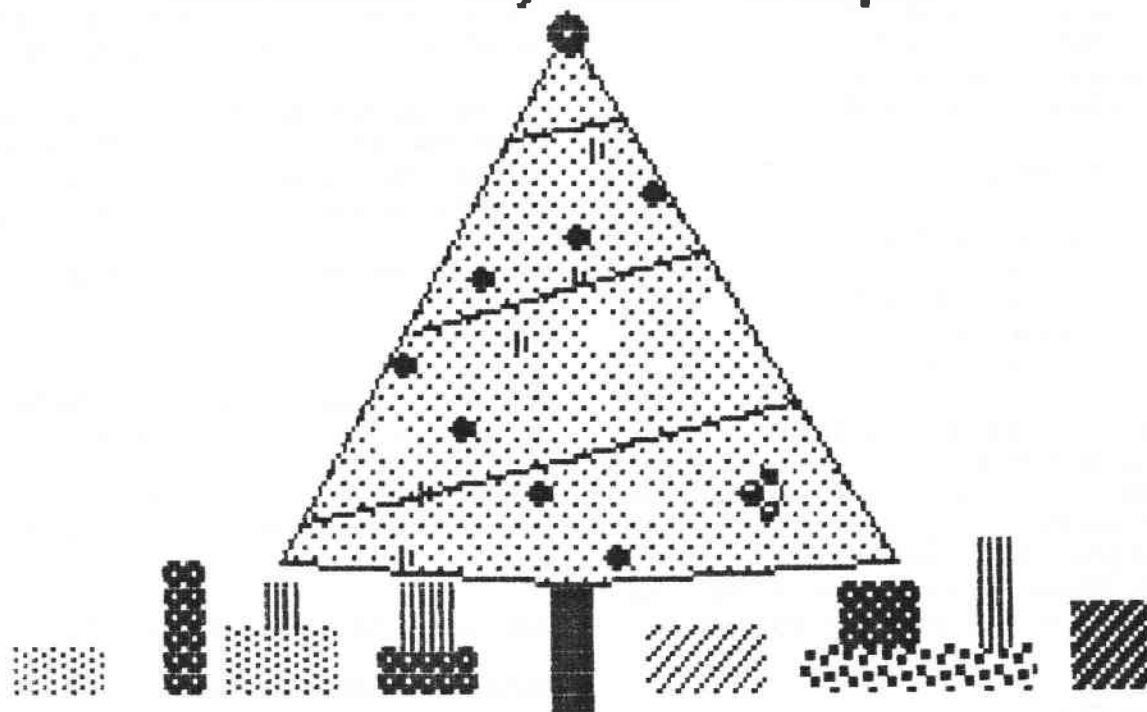# The Central Ohio Grotto Squeaks
December 1987

**Come to the COG
Christmas party and meeting
December 12, 1987   6:00pm**

Don't forget your gift.

COG SQUEAKS
DECEMBER 1987

MERRY CHRISTMAS
AND
HAPPY CAVING
IN
1988

Grotto Information

The Central Ohio Grotto meets the second Friday of each month or the Saturday following the second Friday at 8:00 PM. Meeting notices are published in the Squeaks, the Grotto newsletter. Please call any officer for meeting information or caving trips.

COG officers are:

Clovis Dawson	Chairman	614-262-2073
Nancy Mahoney	Secretary	614-866-6767
Karen Walden	Treasurer	614-965-2942
Bill Walden	Squeaks Editor	614-965-2942
Paul Unger	Boone Karst	513-839-4258

The official grotto address is:

Central Ohio Grotto
C/O Bill Walden
1672 South Galena Road
Galena, Ohio 43021
614-965-2942

The official newsletter of the Central Ohio Grotto is the COG Squeaks. Subscription is $10 per year. The COG Squeaks is published 10 times each year. Articles may be reprinted by other NSS member organizations provided that the author and COG Squeaks are given credit. Please contact Bill Walden regarding the COG Squeaks. Articles, poetry, fiction, and information related to cave exploration and study are welcome.

MEETING NOTICE

Annual Christmas Party
Saturday December 12, 6:00 PM
Map on page 4.

Members of other area grottos are invited to attend.

The annual Christmas party and meeting will be hosted by Bill and Karen Walden at their home in Galena, Ohio. The party will begin at 6:00 PM with a social hour. Dinner will be served at 7:00. Following dinner the COG will have a very short business meeting. We must appoint a nominating committee to select a slate of officers for the new year.

After the meeting we will have the annual gift exchange.

Everyone is encouraged to participate in the gift exchange. The emphasis is on humor. The original object of the gift exchange was that the receipiant must use the gift on his or her next cave trip. The sprit of this has been maintained over the years.

It is the thought and humor which count. The material value of the gift may be nothing at all. In other words don't spent a lot of money but use your head!

Examples of past gifts are:

The portable hand hold for the cave climber. -- A 50 pound hunk of limestone with a simi-usefull grip.

Expendible cave camera -- A pin hole camera kit consisting of a shoebox painted black, a pin to punch the hole, aluminum foil, a roll of 126 film and, of course, the instructions.

Brass carbide lamp -- heavy brass cast parts. Yes it works but, oh, that damn helmut keeps falling over the users face!

High level lead spotting flashlight -- Lucas Flame Thrower lamp mounted on an ammo case which contains the car battery to power the light. Really great for spotting those high level leads in the giant passages such as COGer's and MVGer's are acquainted.

Bat cake -- never makes it home from the party though!

Cricket candy -- ditto!

Back up light source -- A panic light, the faster you squeeze on the handle, the more light it produces.

Ohio Cave light set -- Similar to eyeglass frame but with two small lights powered by two AAA batteries. Really great for those tight buckeye caves.

Should you not feel creative, straight gifts are welcomed.

Please plan to come and have fun.

The December Squeaks

This month's Squeaks is rather special. It contains Jay Kessel's paper on the work he did in Sloan's Valley. Jay's paper is titled Speleogenesis, Landfill Management, and Polution of Water in Sloan's Valley, Kentucky. Also, Mike Gray submitted a paper on a cave plotting program for the Hewlett Packard HP-11C calculator.

Jay's tables that go with his paper and Mike's program are included in the appendix to this issue. The appendix is at the end on pages I through IV. Jay's tables are on pages I and II, and Mike's program is on page's III and IV.

The Hewlett Packard HP-11C
Cave Plotting Program

by Mike Gray

The Hewlett Packard HP-11C calculator with continuous memory can be a useful tool in creating cave maps. This calculator has five user programmable keys that can access up to 203 lines of program memory, a index register and 20 storage registers. Since it a continuous memory it can be turned off without erasing your program.

When the COG Mapped the sloans valley cave system a program written in fortran was used to covert the survey data in to rectangular coordinates which was then plotted by hand. The program also included loop closure error correction. Unfortunately this program required access to a computer center that could run this program. Nowadays the trend is for the entire map to be created by the computer which is fine if you like large cave systems printed on 8 1/2 by 11 paper. The other problem with plotting by computers is that unless you want to take several thousands of dollars worth of equipment to wherever you cave you can not get accurate map within a few hours after the one exits the cave.

With the use an HP-11C and this program a map can be drawn quickly and accurately by the coordinate system. if graph paper is used a map can be ready for review in an hour or two and detail filled in while it is fresh in mind.

To program the HP-11C press <g> <P/R> and enter the program.After entering the program.press <g> <P/R> again . Refer to the HP-11C owners manual for more detail about entering and running programs.

To use this program check to see if "user" is displayed in the lower left corner of the display. If not press <f> <user> to enter user mode. This reverses the top first five keys so that the yellow user A though E keys are a single key stroke and the white primary key funtions are now shifted funtions.

The user A tough E keys start the programs that make up the HP-11C cave plotting system. Pressing one of them runs the specified program on the numbers on the memory stack. Remember that if a number is on the display it is in the X-register of the stack.

While a program is running the calculator will flash the word running on the display. when a number reappears the program has ether finished or is at a programmed stop. Pressing the Run/Stop will restart the program from the point it was programmed to stop or restart the program if it had finished execution of the program

Before starting to enter the data clear the storge registors of any old data by presssing <f> then the <REG> keys. Store

the startting elevation for the survey into storage registor 7. If the starting elevation is not known the calculator will use 0.0 for the starting elevation.

The program "A" is used to change a compass bearing by 180 degrees. this is useful convert the back sight bearing to the form needed by program "B". Program "A" requires that the bearing to be converted be placed in the X-register of the memory stack.Since this is equal to the display keying a number onto the display is all that is required. For example if the bearing to be converted was 230.5 degrees you would press the keys <2> <3> <0 <.> <5>. the number 230.5 would the be on the display. Pressing the "A" key would start the program. The display would flash "running" several times then display the number 50.50 (if more decimal places are required the display can be set to display them. But remember that no matter how many places are displayed the calculator always works with a 10 digit number raised to a 2 digit exponent of 10). This is the end of the program and pressing the <R/S> (Run/Stop) button would only restart the program working with the number now in the display (the program will return with 230.5 for a result).

Program "B" will average two compass bearings and both display the results and store the result in storage register 2. This program needs a valid bearing in the x and the y registers of the memory stack. This program needs the front sight to be in the form where reading is from the alternate set of numbers or the other end of the compass needle then the person taking the front sight is using(fig.2). If the data taken down during the survey is not in this form the bearing can be converted by program "A".

Pressing the <ENTER> key will move a number from the X-register and place it in the Y-register. Pressing the "B" key will start the program. The number in the display when it has finished running is the averaged bearing (fig.3. Pressing <R/S> again will restart the program from the beginning).

This value was also placed in storage register number 2 for use by program "D". Since program "d" requires the average bearing to stored ahead of time it is a good habit to use program "B" even if the bearings are equal. If the two bearing are equal they can be entered by keying the bearing in then pressing <ENTER>.

This works because when "ENTER"is pressed the number in the X-register is copied into the the Y-register but does not erase the value in the X-register till a number is entered. If a operation is performed instead entering a new number the former value of the X-register is used for the operation.

Program "C" is used to average the front and the back clinometer readings. as in program be the values must be changed for the back sight. If the value for the front sight was -10.2 degrees then reading on the back sight would be 10.2 (fig.4). The sign of the back sight would have to be changed to -10.2 to be in the proper form for use by the program "C".This

is done by pressing the <CHS> key.

Note that it is possible to have two sights with the same sign (before changing the sign) this is a valid sight (fig.5). That is can happen sometimes on sights very close to level. Program "C" will still return the proper value.

Program "D" processes the remaining values. The average clinometer value must in stack memory Y-register. The measured distance is placed in the X-register. If program "C" has just been run and its results are still on the display then simply entering the value for the measured distance will automatically place the clinometer reading in the Y-register. If the value on the display is not the proper value it can be placed in the Y- register by keying the value in then pressing the <ENTER> key.

If the average bearing was not stored in storage register 2 it must be entered before the program is run. This is done by keying in the value of the average bearing to the display then pressing the <STO> then the <2> Keys.

After program is started it will flash "running" on the display,it will then stop and display the corrected distance of the sight across level ground (fig.6). This value was also stored in storage register 5.

Press the <R/S> key to restart the program. When it stops again it displays the total distance this series of sights. This value was really calculated before the calculator displayed the previous display. The value had been stored in storage register 6 then recalled to the display. Look at fig.7 to see which values are stored and where by the calculator.

After pressing <R/S> again the calculator will display the elevation change of the sight. Press <R/S> and the calculator will display the elevation deference of the current location and the start of the survey (this value will be the elevation above sea level if before processing the survey data the starting elevation is stored in storage register 7).

After the <R/S> button is pressed again the distance North or South from the previous station will be displayed. A negative number means the the distance is the distance south of the previous station. A positive number would be the distance North of the previous station.(fig.8)

Press <R/S> again to get the distance East or West from the starting station. A negative number will be the West of the starting station.

After <R/S> is pressed again the next displayed value is the total distance North or South from the starting station. After that Press <R/S> and get the total distance distance East or West. (fig.9) The value positive or negative indicate the direction are earlier.

After these distances are given in rectangular coordinate form the program then converts the location into polar notation and displays the bearing from the starting station to the current station when <R/S> is press again.

Push <R/S> and the next and final display for the program is the straight line distance from the starting station to the current station.

Pressing <R/S> again will result in restarting the program from the beginning. Unless proper values for starting the "D" program have been entered in to the and the Y registers invalid answers will result. If an other sight is to be entered restart the procedure by using the "A", "B" and "C" to load the proper values then press "D" again.

If an error is made when entering the data of a sight the program can be restarted after entering the values of the last correct sight data into storage registers 1,5,7 and 9.(see fig.7.) Then re-enter and run the survey data for the next sight. For example if the data for the sight form station 23 to 24 was garbaged enter the data from the sight from station 22 to 23 then re-enter the sight from 23to 24 will correct any errors and give the proper results.

Program is on pages III and IV of the appendix.

Christmas Meeting Site

Bill and Karen Walden
1672 South Galena Road
Galena, Ohio 43021
Phone: 614-965-2942
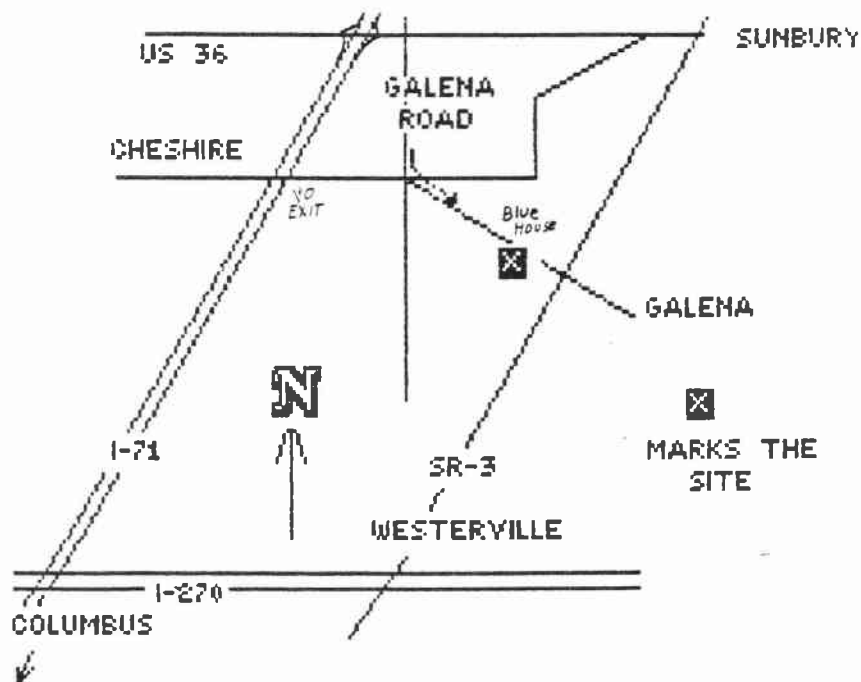
Speleogenesis, Landfill Management, and Pollution of Water in Sloan's Valley, Kentucky
by Jay Kessel

Abstract

Water samples were taken at the Dixie Bend Sanitary Landfill, the Middle and the U.S. Highway 27 sediment ponds to the west of the landfill, and within the northern and southern Railroad Tunnel Passages that enter into the Sloan's Valley Cave System of Pulaski County, Kentucky. Samples were analyzed for levels of pH, specific conductivity, total Fe, Mn^{+2}, Cr^{+6}, and NO_3^-. Water throughout the study area was found to range from moderately acidic to slightly basic due to speleogenetic and surface solutional activities within the limestone terrain. High levels of specific conductivity, total Fe, Mn^{+2}, and Cr^{+6} in Sloan's Valley water were the result of accelerated soil erosion. Apparently, these heavy metals precipitated out of solution and/or adsorbed onto sediments as water from the top of the landfill flowed down gradient into the two adjacent sediment ponds. Statistical analysis shows that specific conductivity, total Fe, Mn^{+2}, and Cr^{+6} levels increased significantly, when water from the U.S. Highway 27 Pond entered the southern Railroad Tunnel passage of the cave. Nitrate levels were anomalously high, probably attributed to interference from elevated concentrations of copper and molybdenum.

Introduction

Because water is a universal solvent, it may contain any water soluble material. Increasing concentrations of material in a volume of water are a function of chemical solubility, accumulating residence times and/or movement through a medium within the global hydrological cycles (Sweeting, 1973). The type of solute present in a water is also dependent upon its source (Langmuir, 1971, quoted in Back and Freeze, 1983). Water quality is determined by the concentrations of dissolved or suspended materials. Concentrations of certain organics and inorganics beyond standards set by the Environmental Protection Agency (EPA) could indicate pollution.

Water quality is affected by the interactions between environmental (biophysical, geographical, and meteorological) and cultural (human) factors. For instance, water quality in a rural, intensively farmed environment may have high concentrations of ions associated with fertilizers (e.g., nitrates, NO_3^-, orthophosphate, PO_4^-, and potassium, K^+). Biological wastes (e.g., untreated sewage) could result in a water having a high concentration of ammonium ions, NH_4^+, or salts such as potassium nitrate, KNO_3 (Wetzel, 1970). The EPA (1973) has limited NO_3^- levels to 45 mg/l because higher levels may cause infant methoglobinemia (Hach Chemical Corp., 1978). Langmuir (1971) similarly noted that polluted groundwater had NO_3^- concentrations >55.0 mg/l.

Other sources of soluble salts (e.g., sodium chloride, NaCl) are highways. Salts applied on icy roads may result in higher sodium or chloride levels in a water (Werner, 1983, quoted in Dougherty, 1983).

Another potential source of water pollution is a sanitary landfill. A landfill may typically harbour waters or produce leachate containing high levels of copper, iron, zinc, manganese, cobalt, chromium, lead, calcium, and magnesium in excess of EPA (1973) standards (Murray et. al., 1981 and Freeze and Cherry, 1979, quoted in Ferry, 1984).

Iron is a major constituent of many types of minerals found in limestone based soils and bedrock. Its solubility in water is very low; however in carbonate waters, it is readily oxidized to form the mineral limonite ($Fe(OH)_3$). The concentration of soluble iron in this water is dependent upon the aqueous solution's pH and the amount of bicarbonate present (Hem, 1967; quoted in Back and Freeze, 1983). Hem's study of laboratory controlled samples show increasing ferrous iron (Fe^{+3}) concentrations <0.5 mg/l in waters either acidic (pH <5.5) or basic (pH >8.0). Bicarbonate levels were 6.0 mg/l. His data also showed that Fe^{+3} solubility decreased ten-fold to <0.05 mg/l as bicarbonate alkalinity was increased to 61.0 mg $CaCO_3$/l and the water's pH approached neutrality (7.0). At this pH, siderite ($FeCO_3$) was more likely to form in minute concentrations. EPA secondary water quality standards restrict total iron (Fe) concentrations to 0.3 mg/l due to staining and encrustation effects caused by the low solubility of this metal (EPA, 1973).

Manganese and its oxides are associated with the erosion of limestone based soils and bedrock as describe above (Becht and Belzung, 1975). Its water solubility is very low (Hach Chemical Corp., 1978). Due to its staining characteristics and its effects upon a water's taste, the EPA (1973) has limited manganese concentrations to 0.05 mg/l.

Chromium, usually measured in the form of hexavalent chromium (Cr^{+6}), is not normally found in significant amounts in most soils. This element is needed in minute quantities in order to maintain a healthy nutritional balance. However, in concentrations >0.003 mg/l, chromium can be carcinogenic (Hach Chemical Corp., 1978). For these reasons, the EPA (1973) has limited acceptable levels of hexavalent chromium to 0.003 mg/l.

Because contaminated waters often have a high concentration of dissolved ionic metals and salts, specific conductance is usually great. Specific conductance of water is a measure of water quality that may be particularly reflective of the content of certain cations such as Ca^{+2}, Mg^{+2}, K^+, and Na^+, as well as anions, such as HCO_3^-, CO_3^{-2}, SO_4^{-2}, and Cl^-. Other metals (e.g., Fe, Mn, Cu, and P) will have minor effects upon a water's specific conductivity (Wetzel, 1974). Investigations in carbonate terrains frequently show that polluted groundwaters have specific conductances ranging as high as 945 umhos (Langmuir, 1971). Specific conductance of uncontaminated waters

in his study averaged 173 umhos.

Water pollution, while easy to assess, is frequently difficult to trace. Whereas surface water and water pollution can be traced to a source point(s) by following the outlines of its drainage basin, groundwater and water pollution can come from more than one watershed. Groundwater typically originates from a multitude of sources, flowing or seeping through vadose soil and bedrock above the water table to a phreatic aquifer (repository of subterranean water) at or below the water table. Outflow of the aquifer is usually observed at or below the surface of a stream, river, or ocean basin. Tracing and assessing the source(s) of groundwater contamination is further complicated by the dilution of dissolved materials caused by mixing or overflow of waters following a flood event, by diffusion of water resulting in lowered saturation levels and the precipitation and/or adsorption of the solutes onto sediments, and by the geochemistry of the aquifer itself. The last factor complicating water assessment, geochemistry of the aquifer, is particularly conspicuous in a karst solutional aquifer.

An aquifer is typically located within a granular bedrock (e.g., sandstone or limestone). Recharging waters percolate through an aquifer of this type at a very slow velocity due to low permeablity, restricted pore space, and cohesion of the water molecules to soil and bedrock particles (capillary force) (Dunne and Leopold, 1978). If pore space is small enough, bacteria and some toxic and/or hazardous compounds can be filtered from the water before it enters the phreatic zone. On the other hand, short residence times in conjunction with high permeablity, large pore space, and a high ionization potential may permit many minerals and, if present, contaminants to enter this water in aqueous solution. Aquifers of this type are defined as solutional (Jennings, 1972).

A solutional aquifer is frequently associated with a cavernous system of conduits dissolved between joints of limestone (CaCO3) or dolomite (MgCO3) (Thrailkill, 1968, quoted in Back and Freeze, 1983). Water movement is mostly restricted to these conduits, at times flowing like a river. At other times the water seeps through slightly enlarged joints and bedding planes. Cave water can also be still as in a lake. Flow velocities are primarily a function of the passage's dimensions, shape, and gradient.

Quality of a water in a karst drainage basin is the product of the aquifer's solutional equilibrium, which in turn is a function of residence time and/or movement through the largely porous and permeable bedrock. Solutional processes are best described by Bogli (1960, quoted in Sweeting, 1970). Waters in this type of aquifer usually contain high levels of Ca+2 and Mg+2 and are extremely hard*. Concentrations of these ions generally rise with increasing depth. Whether water dissolves or precipitates limestone, dolomite, or any other mineral associated with the given formation is determined by the changing saturation points of atmospheric and free dissolved carbon dioxide, Ca+2 and Mg+2.

Cave formation occurs in acidic (carbonic acid solution; pH <5.5), neutral (bicarbonate solution; pH 7.0), or basic conditions (carbonate solution; pH >9.0). Concentrations of Ca+2 and Mg+ and Ca/Mg hardness in cave waters rise correspondingly with increasing pH. Carbonic acid solution of CaCO3 and MgCO3 is very efficient (within minutes) and is mostly seen in running waters of the vadose zone where CO2 uptake is limited by a short residence and/or dilution (Grooms and Williams, 1965, quoted in Sweeting, 1973). Bicarbonate solution can be observed in slower moving or seeping waters throughout much of the aquifer, from the vadose zone inside the cave entrance to the phreatic zone. Solution of bedrock is less efficient (within hours). Carbonate solution occurs in still waters, usually at or below the water table within the phreatic zone. Solution at this pH is very inefficient (days). Bedrock solution continues as long as the concentration of dissolved CO2 in water is greater than that of the free CO2 (that CO2 in water not consumed by carbonate formation) or until the water becomes saturated with Ca+2 and/or Mg+2. At this point the water dissolves as much bedrock as it precipitates. Hardness is typically maximal at this point in the karst groundwater cycle. As the water becomes supersaturated with these ions, CaCO3 and/or MgCO3 is precipitated. Calcium or magnesium ions may also be precipitated as a function of degassing CO2 from waters as different waters mix (Runnells, 1969, quoted in Back and Freeze, 1983).

Cavern formation within the phreatic zone may be caused by a collectively changing solutional equilibrium and the effects of corrasion as differing waters mix, particularly during a backflow caused by flooding of the aquifer. This process has been described as "Mischungkorrosion" (Bogli, 1965, quoted in Sweeting, 1973, Jennings,1972, and Thrailkill, 1968, quoted in Back and Freeze, 1983).

A karst water increasingly reflects the environmental chemistry of its surrounding drainage basin as it moves through a series of conduits. Waters of this type, because of their solutional nature, are extremely vulnerable to any source of contamination (Dougherty, 1983). This finding was borne out in his study of the Sinking Valley Cave System of east-central Kentucky. Results, derived from the Thornthwaite-Mather water budgeting method (1948), reveal that human impact in the form of farming and/or livestock grazing leads to significantly higher sediment loads in cave waters.

* Hardness is defined as the total Ca+2 and Mg+2 content in water expressed as the equivalent level of CaCO3 (Hach Chemical Corp., 1978).

The difficulties of tracing the source(s) of possible groundwater contamination in a karst aquifer are illustrated in the Sloan's Valley Cave System (SVCS). Contamination of SVCS water is suspected to originate from a sanitary landfill and/or possibly from outhouses directly overlying parts of the cave.

The Study Area

The SVCS is located in Pulaski County, in south central Kentucky (see Figure 1). The cave lies in a karst solutional drainage basin surrounded by the Daniel Boone National Forest and includes the Dixie Bend Sanitary Landfill and the agricultural community of Sloan's Valley. The Martin's Creek drainage basin is located directly east of the Sloan's Valley drainage basin.

The cave is situated on the western edge of the Cumberland Plateau. There are 23 miles of horizontally joint controlled passage formed in upper Mississippian limestones at the junction of the St. Louis and St. Genevieve members. Passages follow the two layers at right angles to their junction. Water generally flows from the southwest to the northeast towards Lake Cumberland. Directly above the caverns are layers of Pennington shale interbedded with limestone and sandstone. Above this layer is a caprock of Pennsylvanian clastic sandstone. Manganese rich soils cover this shale layer (Dougherty, personal communication, 1981).

Minerals in these rocks include pyrite (FeS_2), limonite ($Fe(OH)_3$), siderite ($FeCO_3$), and chert. Magnesium and calcium sulfates, as well as manganese and iron oxides are also found in abundance due to the weathering of bedrock.

Biota in the cave system is limited. Insects, such as cave crickets are commonly encountered in the cave. The cave also hosts a number of rare and endangered species, notably the white blind cave fish, Typhylicty subterranens, and the Virginia long-eared bat, a species uncommon west of the Appalachians. Bacteria (e.g., fecal coliforms) are also suspected to live in cave waters due to the use of outhouses known to overlie cave passages.

Surface waters and sediments from the entire watershed drain into the SVCS through sixteen entrances. The Post Office, Hughes, Scowling Tom's, Garbage Pit, two Great Rock Sink, and the four Martins Creek entrances receive agricultural and residential runoff from the southern edges of the drainage basin. The three Minton Hollow entrances, those to Screaming Willies and the northern Railroad Tunnel collect water and sediments from intermittently running streams originating in the national forest located further to the south and west of the cave. The northern Railroad Tunnel entrance also receives surface drainage from above its entrance in the form of dripping water. Runoff from the landfill immediately to the east flows into a continuously flowing stream that sinks into the southern Railroad Tunnel entrance. Water flows from these

entrances through vadose passages to phreatic levels where they mix.

The Dixie Bend Sanitary Landfill operates upon the Pennington shale layer immediately to the east of the cave. The landfill occupies what was once a coal strip mine. Five sediment ponds were built around this mine to prevent sulfates and acids from leaching into the surrounding valley (see Figure 3). Three are located in the Martin's Creek drainage basin east of the SVCS. One of these three ponds retains sediments properly. One became inoperative when its earthen dam was breeched. Another has a swallow hole and drains directly into the underlying bedrock.

The two ponds constructed to the west of the landfill are nearly filled with sediments. The northern pond is closer to the landfill than the southern pond. Surface water and sediments flow from a drainage pipe at the top of the landfill and into the northern pond (Middle Pond). This pond also receives runoff from a thin stand of evergreen forest to the north of the landfill. Soils surrounding the pond's edge are generally plant covered. Following a flood of the Middle Pond, water and sediments flow west, down gradient into a depression adjacent to U.S. Highway 27.

The southern pond (U.S. Highway 27 Pond) is located southeast from the Middle Pond, directly to the east of the SVCS. Soils around this reservoir are generally bare. The pond receives leachate from a gently sloping channel originating from another pipe located in the uppermost layers of the landfill. Following heavy precipitation, this same water and its suspended sediment load is diverted through a cut in the drainage channel. This runoff moves down slope through another thin patch of evergreen forest and eventually drains into the Highway 27 Pond. Drainage from the pond follows a pipe into the continuously flowing stream that sinks into the southern Railroad Tunnel entrance (Dougherty, personal communication, 1981).

Suspicions of water pollution from the aforementioned sources have forced many of the residents to obtain water from cisterns or to purchase bottled water. Due to the above reasons, residents want the state to provide a clean source of drinking water.

Previous attempts (Ferry, 1984, Dougherty, 1981) to identify who or what is responsible for the suspected pollution of the SVCS have been hampered by the likelihood of multiple sources, both periodic and continuous. Dougherty's investigation illustrated the primary movement of waters throughout the cave system. His study focused attention upon the possibility that the landfill was the primary cause of water pollution in the SVCS.

Ferry studied the distribution of alkaline, alkaline earth, and heavy metals in surface and ground waters from the landfill, the adjacent sediment ponds, and throughout the Sloan's Valley drainage basin. Samples were collected seasonally at fifty stations. Seasonal concentrations of these metals were not

significantly different. All metals concentrations in water sampled in the landfill, the adjacent sediment ponds, and the Railroad Tunnel entrances were in excess of EPA (1973) standards. Iron, zinc, and manganese were the only metals present in levels beyond those expected by Murray et. al., 1981 and Freeze and Cherry (1979) (quoted in Ferry, 1984). Concentrations of cobalt, lead, calcium, and magnesium, and total hardness were less than expected (Murray et. al., 1981).

Within cave passages, Ca^{+2} and Mg^{+2} levels rose with increasing depth, particulary in the deeper phreatic zone. Cadmium, copper, iron, lead, and zinc concentrations in excess of EPA (1973) limits were seen in isolated cases within the cave.

Ferry theorized that a decrease in heavy metal concentrations inside the entrances was caused by precipitation out of solution or adsorption onto sediments. His theory was based on findings that sodium concentrations were relatively uniform throughout waters of the SVCS (x = 4.18 mg/l). Sodium does not react chemically with heavy metal ions in solution. He concluded that the landfill was not polluting the aquifer given its young age (2.5 years) at the time of the study.

Current Study

This study is designed to test statistically whether the Dixie Bend Landfill is or is not polluting waters of the SVCS. Water in the two Railroad Tunnel passages, the Dixie Bend Landfill, and the two sediment ponds adjacent to U.S. Highway 27 were sampled and analyzed for iron, manganese, hexavalent chromium, pH, and specific conductivity levels. Nitrate concentrations were measured in water at the landfill and the stream inside the southern Railroad Tunnel entrance.

Water in the Dixie Bend Sanitary Landfill was hypothesized to have concentrations of total Fe, Mn^{+2}, and Cr^{+6} in excess of EPA (1973) clean water standards due the presence of bare pyrite and $CaCO_3$ rich soils and the probability that a large volume of metallic materials is buried within the repository. Levels of hexavalent chromium were also expected to be higher than that permitted by the EPA (1973). Elevated Cr^{+6} levels could be attributed to the burial of metallic cleaning solutions. Collectively, such conditions should cause water at the top of the landfill to have high specific conductivity (>600 umhos). Water of the landfill would also have nitrate levels exceeding EPA (1973) guidelines (maximum allowable concentration of 45 mg/l) assuming that refuse such as food, dead animals, and/or other organic material is being buried within the landfill.

It was also hypothesized that water sampled at this site would be acidic (pH <7.0). The origin of the water's acidity was thought to be the production of sulfuric (H_2SO_4) and nitric acids (HNO_3) derived from the erosion of pyrite rich soil, the decomposition of organic materials, and the

presence of buried materials such as batteries.

Water in the U.S. Highway 27 and the Middle Ponds was expected to contain significantly lower levels of heavy metals and specific conductivity than water at the top of the landfill. These results would be attributed to longer residence times of lentic systems which in turn, would cause pH to rise, and the precipitation out of solution and/or adsorption of heavy metals onto soil and sediments lining the ponds. It was also expected that total Fe and Mn^{+2} levels in water sampled at the top of the landfill and the sediment ponds would be greater than that obtained by Ferry (1984), because the repository was approximately five years old and soils covering the repository were still bare.

Pollution of SVCS water from landfill leachate would be indicated by statistically uniform levels of total Fe, Mn^{+2}, and Cr^{+6} in water sampled at the top of the Dixie Bend Sanitary Landfill, the U.S. Highway 27 Pond, and the southern Railroad Tunnel entrance. Water sampled at the control site, the northern Railroad Tunnel entrance would have significantly lower levels of heavy metals and specific conductivity than the southern Railroad Tunnel entrance, assuming that metallic materials are not buried in covered soils of the drainage basin recharging the former site.

Organic pollution of SVCS water from landfill leachate would be indicated by nitrate levels greater than EPA (1973) clean water standards (45 mg $NO-3$/l). Nitrate concentrations at both sites would not differ significantly.

However, if the Dixie Bend Sanitary Landfill was not polluting the SVCS, samples would display iron and manganese concentrations nearly identical with those observed in Ferry's study in 1984. Ionic concentrations would not differ significantly between the two railroad entrances noted above. Total Fe and Mn^{+2} levels in water of the SVCS would be significantly lower than that water sampled at the top of the landfill and the sediment ponds. The distribution of Cr^{+6} would be similar to that of total Fe and Mn^{+2} and be within EPA (1973) limits. Nitrate levels in water at the southern Railroad Tunnel entrance would be under the limits established by the EPA (1973), although contamination by the overlying outhouses in the valley could distort the potential findings.

It was hypothesized that water entering either of the Railroad Tunnel passages should become more basic and conductive as heavy metals precipitate out of solution and/or adsorb onto sediments as a function of of increased distance from the cave entrances. These results would be attributed to karst solutional activity described by Ferry (1984), Sweeting (1973), Hem (1967), and Bogli (1965).

Methods

Surface samples were taken just below a drainage pipe at the top of the Dixie Bend Sanitary Landfill, the Middle Pond, and

the U.S. Highway 27 Pond. Water at the top of the landfill was continuously flowing down gradient, contained within a ditch. Water in the two ponds was nearly stagnant.

Additional surface samples were collected by the two Railroad Tunnel entrances adjacent to their respective drip lines (those points defining the boundary between surface and subterranean waters). Samples at the southern entrance were obtained at the base of a waterfall. Samples at the northern entrance were collected from dripping water originating directly overhead.

The remaining samples were taken in the two Railroad Tunnel passages. Collection of water samples was limited to locations 30.5 and 40.6 ft. within the continuously wet southern Railroad Tunnel due to the presence of a impassible 15 ft. deep waterfall. Sampling of the drier northern Railroad Tunnel was restricted to puddles located 215.6 and 330.7 ft. from the entrance because of the scarcity of available water.

Levels of pH, specific conductivity, total Fe, Mn+2, and Cr+6 were measured three times apiece at each sampling site. Nitrate levels were measured one time each at the top of the landfill and 30.5 ft. inside the southern Railroad Tunnel.

The pH of surface and ground waters was tested at the sampling sites with a portable Cole-Parmer "Digi-Sense" digital pH meter, model #5986 (which was standardized to a range between 4.0 and 10.0). Specific conductivity was also analyzed at the sampling sites using a portable Cole-Parmer digital conductivity meter, model #1481-50. Both meters were calibrated for ambient water temperatures and operated according to their respective instruction manuals.

Total Fe, Mn+2, Cr+6, and NO3- were measured in the laboratory using a Hach Chemical Corp. DREL/4 portable spectrophotometer. Detailed standardization and operating procedures were followed according to the DREL/4's instruction manual.

All samples obtained for the determination of pH, specific conductivity, total Fe, Mn+2, and Cr+6 were collected on 3 March 1987. Samples taken from the cave to the laboratory were stored in 250 ml plastic containers and immediately fixed with 5.0 ml of concentrated nitric acid (HNO3). The plastic bottles had been washed previously with a 1:1 solution of HNO3 and rinsed with distilled water.

Water samples for nitrate tests were obtained and stored in plastic containers, similar to those mentioned above, on 21 March 1987. These sample bottles had been washed earlier with a 1:1 solution of hydrochloric acid (HCl) and rinsed with distilled water. Analysis of the unfixed samples was performed immediately following collection in the field.

pH, specific conductivity, total Fe, Mn+2, and Cr+6 levels were averaged at each sampling site of the two tunnel passages, the sediment ponds, and the landfill. These mean values were analyzed for significant differences as a function of distance from the entrances, hydrological conditions (wet and dry), and the interaction of these treatments and levels. The statistical analysis of these relationships was based on a treatment by levels design described in Bruning and Kintz (1977). Mean values of pH, specific conductivity, total Fe, Mn+2, and Cr+6 were also analyzed for significant differences between the landfill, the two sediment ponds, and within the southern Railroad Tunnel as a function of distance from the landfill. These relationships were analyzed statistically using a one-way analysis of variance described by Skillings (1984).

Results

The concentrations of total Fe, Mn+2, and Cr+6 at each site per sample are presented in Table 1. (Tables 1 and 2 are at the end of this report -- Ed.) Specific conductivity and pH levels are also given. Mean values and standard deviations of the previously mentioned data may be seen in Table 2.

Average levels of pH, specific conductivity, total Fe, Mn+2, and Cr+6 in waters sampled at and below the surface are illustrated in Figures 6 - 10 a and b. These sites correspond to those seen in Figures 4 and 5. (Sorry Jay did not supply the Figures. -- Ed.)

pH

The pH of all water samples ranges from 4.98 - 8.46 with a mean of 7.62. Acidic water is found only in the samples taken from the U.S. Highway 27 Pond, while remaining water samples are either neutral or slightly basic.

Statistical analysis of samples reveals that pH of waters in the wet southern Railroad Tunnel (x = 8.22, s.d. = 0.39) are significantly higher than those found in the dry northern Railroad Tunnel (x = 8.04, s.d. = 0.309), $F = 16.0$, $p < 0.005$. Distance from the cave entrance, alone, has no significant effect upon the water's pH. However, the interaction between increased distance from cave entrances and the differing hydrological conditions of the southern and northern Railroad passages is also significant, $F = 24.097$, $p < 0.001$. These relationships are illustrated by rising pH in the continuously wet passage of the southern Railroad Tunnel, while the converse occurs in the dry passage of the northern Railroad Tunnel.

pH appears to significantly vary with increasing distance from the top of the landfill, $F = 41.09$, $p < 0.001$. This relationship is noted by a significantly lower pH in the U.S. Highway 27 Pond, followed by a slowly increasing pH in the southern Railroad Tunnel.

Specific Conductivity

The specific conductivity of all samples ranges from a low of

147.8 umhos in dripping water at the entrance to the northern Railroad Tunnel to an anomalous high of 2940 umhos in water at the top of the landfill. A wide range of sampling conditions results in a sample mean specific conductivity of 729.98 umhos.

Statistical analysis of results reveals that specific conductivity of waters is significantly higher in the wet southern Railroad Tunnel (x = 687.33 umhos, s.d. = 38.44) compared to that water inside the dry northern Railroad Tunnel (x = 229.6 umhos, s.d. = 78.21), F = 1190.75, p <0.001. While distance from the passage entrance does not affect the specific conductivity, the interaction between this distance and hydrological conditions does, F = 12.56, p <0.005. This interactive relationship is illustrated by slightly increasing specific conductance as distance increased from the dry northern Railroad Tunnel entrance, while the converse of this relationship occurred within the wet southern Railroad Tunnel.

Specific conductivity also appears to vary significantly with increasing distance from the top of the landfill, F = 2801.75, p <0.001. This relationship is illustrated by a quickly decreasing specific conductance in both the sediment ponds tested (x = 352.0 umhos and x = 567.0 umhos in the Middle Pond and the U.S. Highway 27 Pond, respectively). Specific conductivity rises slowly as waters move towards the southern entrance of the Railroad Tunnel, only to rapidly decrease as the flow proceeds deeper into the aquifer.

Total Iron

The concentration of total Fe in all samples ranges from a low of 0.12 mg/l in water at the entrance to the northern Railroad Tunnel to a high of 21.33 mg/l in water at the top of the landfill. The mean concentration of total Fe in all samples is 2.61 mg/l. These values show that the landfill has a great impact on water quality.

Water in the southern Railroad Tunnel has significantly higher levels of total Fe (x = 0.49 mg/l, s.d. = 0.21) than waters found in the northern Railroad Tunnel (x = 0.34 mg/l, s.d. = 0.15), F = 32.05, p <0.005. While distance from the cave entrance alone did not significantly affect total Fe levels, the interaction between this distance and hydrological conditions (wet or dry) does, F = 31.38, p <0.001. This relationship is exemplified by rapidly decreasing total Fe concentrations in water flowing downstream into the southern Railroad Tunnel, while total Fe levels increased gradually as water moves further into the northern Railroad Tunnel.

As with specific conductivity, levels of total Fe are a function of distance from the top of the landfill, F = 1227.9, p <0.001. The concentration of total Fe drops precipitously as water flows into the two sediment ponds. Total Fe levels then rise until the water reaches the

entrance to the southern Railroad Tunnel. As water moves deeper into the aquifer, the concentration of total Fe decreases.

Manganese

Concentrations of Mn+2 could not be measured in water at the top of the landfill because of interferences caused by iron levels >5.0 mg/l. But, a survey of the remaining sites reveals that Mn+2 concentrations vary from a low of 0.75 mg/l in water sampled in the northern Railroad Tunnel to a high of 5.70 mg/l in the southern Railroad Tunnel. The mean concentration of Mn+2 in all waters tested in the Sloan's Valley drainage basin is 3.42 mg/l.

Statistical analysis reveals that Mn+2 concentrations vary significantly between the two Railroad Tunnel passages as a function of their hydrological conditions (wet or dry), F = 879.37, p <0.001. This is confirmed by the observation that mean levels of Mn+2 are significantly higher in waters of the southern Railroad Tunnel (x = 5.30 mg/l, s.d. = 0.30) than those found in waters of the northern Railroad Tunnel (x = 1.25 mg/l, s.d. = 0.39). Neither distance from the passage entrance nor the interaction between this distance and hydrological conditions have any significant effect upon Mn+2 concentrations.

However, distance from the U.S. Highway 27 Pond does affect the concentration of Mn+2, F = 12.85, p ≤0.005. This relationship is illustrated by generally increased Mn+2 levels as the distance of the sample site from the pond increases.

Hexavalent Chromium

Hexavalent chromium levels range between a low of 0.005 mg/l at the entrance to the southern Railroad Tunnel to a high of 0.075 mg/l at the northern Railroad Tunnel entrance. The mean concentration of Cr+6 in all samples is 0.037 mg/l.

Further analysis shows that Cr+6 concentrations vary significantly as a function of differing hydrological conditions, F = 24.22, p <0.005. This observation is confirmed by significantly higher mean concentrations of Cr+6 in waters of the dry northern Railroad Tunnel (x = 0.044 mg/l, s.d. = 0.027) compared to levels found in waters of the wet southern Railroad Tunnel (x = 0.019 mg/l, s.d. = 0.008). Hexavalent chromium levels in groundwaters are also affected significantly by the sampling site's distance from the passage entrance, F = 6.11, p <0.025. Mean concentrations of Cr+6 gradually increase as water of the southern Railroad Tunnel flows deeper into the aquifer. However, the interaction between hydrological conditions and distance from the cave entrance does not affect significantly the levels of Cr+6.

It appears that Cr+6 levels vary significantly as a function of distance from the top of the landfill, F = 7.25, p <0.005. This relationship is verified by a significantly decreasing concentration of Cr+6 in water as it flows down gradient into

the sediment ponds. Down gradient from the U.S. Highway 27 Pond, concentrations of Cr^{+6} gradually increase.

Nitrates

Nitrate analysis, because of presumed interference by high levels of copper and molybdenum, yielded what might be an anomalous reading of 30.5 mg/l in water at the top of the landfill. Subsequent testing of water 30.5 ft. inside the southern Railroad Tunnel revealed a nitrate level of 0.30 mg/l.

Summary of Results

Waters tested in the Sloan's Valley drainage basin tend to have a neutral or slightly basic pH. These waters generally have high specific conductivity (>600 umhos) and a high concentration of heavy metals.

Levels of specific conductivity and heavy metals are generally highest in water sampled near the top of the landfill. As water moves down gradient, these levels tend to drop precipitously, only to rise gradually as the water approaches the southern Railroad Tunnel entrance. Once inside the wet cave passage, specific conductivity and total Fe levels fall, while pH, Mn^{+2}, and Cr^{+6} levels rise as distance from the entrance increases.

Samples tested show that the two Railroad Tunnel passages have significantly different levels of pH, specific conductivity, total Fe, Mn^{+2}, and Cr^{+6}, generally due to varied hydrological conditions and to a limited degree, distance of the sampling site from the cavern entrance. pH, specific conductivity, total Fe, and Mn^{+2} levels are significantly higher in waters of the wet southern Railroad Tunnel than those of the drier northern Railroad Tunnel. The concentration of Cr^{+6} is higher in the passage of the northern tunnel compared to the southern Railroad Tunnel.

In the dry northern Railroad Tunnel passage, specific conductivity and total Fe levels rise at the same time pH, Mn^{+2}, and Cr^{+6} readings fall or fluctuate as distance from the entrance increases. pH, specific conductivity, total Fe, Mn^{+2}, and Cr^{+6} are distributed within the wet southern passage as noted previously.

Analysis of Water Quality in Sloan's Valley Samples

The Dixie Bend Sanitary Landfill

Water at this site can be considered very polluted. The mean pH of water samples taken at this site is slightly basic (x = 7.58). The samples display very high specific conductivities (>2000 umhos) that indicate supersaturated concentrations of Ca^{+2} and Mg^{+2}. High specific conductivity of landfill waters may also be related to the supersaturated concentrations of total Fe and Cr^{+6} (x = 20.13 mg/l and x = 0.055 mg/l,

respectively) that are far in excess of EPA (1973) standards (0.3 mg Fe/l and 0.003 mg Cr^{+6}/l). Following this line of reasoning and the fact that soils covering the landfill are bare, it may be expected that landfill waters exhibit Mn^{+2} concentrations in excess of EPA (1973) standards (0.05 mg/l).

Total iron concentrations found previously in other waters are presented in Table 3. (Table 3 is at the end of this report. -- Ed.) Results of this study show that total Fe concentrations in water at the top of the Dixie Bend Sanitary Landfill are greater than the levels of total Fe in data reported by Murray et. al. (1981) by a factor of 2.0, but, well within hypothetical ranges set by Freeze and Cherry (1979). Present iron levels (x = 20.13 mg/l) in water sampled at this site are approximately 2.5 times higher than the concentration of total Fe (8.98 mg/l) obtained by Ferry (1984). This contrast indicates further aging of the Dixie Bend Sanitary Landfill.

A high concentration of total Fe in neutral water, such as that seen in the Dixie Bend Sanitary Landfill, is contrary to theories postulated by Hem (1967). Hem theorized that neutral water (pH = 7.0) in conjunction with high bicarbonate alkalinity, could maintain only a small concentration of Fe^{+2} derived from the dissolution of siderite ($FeCO_3$). However, a high level of Fe^{+2}, may also be the result of the dissolution of large quantities pyrite (FeS_2) associated with past surface mining of coal deposits. An additional explanation may be the possible relations between the solubilities of $CaCO_3$, Fe^{+2} and Fe^{+3}, and the hydrographic curve.

Although the NO_3^- levels appear to be extremely high (30.5 mg/l), this reading could be the result of intensive organic decomposition within the landfill. This finding would be in accordance with the hypothesis that a large fraction of trash in the landfill is organic matter. Additionally, Pulaski County and the surrounding areas are primarily agricultural in nature.

The Sediment Ponds

U.S. Highway 27 Pond water is moderately acidic (xpH = 5.02) and conductive (x = 567 umhos). While total Fe concentrations (x = 0.253 mg/l) are within clean water standards set by the EPA (1973) (x = 0.3 mg Fe/l), this water may be considered polluted with Mn^{+2} (x = 5.0 mg/l) and Cr^{+6} (0.040 mg/l) levels beyond limits set by the same agency (x = 0.05 mg Mn^{+2}/l and x = 0.003 mg Cr^{+6}/l). U.S. Highway 27 Pond water has significantly lower levels of pH, specific conductivity, and heavy metals than water sampled at the top of the landfill. These findings indicate that a significant concentration of total Fe, Mn^{+2}, and Cr^{+6} are adsorbed onto soils and sediments and/or precipitated out of solution before water flowing down gradient from the top of the landfill reaches the U.S. Highway 27 Pond. However, high levels of specific conductivity and Mn^{+2} in this water still indicate accelerated erosion of soils and sediments covering the sanitary landfill. High concentrations of Mn^{+2} and Cr^{+6} may also be attributed to the burial of metallic household refuse such as old batteries, car parts,

plumbing fixtures, etc.

The acidity of U.S. Highway 27 Pond water may be attributed to the decomposition of biota within and without the reservoir. Decaying plants and animals would form high levels of nitric acid (HNO3). However, it is more plausible that this water's acidity is caused by the erosion of pyrite rich soils and sediments covering the landfill. As water flowing from the top of the landfill erodes this soil, pryrite could be dissolved into its ionic constituents, $Fe+2$ and $2S-$. The reaction between the sulfur and the water would result in the production of sulfuric acid (H2SO4). Water recharging the U.S. Highway 27 Pond would probably contain a high concentration of H2SO4 and would be acidic. Significantly decreased concentrations of total Fe in U.S. Highway 27 Pond water may be attributed to a mean pH >5.0, which should cause this metal to adsorb onto sediments and/or to precipitate out of solution. This interpretation would be in accordance with theories advanced by Hem (1967).

In terms of total Fe, water sampled in the U.S. Highway 27 Pond (x = 0.253 mg/l) is believed to be cleaner than that assessed by Ferry (1983) (x = 2.18 mg/l). Currently, this same water is more contaminated in terms of $Mn+2$ (x = 5.0 mg/l) than that analyzed by Ferry (1983) (x = 2.88 mg/l). These findings further support the interpretation that heavy metals pollution of the U.S. Highway 27 Pond is due primarily to soil erosion.

Water in the Middle Pond, while nearly neutral (xpH = 7.20) and moderately conductive (x = 352 umhos), can be considered polluted with total Fe (x = 0.47 mg/l), $Mn+2$ (x = 2.68 mg/l), and $Cr+6$ (x = 0.052 mg/l) in excess of EPA (1973) clean water standards. Although levels of total Fe and $Cr+6$ are significantly lower in Middle Pond water than that near the top of the landfill, a high concentration of $Mn+2$ indicates further erosion of surrounding landfill soils and sediment. Total Fe concentrations higher than expected under Hem's (1967) hypothesis of Fe solubility can be related to high sediment loads, extended residence times, and the dissolution of pyrite. Present levels of total Fe in water at the Middle Pond (x = 0.47 mg/l) are significantly lower than that obtained by Ferry (1983) (x = 11.8 mg/l). At this time, $Mn+2$ concentrations in water at this site (x = 2.68 mg/l) have also declined significantly since Ferry's (1983) study (x = 12.02 mg/l). Thus, water of the Middle Pond may be considered much less polluted with total Fe and $Mn+2$ than it was three years ago.

In terms of pH, specific conductivity, and $Mn+2$, water in the U.S. Highway 27 Pond is more polluted than that tested in the Middle Pond. This belief is attributed to the greater potential for erosion of soils, afforded by a longer distance between the U.S. Highway 27 Pond and the top of the landfill compared to that distance between the top of the landfill and the Middle Pond. Intermittent flow to the Middle Pond would also tend to limit the amount of heavy metals brought by

eroded soils.

The Railroad Tunnels

The entrances

Water entering the Southern Railroad Tunnel passage is moderately basic (xpH = 8.21) and highly conductive (x = 726.33 umhos). Water sampled at this location, as that of the U.S. Highway 27 Pond, is found to be polluted with concentrations of total Fe (x = 0.717 mg/l), $Mn+2$ (x = 4.97 mg/l), and $Cr+6$ (x = 0.010 mg/l) in excess of standards set by the EPA (1973) (0.3 mg Fe/l, 0.05 mg $Mn+2$/l, and 0.003 mg $Cr+6$/l). Collectively, these readings indicate that water entering this passage carries a heavy sediment load of soil rich in $Ca+2$, $Mg+2$, total Fe, and $Mn+2$. This sediment load appears to originate primarily from an area located between the U.S. Highway 27 Pond and the Southern Railroad Tunnel entrance as indicated by lower specific conductivity and total Fe levels in water sampled at the former location.

Nitrate analysis of water samples taken at the southern Railroad Tunnel entrance (0.30 mg/l) are within limits set by the EPA (1973) (45.0 mg/l). This finding suggests that biological pollution of the southern Railroad Tunnel is minimal in terms of decomposition. Nitrate production from decomposing phytoplankton would be limited due to winter dormancy.

Analysis of samples taken outside the southern Railroad Tunnel entrance shows that total Fe (x = 0.717 mg/l) and $Mn+2$ (x = 4.97 mg/l) levels have dropped since Ferry's (1984) results (x = 16.4 mg Fe/l and x = 21.02 mg $Mn+2$/l). These findings indicate that water entering the Southern Railroad Tunnel entrance is less polluted than it was two years previous to this study.

As described earlier, the northern Railroad Tunnel entrance receives basic water (xpH = 8.43) from an intermittently flowing stream originating in the Daniel Boone National Forest located to the north. Water sampled at the Northern Railroad Tunnel entrance may be considered polluted with concentrations of $Mn+2$ (x = 1.30 mg/l) and $Cr+6$ (x = 0.068 mg/l), well in excess of EPA (1973) limits (0.5 mg $Mn+2$/l and 0.003 mg $Cr+6$/l). Relatively low levels of total Fe (x = 0.147 mg/l) and specific conductivity (x = 155.37 umhos) indicate light sediment loads and limited soil erosion within this part of the drainage basin.

Inside the passages

As mentioned previously, water flowing inside the southern Railroad Tunnel passage becomes more basic and loses iron and specific conductivity as a function of increasing distance from the cavern entrance. But, this same water gains significant amounts of $Mn+2$ and $Cr+6$ above EPA (1973) guidelines. The distribution of total Fe in the southern Railroad Tunnel is in agreement with the hypothetical patterns postulated by Hem

(1967) and Bogli (1960), and may be attributed to speleogenetic activity. Increased levels of Mn^{+2} and Cr^{+6} can be traced to their presence within the bedrock of the aquifer. Decreasing specific conductance may be caused by the precipitation of CO_3^{-2} compounds such as Ca and $MgCO_3$. Based upon this data, it is concluded that water of the southern Railroad Tunnel remains polluted with concentrations of total Fe, Mn^{+2}, and Cr^{+6} in excess of EPA (1973) clean water standards.

pH, specific conductivity, total Fe, and Mn^{+2} readings of water sampled within the northern Railroad Tunnel passage tend to decrease significantly to levels within EPA (1973) clean water standards. Levels of the above mentioned variables decrease as a function of increasing distance from the cavern entrance. Decreasing pH as a function of distance from the entrance may be possibly the result of degassing CO_2 (Runnells, 1969) and/or a prolonged residence time.

Water sampled in the northern Railroad Tunnel passage shows signs of fluctuating Cr^{+6} concentrations as a function of increasing distance from the passage entrance. These findings are most likely attributed to the presence of plated metallic items located close to the sampling sites and extended residence times within the pooled environment. Analysis of the factors mentioned above lead to the conclusion that Northern Railroad Tunnel water is fairly clean.

Conclusions

An analysis of Sloan's Valley water samples indicates that the Dixie Bend Sanitary Landfill is not polluting the SVCS. Instead, it is believed that contamination of the SVCS water within the southern Railroad Tunnel passage is the product of eroded iron, manganese, and hexavalent chromium (to a lesser extent) rich soils and sediments. These soils and sediments are carried in the continuously flowing stream that originates at a point just below the U.S. Highway 27 Pond.

This interpretation is supported by evidence that pH, specific conductivity, total Fe, Mn^{+2}, and Cr^{+6} levels in landfill water, drop precipitously as this water flows down gradient towards the two sediment ponds, particularly the U.S. Highway 27 Pond. Rising concentrations of total Fe, Mn^{+2}, and Cr^{+6} do not appear until this same water approaches the southern Railroad Tunnel entrance to the SVCS. Speleogenetic activity of this water may allow pH to rise slowly as the concentration of total Fe declines quickly with increasing distance from the entrance. The distribution pattern of Mn^{+2} and Cr^{+6} in the southern Railroad Tunnel passage can possibly be attributed to the composition and the chemical weathering of the bedrock within the SVCS. Decreasing specific conductivity as a function of increasing distance from the cavern entrance suggests that solution is retarded due to dilution from large volumes of continuously moving water.

Sample data obtained from this project may, in part, contradict theories advanced by Hem (1967) and Bogli (1960) in that neutral water at the top of the Dixie Bend Sanitary Landfill and the southern Railroad Tunnel entrance may hold high concentrations of heavy metals. These findings may be linked to a continuous fast flowing supply of water, the erosion of calcium - magnesium rich soils, and an abundant supply of decaying plants and animals which may provide a continuous supply of free CO_2. Collectively, these factors may raise quickly a water's pH, bicarbonate and carbonate alkalinity, and Ca^{+2} and Mg^{+2} levels. This interpretation suggests that speleogenetic activity is regulated by hydrographic properties such as residence time, and the volume and origin of water recharging the aquifer.

This data suggests that landfill management investigate ways to control more effectively soil erosion, particularly in areas located down gradient from sediment traps. Possible ways to control this erosion would be to terrace the hillsides surrounding the landfill Dasmann (1980) and/or to plant protective deep rooted vegetation; e.g., crown vetch or pine seedlings (Greene, 1985).

Therefore, it is advised that future studies of groundwater and groundwater pollution explore the concentrations of heavy metals, pH, and specific conductivity in relation to the hydrographic curve. It is also recommended that standard additions checks be performed to assure higher reliability of test procedures. Higher reliability of results may also be achieved with the procurement of additional samples, particularly at phreatic levels.

Further analysis of Sloan's Valley waters should be performed with an atomic absorption spectrometer, if possible. Analysis of samples with such an instrument would eliminate most interferences to heavy metals measurement.

It is suggested that any future investigation of surface and groundwater contamination in the Sloan's Valley drainage basin include assessment of Ca^{+2} and Mg^{+2} levels. The concentrations of Ca^{+2} and Mg^{+2} would be compared to those of Fe, Mn^{+2}, and Cr^{+6} in order to assess more clearly the proportionate effects of the latter three upon a water's specific conductivity. Sulfates and nitrates concentrations in these waters should also be examined. Such an analysis could be used to determine if acidity of U.S. Highway 27 Pond water is the product of weathered pyrite rich soils and sediments carried from the top of the landfill or that of decaying biota within and without the reservoir.

Moreover, results of this study support the viewpoint that soil and bedrock of the study area seem to have high levels of heavy metals naturally present. Thus, it is suggested that future studies of Sloan's Valley water investigate whether non-naturally occurring organics (e.g., surfactants, industrial and household solvents, etc.) are present, particularly in water flowing down gradient from the Dixie Bend Sanitary Landfill.

Such a study would provide a more definitive, more reliable assessssment of water quality for the SVCS.

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TABLES

Table 1:
Water sample levels of
pH, specific conductivity, total Fe, Mn+2, and Cr+6.

Station #	Sample #	pH	Specific cond. umhos	Total Fe mg/l	Mn+2 mg/l	Cr+6 mg/l	Hydr. cond.	Dist. from cave entr.
1	1	7.52	2940	21.33	*	0.055		
landfill	2	7.58	2940	19.47	*	0.052	wet	*
	3	7.65	2820	20.13	*	0.058		
2	4	7.25	353	0.44	2.40	0.050		
surface Middle	5	7.18	351	0.48	2.75	0.055	wet	*
Pond	6	7.17	352	0.40	2.90	0.050		
3	7	5.08	566	0.27	5.00	0.035		
U.S. Hwy	8	5.00	570	0.25	4.80	0.040	wet	*
27 Pond	9	4.98	565	0.24	5.20	0.045		
10	10	8.17	738	0.70	4.90	0.005		
	11	8.23	713	0.69	5.00	0.015	wet	0.0 ft.
	12	8.23	728	0.76	5.00	0.010		
13	13	8.16	671	0.55	5.40	0.018		
Southern Railroad	14	8.22	703	0.53	5.70	0.025	wet	30.5 ft.
Tunnel	15	8.22	697	0.45	5.25	0.023		
	16	8.25	625	0.20	5.70	0.025		
	17	8.27	670	0.23	5.50	0.022	wet	40.6 ft.
under-	18	8.27	641	0.26	5.30	0.277		
ground 20	19	8.45	159.1	0.13	1.60	0.060		
	20	8.39	159.2	0.12	1.20	0.075	dry	2.9 ft.
	21	8.46	147.8	0.19	1.10	0.070		
90	22	8.03	242	0.40	0.75	0.012		
Northern Railroad	23	7.88	184.3	0.41	0.80	0.008	dry	215.6 ft.
Tunnel	24	7.90	195	0.42	0.95	0.015		
130	25	7.76	316	0.41	1.90	0.055		
	26	7.74	313	0.45	1.60	0.035	dry	330.7 ft.
	27	7.75	350	0.51	1.35	0.065		

* not applicable

** unable to assess due to interference by levels of total Fe >5.0 mg/l

Table 2:
Sample means and standard deviations of pH, specific conductivity, total Fe, Mn+2, and Cr+6.

Station #	pH		Specific cond. umhos		Total Fe mg/l		Mn+2 mg/l		Cr+6 mg/l	
	x	s.d.	x	s.d.	x	s.d.	x	s.d.	x	s.d.
1. land-fill	7.58	0.065	2900	69.28	20.31	0.943	*	*	0.055	0.003
2. Middle Pond	7.20	0.044	352	1.0	0.47	0.026	2.68	0.257	0.052	0.003
3. U.S.Hwy 27 Pond	5.02	0.053	567	2.65	0.253	0.015	5.00	0.200	0.040	0.005
10. s.Rail-road Tunnel entrance	8.21	0.035	726.33	12.58	0.717	0.038	4.97	0.058	0.010	0.005
13. 30.5' inside s. tunnel	8.20	0.035	690.33	17.01	0.51	0.053	5.45	0.229	0.022	0.004
14. 40.6' inside s. tunnel	8.26	0.012	645.33	22.81	0.23	0.030	5.50	0.200	0.025	0.003
20. n.Rail-road Tunnel 2.9'inside entrance	8.43	0.038	155.37	6.55	0.147	0.038	1.30	0.265	0.068	0.008
90. 215.6' inside n. tunnel	7.94	0.081	207.10	30.69	0.41	0.010	0.83	0.104	0.012	0.004
130. 330.7' inside n. tunnel	7.75	0.010	326.33	20.55	0.46	0.050	1.62	0.275	0.052	0.015
ALL SAMPLES	7.62	**	729.98	**	2.61	**	3.42	**	0.037	0.021

* unable to assess due to interferences by levels of total Fe >5.0 mg/l

** not an appropriate use of the standard deviation

Table 3:
Iron concentrations of waters in various landfill sites.

	Sloan's Valley Landfill (1987)	Sloan's Valley Landfill Ferry, (1984)	Murray et.al. site* (1981)	Freeze and Cherry site* (1979)
Metal	x = mg/l	x = mg/l	mg/l	range - mg/l
Fe	20.31	8.28	9.0	1 - 1000

* Sanitary landfill

FIGURE 7
Mike Gray's HP11C Program

```
        register !
            #     !


--------------------------------------------------------------------
            1      !   The total distance North or South form the start.
            2      !   the average bearing of the current sight.
            3      !   not used.
            4      !   true level ground distance of the current sight.
            5      !   total distance of all the sights.
            6      !   change in elevation  of the current sight.
            7      !   the current  elevation or the total change in elevation
            8      !   distance east or west from the last station (neg#=west)
            9      !   total distance east or west from start of survey.
            0      !   distance North or South from the last station.
           .1      !   distance from the start to the current location.
           .2      !   bearing from the end to the current location.

       ( Those last locations are point 1 and point 2 )
       ( These are valid storage register locations )

LINE- Display !   Key stokes use program "A" to do the conversion.
 001-42,21,11  !<f> <LBL> <A>! Reverse bearing by 180 degrees is user
"A" ***
 002-       1 ! <1>            !
 003-       8 ! <8>            !
 004-       0 ! <0>            !
 005-      30 ! <->            !
 006- 43   10 ! <g> <x y>      ! Is X  < or = Y ?
 007-   32  8 ! <GSB> <B>      !
 008- 43   32 ! <g> <RTN>      !
 009-42,21,12  !<f> <LBL> <B>! Average two bearings is user "B ************
 010-43, 5, 1  !<g> <CF> <1> ! Clear flag  1
 011-   42 20 ! <f> <x y>      !  Is X  < Y ?
 012-      34 ! <X Y>          !  Exchange x and y registers
 013- 44    2 ! <STO> <2>      !
 014-      30 ! <->            !
 015-       2 ! <2>            !
 016-      10 ! < >            ! Divide
 017-       4 ! <4>            !
 018-       5 ! <5>            !
 019- 42   10 ! <f> <x y>      ! Is X < or = Y ?
 020-43, 4, 1 ! <g> <SF> <1>! Set flag 1
 021- 43   35 ! <g> <clx>      !
 022-      33 ! <R >           ! Rotate stack down
 023-43, 6, 1 ! <g> <F?> <1>! Is flag 1 set ?
 024- 32    9 ! <GSB> <9>      !
 025- 45    2 ! <RCL> <2>      !
 026-      40 ! <+>            !
 027- 43   10 ! <g> <x 0>      ! Is X<0 ?
 028- 32    8 ! <GSB> <8>      !
 029- 44    2 ! <STO> <2>      ! Store average bearing
 030- 43   32 ! <g> <RTN>      ! ------------------------
 031-42,21, 9  !<f> <LBL> <9>! Subroutine  "9"******************
 032-       1 ! <1>            !
 033-       8 ! <8>            !
 034-       0 ! <0>            !
```

```
035-        30 ! <->         !
036-   43  32 ! <g> <RTN>    !    ---------------------
037-42,21, 8 !<f> <LBL> <8>! Subroutine  "8" ******************
038-        3 ! <3>          !
039-        6 ! <6>          !
040-        0 ! <0>          !
041-       40 ! <+>          !
042-   43  32 ! <g> <RTN>    !    ---------------------
043-42,21,13 !<f> <LBL> <C>! Average two Clinometer Readings is user "C"***
044-       40 ! <+>          !
045-        2 ! <2>          !
046-       10 ! < >          ! divide
047-   44   6 ! <STO> <6>    ! Store average Clinometer reading
048-   43  32 ! <g> <RTN>    !    ---------------------
049-42,21,14 !<f> <LBL> <D>! Calculate and store is user "D" *********
050-   42  26 ! <f> < R>     ! Convert to Rectangular
051-   44   4 ! <STO> <4>    ! Store true distance of shot
052-44,40, 5 !<STO> <+> <5>! Add to stored total true distance
053-       34 ! <X Y>        ! exchange X and Y registers
054-   44   6 ! <STO> <6>    ! Store "Rise/drop" of shot
055-44,40, 7 !<STO> <+> <7>! Store new current elevation
056-       34 ! <X Y>        ! exchange X and Y registers
057-       31 ! <R/S>        !           Run/Stop -display distance
058-   45   5 ! <RCL> <5>    ! display total true distance
059-       31 ! <R/S>        !           Run/Stop
060-   45   6 ! <RCL> <6>    ! display  Rise/Drop
061-       31 ! <R/S>        !           Run/Stop
062-   47   7 ! <RCL> <7>    ! display  Current Elevation
063-       31 ! <R/S>        !           Run/Stop
064-        3 ! <3>          !
065-        6 ! <6>          !
066-        0 ! <0>          !
067-   45   2 ! <RCL> <2>    !
068-       30 ! <->          !
069-        9 ! <9>          !
070-        0 ! <0>          !
071-       40 ! <+>          !
072-   45   4 ! <RCL> <4>    !
073-   42  26 ! <f> < R>     !  Change to rectangular
074-   44   8 ! <STO> <8>    ! Store E<>W Change of shot  (west is (-))
075-44,40, 9 !<STO> <+> <9>! Add to stored E<>W Total location
076-       34 ! <X Y>        ! exchange X and Y registers
077-   44   0 ! <STO <0>     ! Store N<>S change of shot  (south is (-))
078-44,40, 1 !<STO> <+> <1>! add to stored total N<>S location
079-       31 ! <R/S>        !           Run/Stop
080-   45   8 ! <RCL> <8>    ! display last E<>W
081-       31 ! <R/S>        !           Run/Stop
082-   45   1 ! <RCL> <1>    ! display total N<>S
083-       31 ! <R/S>        !           Run/Stop
084-   45   9 ! <RCL> <9>    ! display total E<>W
085-       31 ! <R/S>        !           Run/Stop
086-   45   1 ! <RCL> <1>    !
087-   45   9 ! <RCL> <9>    !
088-   43  26 ! <g> < P>     ! convert to polar
089-   44  .1 !<STO> <.> <1>! store total polar distance to end
090-       34 ! <X Y>        ! exchange X and Y Registers
091-   44  .2 !<STO> <.> <2>! store bearing to end
092-       31 ! <R/S>        !           Run/Stop
093-   45  .1 !<RCL> <.> <1>! display distance to end
094-   43  32 ! <g> <RTN>    !    ---------------------
```