD	6-15-89		7-25-90		6-15-89		7-25-90	
SAMPLE TYPE	S	B	S	B	S	B	S	B
NAPH	0.03	<0.01	ND	ND	0.07	<0.01	ND	-
2-METHYL NAPH	0.06	<0.01	-	-	0.08	0.01	-	-
1-METHYL NAPH	0.06	<0.01	-	-	0.05	<0.01	-	-
BIPHENYL	0.01	<0.01	-	-	0.02	0.01	-	-
2,6 DIME NAPH	0.05	<0.01	-	-	0.05	0.02	-	-
ACENAPH-THYLENE	<0.01	<0.01	-	-	<0.01	0.01	-	-
ACENAPH-THENE	<0.01	<0.01	-	-	0.10	0.01	-	-
2,3,4-TRI METHYLNAPH	0.06	<0.01	-	-	0.07	0.02	-	-
FLUORENE	<0.01	<0.01	ND	ND	0.15	0.02	0.08	-
PHENAN	0.08	<0.01	0.05	ND	2.26	0.08	1.6	-
ANTHRAC	0.01	<0.01	0.01	ND	0.37	0.02	0.20	-
1-METHYL PHENAN	0.09	<0.01	-	-	0.25	0.03	-	-
FLUORANTH	0.05	<0.01	0.07	ND	2.90	0.18	3.2	-
PYRENE	0.06	<0.01	0.05	ND	2.61	0.15	1.0	-
BENZ(a)ANTHRAC	0.04	<0.01	0.02	ND	2.59	0.11	0.77	-
CHYRSENE	0.06	<0.01	0.02	ND	3.54	0.15	1.2	-
BENZO(b) FLUORANTH	0.04	<0.01	0.03	ND	3.59	0.14	1.7	-
BENZO(k) FLUORANTH	<0.01	<0.01	0.01	ND	1.36	0.07	0.17	-
BENZO(e) PYRENE	0.03	<0.01	0.07	ND	1.91	0.09	1.4	-
BENZO(a) PYRENE	0.03	<0.01	0.03	ND	2.41	0.11	0.88	-
PERYLENE	0.01	<0.01	-	-	0.46	0.01	-	-
INDENO-PYRENE	0.01	<0.01	-	-	1.39	0.07	-	-
DIBENZ ANTHRAC	<0.01	<0.01	0.01	ND	0.39	0.02	0.47	-
BENZO(ghi) PERYLENE	0.02	<0.01	0.01	ND	1.26	0.07	0.22	-
TOTAL	0.83	<0.01	0.38	ND	27.8	1.39	12.89	-

TABLE 1. PAH Analysis of Sediment and Snail Samples Collected in Roebuck Springs During Three Surveys; November 10, 1988, June 15, 1989 and July 25, 1990. PPM, Wet Wt.
S = sediment, B = biota (snails)

LOCATION	Upstream of Tennis Courts				Downstream of Tennis Courts			
STATION #	89-4-5/6				89-4-7/8		01-10	
SAMPLE PERIOD	6-15-89		7-25-90		6-15-89		7-25-90	
SAMPLE TYPE	S	B	S	B	S	B	S	B
NAPH	0.02	<0.01	-	-	0.02	<0.01	0.01	0.01
2-METHYL NAPH	0.03	<0.01	-	-	0.03	<0.01	-	-
1-METHYL NAPH	0.02	<0.01	-	-	0.02	<0.01	-	-
BIPHENYL	<0.01	<0.01	-	-	<0.01	<0.01	-	-
2,6 DIME NAPH	0.02	<0.01	-	-	0.01	<0.01	-	-
ACENAPH-THYLENE	<0.01	<0.01	-	-	<0.01	<0.01	-	-
ACENAPH-THENE	0.01	<0.01	-	-	0.01	<0.01	-	-
2,3,4-TRI METHYLNAPH	0.02	<0.01	-	-	0.01	<0.01	-	-
FLUORENE	0.02	<0.01	-	-	0.02	<0.01	0.04	ND
PHENAN	0.26	<0.01	-	-	0.32	<0.01	0.34	0.02
ANTHRAC	0.03	<0.01	-	-	0.04	<0.01	0.05	ND
1-METHYL PHENAN	0.03	<0.01	-	-	0.03	<0.01	-	-
FLUORANTH	0.41	0.04	-	-	0.57	0.01	0.57	0.02
PYRENE	0.31	0.04	-	-	0.43	0.01	0.59	0.02
BENZ(a)ANTHRAC	0.24	0.03	-	-	0.36	0.01	0.15	0.01
CHYRSENE	0.33	0.05	-	-	0.52	0.02	0.23	0.02
BENZO(b) FLUORANTH	0.28	0.03	-	-	0.39	<0.01	0.64	0.01
BENZO(k) FLUORANTH	0.21	0.02	-	-	0.36	<0.01	0.20	ND
BENZO(e) PYRENE	0.20	0.03	-	-	0.31	<0.01	0.49	0.01
BENZO(a) PYRENE	0.24	0.03	-	-	0.36	<0.01	0.53	0.01
PERYLENE	0.09	<0.01	-	-	0.08	<0.01	-	-
INDENO-PYRENE	0.21	0.02	-	-	0.27	<0.01	-	-
DIBENZ ANTHRAC	0.05	<0.01	-	-	0.07	<0.01	0.08	ND
BENZO(ghi) PERYLENE	0.19	0.02	-	-	0.23	<0.01	0.40	0.01
TOTAL	3.22	0.31	-	-	4.46	0.05	4.32	0.14

TABLE 1. PAH Analysis of Sediment and Snail Samples Collected in Roebuck Springs During Three Surveys; November 10, 1988, June 15, 1989 and July 25, 1990. PPM, Wet Wt. S = sediment, B = biota (snails).

LOCATION	Downstream of Park Recreation Center				Mouth of Unnamed Trib.	
STATION #	88-3-3/5		89-4-9/10		01-11	
SAMPLE PERIOD	11-10-88		6-15-89		7-25-90	
SAMPLE TYPE	S	B	S	B	S	B
NAPH	0.10	<0.01	0.03	<0.01	ND	ND
2-METHYL NAPH	0.15	<0.01	0.03	<0.01	-	-
1-METHYL NAPH	0.10	<0.01	0.02	<0.01	-	-
BIPHENYL	0.02	<0.01	<0.01	<0.01	-	-
2,6 DIME NAPH	0.09	<0.01	0.02	<0.01	-	-
ACENAPH-THYLENE	<0.01	<0.01	<0.01	<0.01	-	-
ACENAPH-THENE	0.04	<0.01	0.02	<0.01	-	-
2,3,4-TRI METHYLNAPH	0.14	<0.01	0.01	<0.01	-	-
FLUORENE	0.07	<0.01	0.04	<0.01	0.03	ND
PHENAN	1.20	0.05	0.54	<0.01	0.41	0.03
ANTHRAC	0.11	<0.01	0.08	<0.01	0.06	ND
1-METHYL PHENAN	0.36	0.07	0.04	<0.01	-	-
FLUORANTH	1.20	0.04	0.78	0.01	0.70	0.03
PYRENE	0.98	0.04	0.63	0.01	0.60	0.02
BENZ(a)ANTHRAC	0.70	0.02	0.54	0.01	0.16	0.01
CHYRSENE	1.07	0.03	0.80	0.01	0.24	ND
BENZO(b) FLUORANTH	0.87	0.02	0.58	<0.01	0.29	0.02
BENZO(k) FLUORANTH	0.51	0.02	0.49	<0.01	0.13	0.01
BENZO(e) PYRENE	0.52	0.01	0.44	<0.01	0.28	0.02
BENZO(a) PYRENE	0.62	0.02	0.53	<0.01	0.28	0.01
PERYLENE	0.15	<0.01	0.11	<0.01	-	-
INDENO-PYRENE	0.58	0.01	0.46	<0.01	-	-
DIBENZ ANTHRAC	0.13	<0.01	0.12	<0.01	0.05	ND
BENZO(ghi) PERYLENE	0.46	0.01	0.42	<0.01	0.21	0.01
TOTAL	10.17	0.34	6.73	0.04	3.44	0.16

TABLE 1. PAH Analysis of Sediment and Snail Samples Collected in Roebuck Springs During Three Surveys; November 10, 1988, June 15, 1989 and July 25, 1990, PPM, Wet Wt. S = sediment, B = biota (snails).

LOCATION	Immediately Below Mouth Of Unnamed Trib.		500' Below Mouth Of Unnamed Trib.	
STATION #	89-4-11/12		89-4-13	
SAMPLE PERIOD	6-15-89		6-15-89	
SAMPLE TYPE	S	B	S	B
NAPH	0.04	<0.01	0.03	-
2-METHYL NAPH	0.03	<0.01	0.03	-
1-METHYL NAPH	0.02	<0.01	0.02	-
BIPHENYL	0.01	<0.01	<0.01	
2,6 DIME NAPH	0.02	<0.01	0.02	-
ACENAPH-THYLENE	0.03	<0.01	<0.01	-
ACENAPH-THENE	0.04	<0.01	0.03	-
2,3,4-TRI METHYLNAPH	0.02	<0.01	0.01	-
FLUORENE	0.08	<0.01	0.04	-
PHENAN	1.14	0.01	0.48	-
ANTHRAC	0.18	<0.01	0.08	-
1-METHYL PHENAN	0.08	<0.01	0.04	-
FLUORANTH	2.77	0.02	0.89	-
PYRENE	2.15	0.02	0.67	-
BENZ(a)ANTHRAC	1.14	0.01	0.56	-
CHYRSENE	1.07	0.03	0.71	-
BENZO(b) FLUORANTH	1.41	0.01	0.56	-
BENZO(k) FLUORANTH	0.98	<0.01	0.42	-
BENZO(e) PYRENE	0.93	0.01	0.40	-
BENZO(a) PYRENE	1.16	0.01	0.53	-
PERYLENE	0.26	<0.01	0.11	-
INDENO-PYRENE	0.01	<0.01	0.44	-
DIBENZ ANTHRAC	0.22	<0.01	0.12	-
BENZO(ghi) PERYLENE	0.88	<0.01	0.40	-
TOTAL	14.67	0.12	6.59	-

TABLE 2. PAH Analysis of Sediment and Snail Samples Collected in Thomas' Spring on July 25-26, 1990. PPM, Wet Wt. S = sediment. B = biota (snails).

LOCATION:	Spring(East Side)		Spring(West Side)	Man Made Pond	
STATION #	01-01S	01-01B	01-02S	01-03S	01-03B
SAMPLE:	S	B	S	S	B
NAPH	ND	ND	ND	ND	ND
2-METHYL NAPH	-	-	-	-	-
1-METHYL NAPH	-	-	-	-	-
BIPHENYL	-	-	-	-	-
2,6 DIME NAPH	-	-	-	-	-
ACENAPH-THYLENE	-	-	-	-	-
ACENAPH-THENE	-	-	-	-	-
2,3,4-TRI METHYLNAPH	-	-	-	-	-
FLUORENE	ND	ND	ND	ND	ND
PHENAN	ND	0.02	ND	ND	ND
ANTHRAC	ND	ND	ND	ND	ND
1-METHYL PHENAN	ND	ND	ND	ND	ND
FLUORANTH	0.01	0.01	0.05	0.05	ND
PYRENE	0.06	ND	0.03	0.04	ND
BENZ(a)ANTHRAC	0.03	ND	0.02	0.02	ND
CHYRSENE	0.03	ND	0.02	0.03	ND
BENZO(b) FLUORANTH	0.04	0.01	0.02	0.01	ND
BENZO(k) FLUORANTH	0.02	ND	0.01	ND	ND
BENZO(e) PYRENE	0.06	ND	0.05	0.03	ND
BENZO(a) PYRENE	0.04	0.01	0.02	0.01	ND
PERYLENE	-	-	-	-	-
INDENO-PYRENE	-	-	-	-	-
DIBENZ ANTHRAC	0.01	ND	0.01	0.01	ND
BENZO(ghi) PERYLENE	0.03	ND	0.01	0.01	ND
TOTAL	0.33	0.05	0.24	0.21	ND

TABLE 3. PAH Analysis of Sediment and Snail Samples Collected in Glenn Spring on July 25-26, 1990. PPM, Wet Wt. S = Sediment, B = Biota (snail).

LOCATION	Main Spring Run		Trib. Near Road
STATION #	01-06S	01-06B	01-05B
SAMPLE	S	B	B
NAPH	0.03	0.03	ND
2-METHYL NAPH	-	-	-
1-METHY NAPH	-	-	-
BIPHENYL	-	-	-
2,6 DIME NAPH	-	-	-
ACENAPH-THYLENE	-	-	-
ACENAPH THENE	-	-	-
2,3,4-TRI METHYLNAPH	-	-	-
FLUORENE	ND	ND	ND
PHENAN	0.05	0.05	0.02
ANTHRAC	ND	ND	ND
1-METHYL PHENAN	-	-	-
FLUORANTH	0.08	0.08	ND
PYRENE	0.07	0.07	ND
BENZ(a)ANTHRAC	0.03	0.03	ND
CHYRSENE	0.03	0.03	ND
BENZO(b) FLUORANTH	0.03	0.05	ND
BENZO(k) FLUORANTH	0.02	0.02	ND
BENZO(e) PYRENE	0.19	0.10	ND
BENZO(a) PYRENE	0.04	0.03	ND
PERYLENE	-	-	-
INDENO-PYRENE	-	-	-
DIBENZ ANTHRAC	0.01	ND	0.01
BENZO (ghi) PERYLENE	0.04	0.04	ND
TOTAL	0.62	0.53	0.03

TABLE 4. Metal Analysis of Snail Samples Collected in Roebuck Springs on July 25-26, 1990. Results Reported as ppm, wet wt.

LOCATION:	Spring Basin	Below Tennis Courts	Mouth of Unnamed Trib
STATION #	DA01-08B	DA01-10B	DA01-11B
MATRIX:	Snails	Snails	Snails
AG	<6.0	<6.0	<6.0
AL	640.0	450.0	510.0
AS	1.1	0.84	1.6
B	<6.0	<6.0	<6.0
BA	83.8	78.9	94.2
BE	<0.3	<0.3	<0.3
CD	<0.7	<0.7	<0.7
CR	7.0	5.0	<3.0
CU	23.0	14.0	12.0
FE	1380.0	1090.0	2330.0
HG	0.044	0.026	0.024
MG	765.0	605.0	618.0
MN	539.0	636.0	651.0
MO	<3.0	<3.0	<3.0
NI	6.0	<3.0	<3.0
PB	<10.0	<10.0	<10.0
SE	0.54	0.54	0.40
SR	64.3	65.0	79.3
TL	<20.0	<20.0	<20.0
V	2.0	2.0	4.8
ZN	23.0	30.0	30.0

TABLE 5. Metal Analysis of Snail Samples Collected in Thomas Springs on July 25-26, 1990. Results Reported as ppm wet wt.

LOCATION:	Lt Side Spring		Rt Side Spring	Man Made Pond	
STATION #	DA01-01B	DA01-01S	DA01-02S	DA01-03/4B	DA01-03S
MATRIX:	Snails	Sediment	Sediment	Snails	Sediment
AG	<6.0	<2.0	<2.0	<6.0	<2.0
AL	924.0	19700.0	21800.0	1165.0	18800.0
AS	2.2	8.0	5.9	7.7	13.9
B	<6.0	2.0	3.0	<6.0	2.0
BA	112.0	99.6	76.8	340.0	103.0
BE	<0.3	0.99	1.3	<0.3	0.69
CD	<0.7	0.4	<0.3	<0.7	<0.3
CR	<3.0	30.0	32.0	<3.0	21.0
CU	3.9	18.0	16.0	9.6	12.0
FE	2770.0	18400.0	18900.0	5720.0	29200.0
HG	0.02	0.093	0.078	0.025	0.066
MG	322.0	2490.0	4000.0	716.0	1940.0
MN	89.5	61.3	48.8	3730.0	324.0
MO	<3.0	<1.0	<1.0	<3.0	<1.0
NI	<3.0	12.0	16.0	<3.0	8.5
PB	<10.0	54.0	46.0	<10.0	38.0
SE	0.3	2.3	2.5	0.52	1.0
SR	100.0	24.2	11.8	130.0	27.7
TL	<20.0	<5.0	<5.0	<20.0	<5.0
V	4.2	38.0	40.7	6.0	37.0
ZN	7.7	86.5	82.0	14.0	57.9

TABLE 6. Metal Analysis of Snail Samples Collected in Glenn Springs on July 25-26, 1990. Results Reported as ppm, wet wt.

LOCATION:	Trib Parallel To Hwy	Main Spring Run		
STATION #	DA01-05B	DA01-06B	DA01-06S	
MATRIX:	Snails	Snails	Sediment	
AG	<6.0	<6.0		<6.0
<2.0				
AL	620.0	190.0	11900.0	
AS	0.83	0.3	5.5	
B	<6.0	<6.0	4.0	
BA	78.4	72.9	74.0	
BE	<0.3	<0.3	1.5	
CD	<0.7	<0.7	0.5	
CR	<3.0	<3.0	19.0	
CU	14.0	12.0	19.0	
FE	918.0	220.0	15100.0	
HG	0.026	0.038	0.093	
MG	442.0	321.0	2110.0	
MN	132.0	67.5	137.0	
MO	<3.0	<3.0	<1.0	
NI	<3.0	<3.0	11.0	
PB	<10.0	<10.0	93.0	
SE	0.46	0.29	1.0	
SR	80.1	88.6	11.5	
TL	<20.0	<20.0	<6.0	
V	2.0	<0.9	26.0	
ZN	14.0	11.0	81.9	

TABLE 7. Metal Analyses of Sediment and Snail Samples Collected in Roebuck Springs Downstream Of The Park Recreation Center On November 10, 1988. Values Reported As ppm, wet wt.

STATION # MATRIX	88-3-5A Snails	88-3-5B Snails	88-3-3A Sediment	88-3-3B Sediment
AL	309.0	248.0	19000.0	12900.0
AS	2.24	2.20	6.54	7.28
SB	<30.0	<30.0	<30.0	<30.0
BA	97.9	89.7	180.0	125.0
BE	<0.10	<0.10	2.02	2.08
B	2.55	0.93	38.0	22.7
CD	<0.40	<0.40	2.76	2.23
CO	3.55	1.79	11.1	11.1
CR	2.13	0.91	41.6	38.9
CU	16.7	10.6	15.8	115.0
FE	696.0	811.0	16300.0	20400.0
HG	<0.02	<0.02	0.127	0.142
PB	<9.0	13.1	158.0	209.0
MG	945.0	1420.0	10100.0	9850.0
MN	911.0	808.0	768.0	717.0
MO	<12.0	<12.0	<16.0	<16.0
NI	(4.5	<4.5	24.6	18.0
AG	<9.0	<9.0	<12.0	<12.0
SE	<0.3	<0.3	0.624	0.373
SR	92.2	79.7	55.3	36.0
SN	<30.0	<30.0	<30.0	<30.0
V	1.44	1.61	42.2	33.8
ZN	39.9	28.6	181.0	262.0

TABLE 8. Aliphatic Hydrocarbon Analyses of Sediment and Snail Samples Collected in Roebuck Springs on November 10, 1988. Results Reported as ppm, wet wt. S = sediment, B = biota (snails)

LOCATION	Downstream of Park Recreation Center	
STATION #	88-3-3/5	
SAMPLE PERIOD	11-10-88	
SAMPLE TYPE	S	B
N-C12	0.15	0.01
N-C13	0.21	<0.01
N-C14	0.45	0.03
N-C15	0.95	0.91
N-C16	0.93	0.09
N-C17	1.11	0.55
PRISTANE	2.61	0.18
N-C18	1.24	0.21
PHYTANE	2.82	0.43
N-C19	0.44	0.09
N-C20	0.95	0.24

FIGURES

FIG 1. ROEBUCK SPRINGS,TOTAL PAH. COLLECTION DATE: 6/15/89
SB=Spring Basin,SD=Storm Drain,UTC=Upstream of Tennis Courts
BTC=Below Tennis Courts,RC=Below Park Rec. Center,
BT=Below Tributary, 500BT=500' Below Tributary

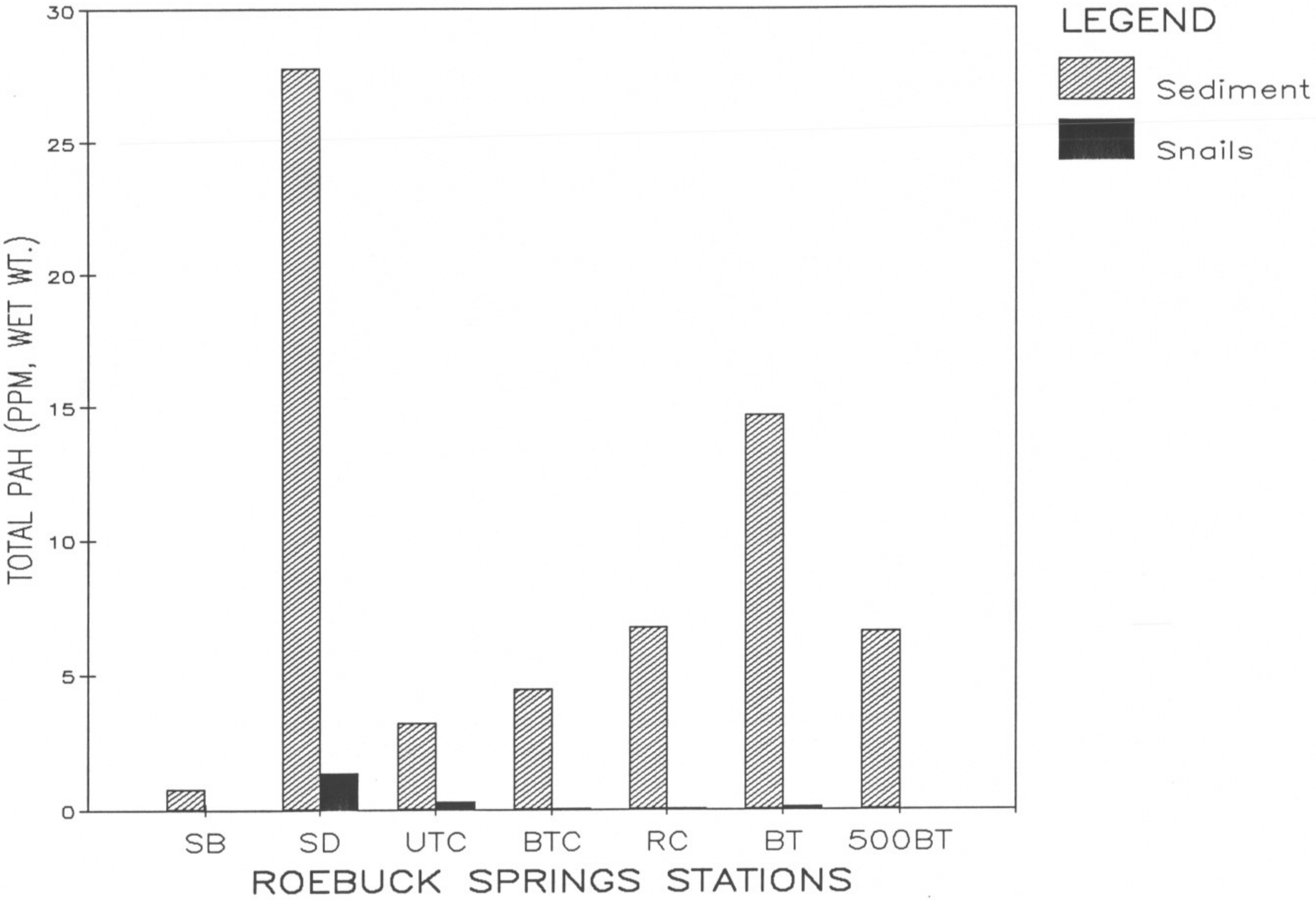


FIG 2. ROEBUCK SPRINGS, TOTAL PAH IN SEDIMENT AND SNAILS
COLLECTION DATE 7/25/90

Note; these values not comparable with previous years data

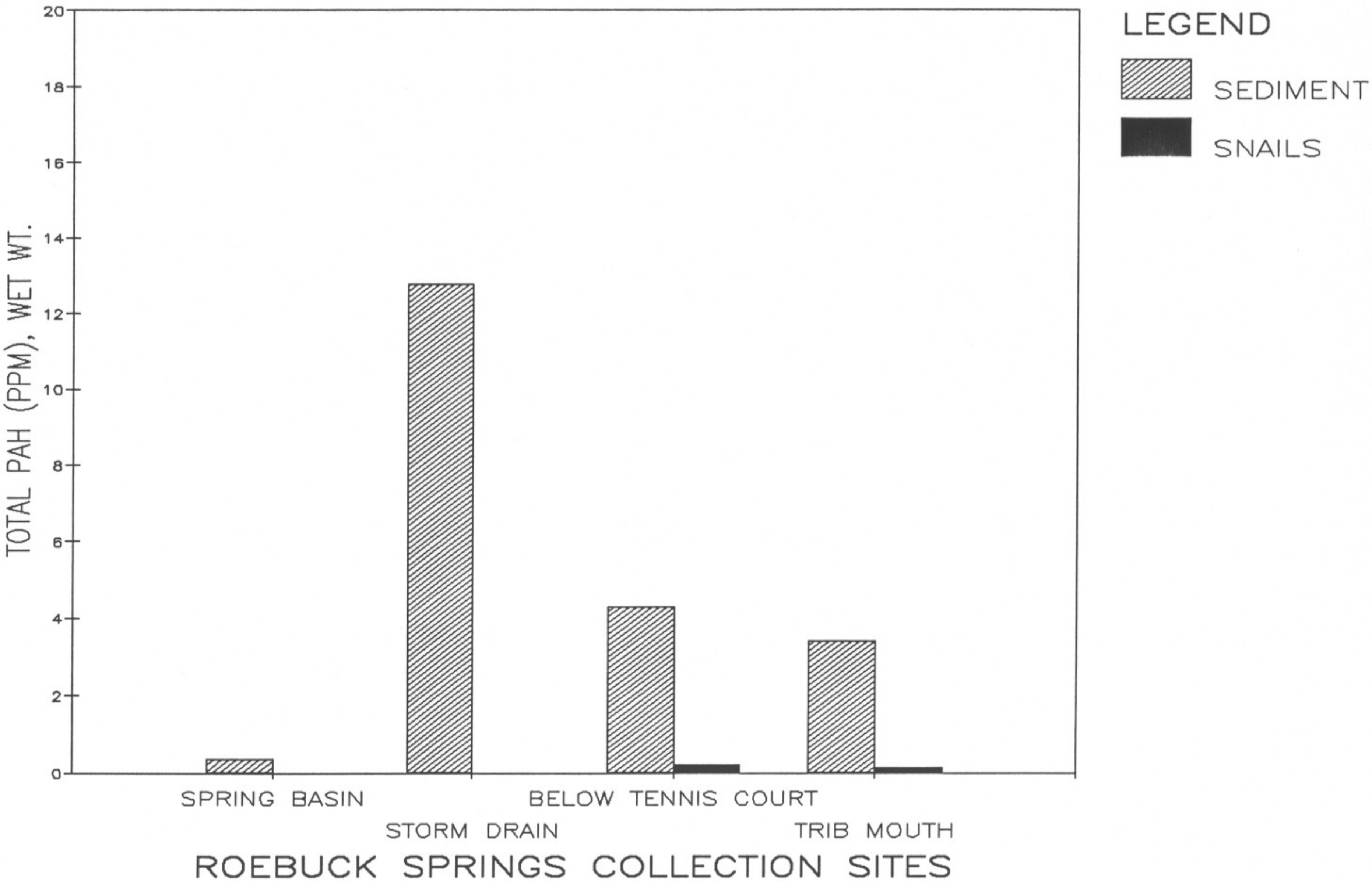
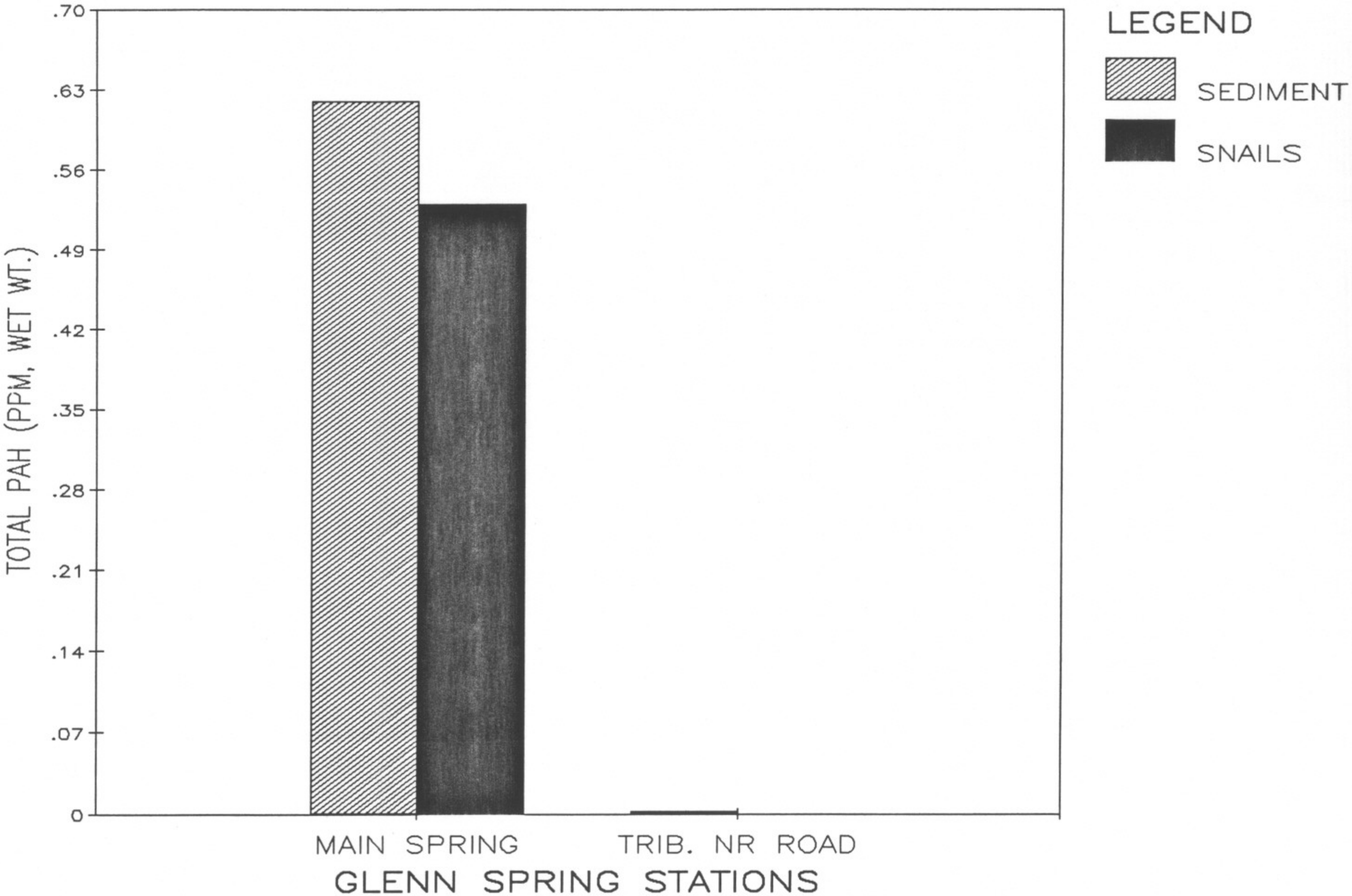


FIG 3. GLENN SPRING. TOTAL PAH, SEDIMENT AND SNAILS COLLECTED 7/25/90



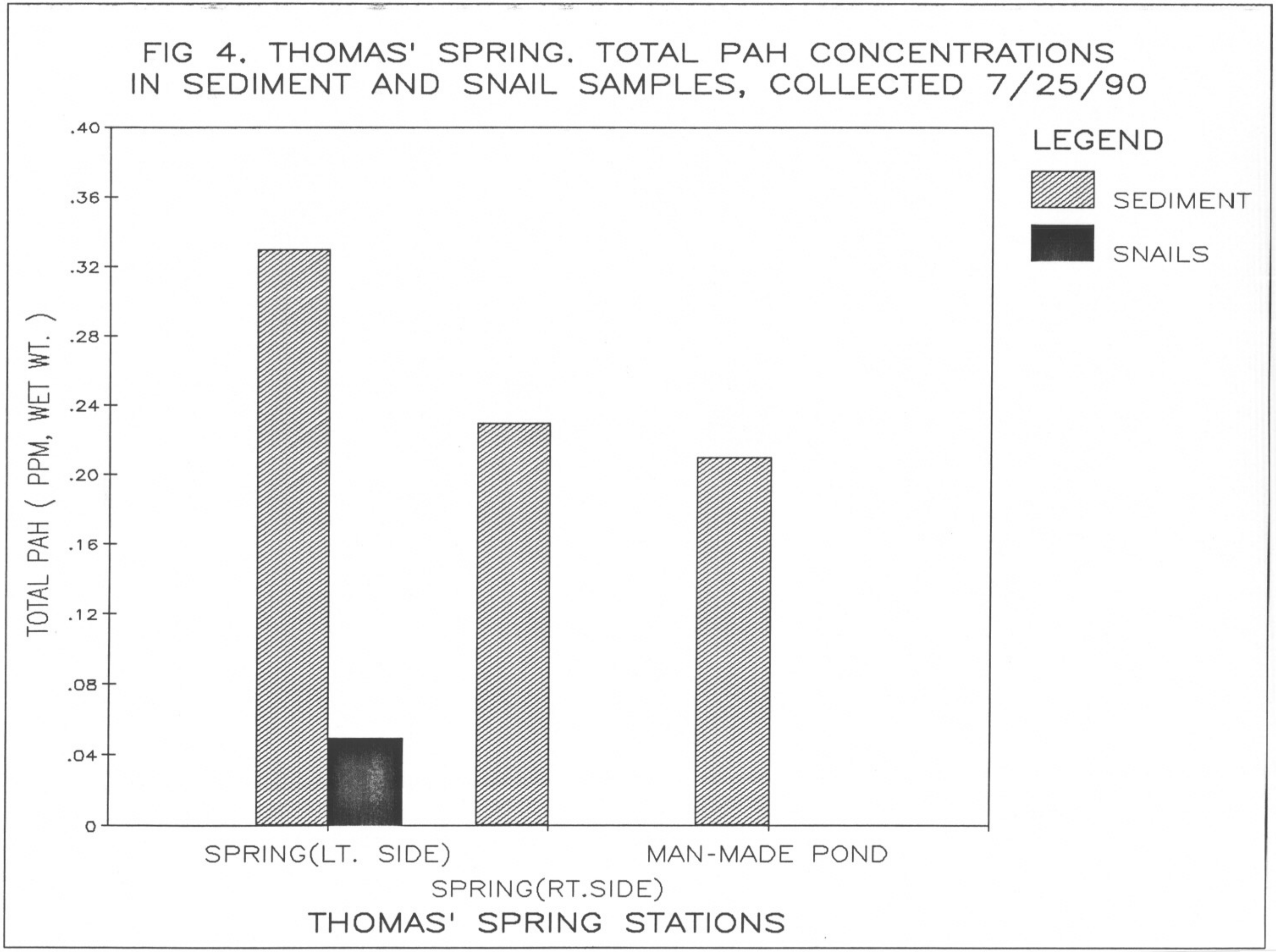


FIG 4. THOMAS' SPRING. TOTAL PAH CONCENTRATIONS
IN SEDIMENT AND SNAIL SAMPLES, COLLECTED 7/25/90
LEGEND
SEDIMENT
SNAILS
TOTAL PAH (PPM, WET WT.)
.40
.36
.32
.28
.24
.20
.16
.12
.08
.04
0
SPRING(LT. SIDE)
MAN-MADE POND
SPRING(RT.SIDE)
THOMAS' SPRING STATIONS

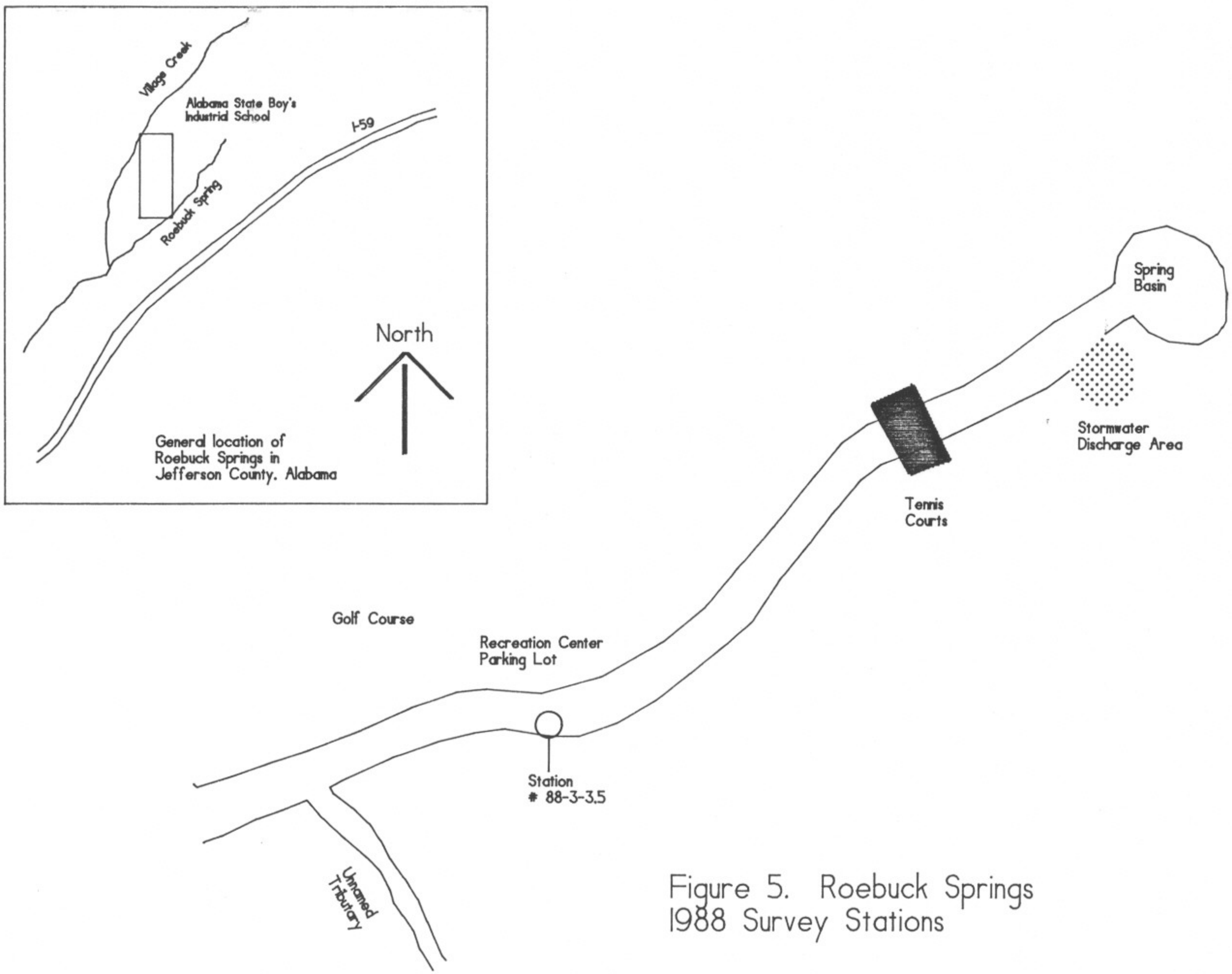


Figure 5. Roebuck Springs 1988 Survey Stations

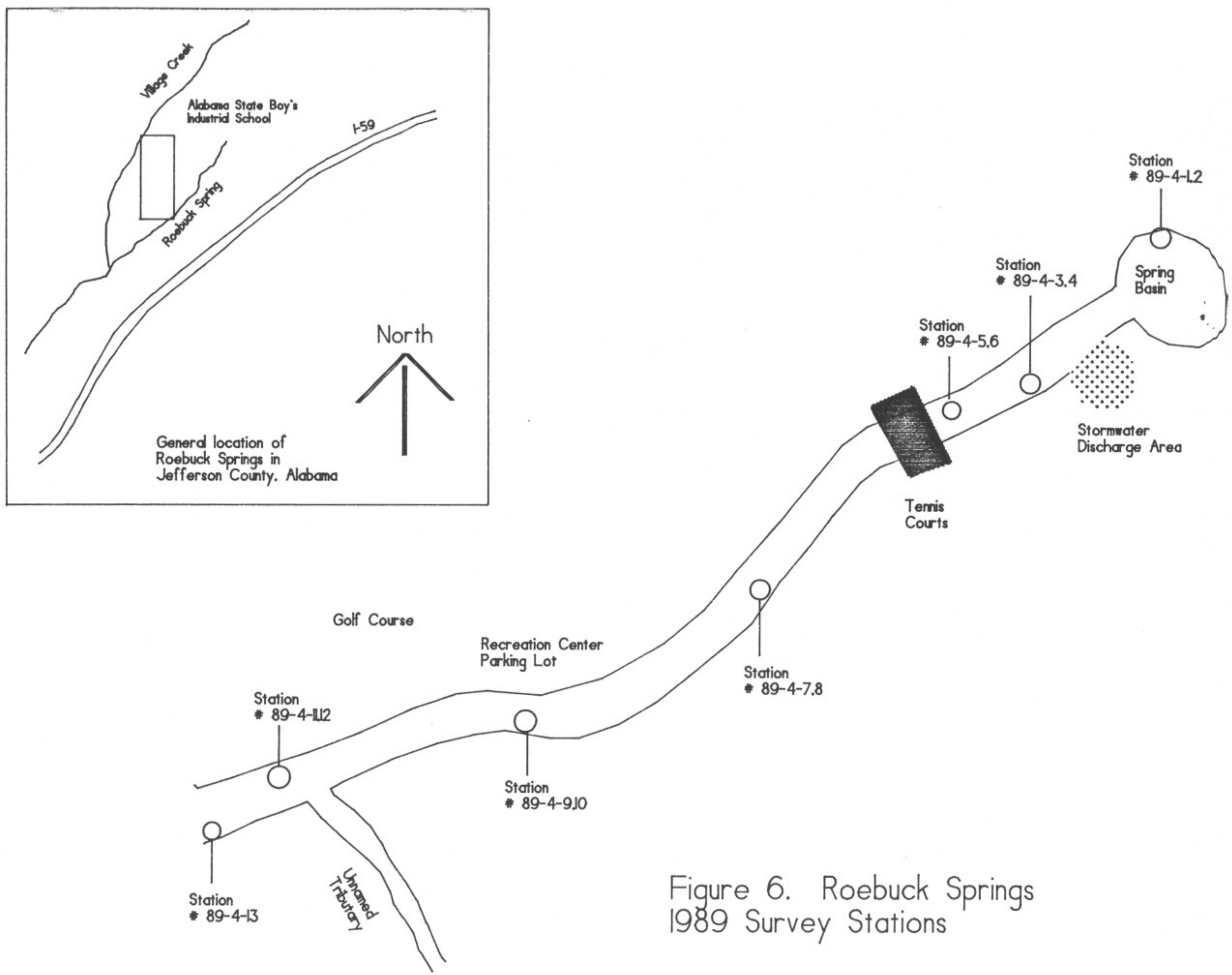


Figure 6. Roebuck Springs 1989 Survey Stations

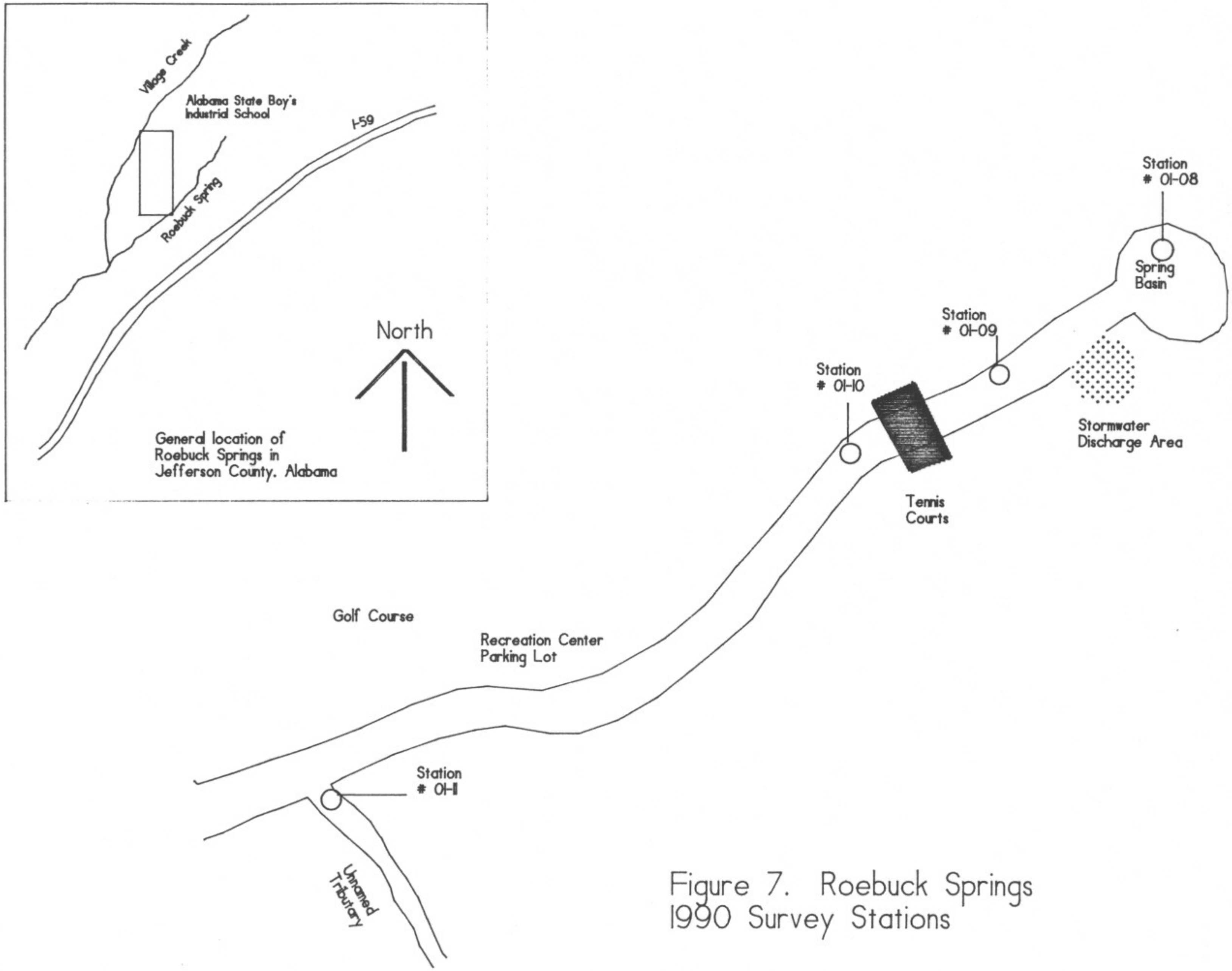


Figure 7. Roebuck Springs 1990 Survey Stations

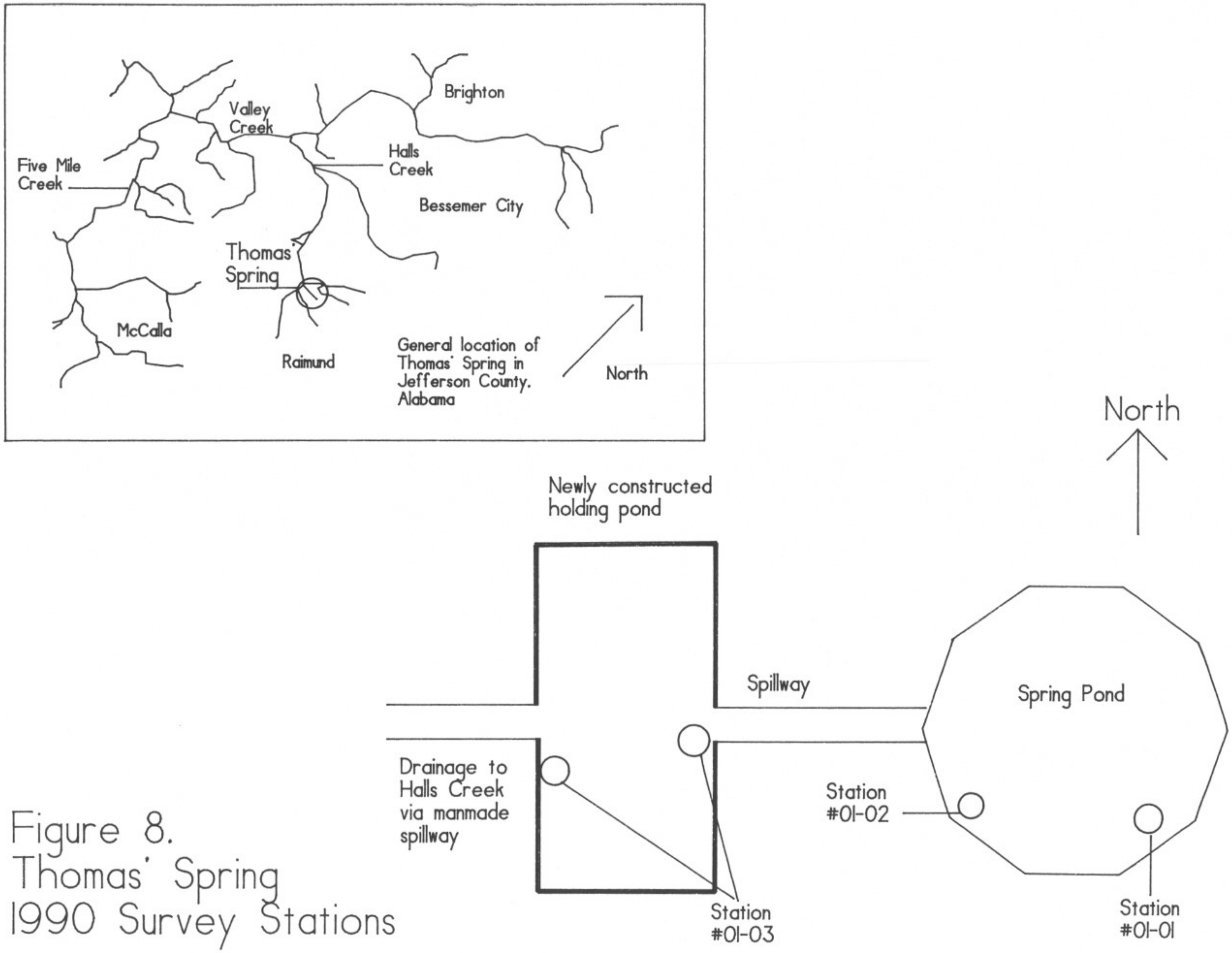


Figure 8.
Thomas' Spring
1990 Survey Stations

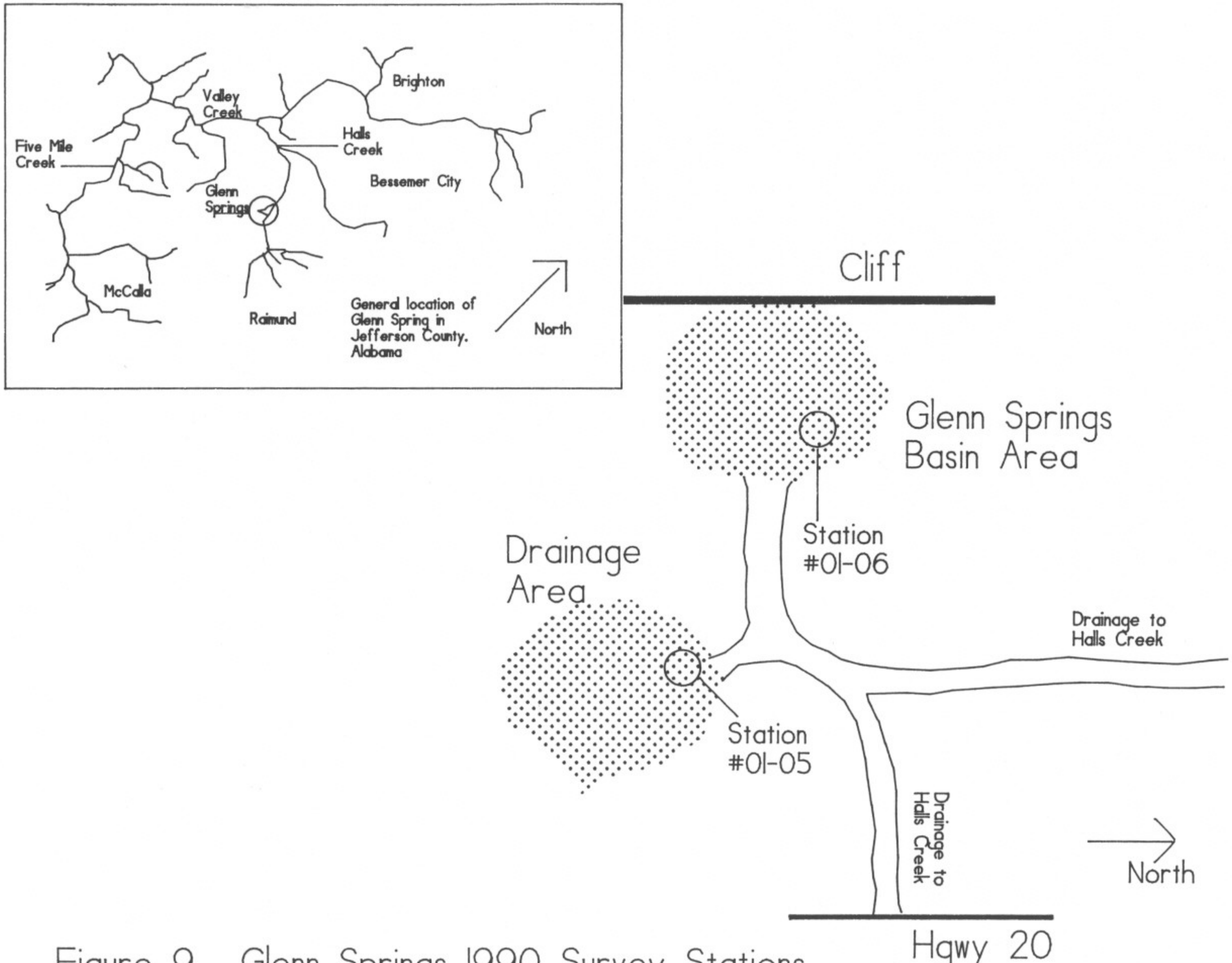


Figure 9. Glenn Springs 1990 Survey Stations