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Environmental Education Projects Built Around Feral Battery Research

Aaron A. Jennings, Jim Clark, Sara Hise, Bryant Kiedrowski
Department of Civil Engineering
Case Western Reserve University
Cleveland, OH 44106-7201

Abstract

Feral batteries are consumer batteries that have "run wild" to litter urban pavements. This problem was first identified during a summer 2001 NSF-REU project to measure heavy metals in brownfield soils. The project required field sampling and shopping to replenish consumables. While shopping, batteries were often observed in parking lots. This led to pavement surveys where littered batteries were collected and characterized. The results were startling. Over 2,000 feral batteries were collected. Average surveys yielded 19 batteries, but there was considerable site variability. Survey results are presented to illustrate the potential environmental significance of consumer battery litter.

The issue of urban battery litter raises several questions that can be answered by traditional laboratory research. Results of work to measure battery deterioration rates and pollutant release properties are also presented. However, battery litter also raises questions that cannot be answered in the laboratory. Almost nothing is known about the distribution of "hot spot" sites where battery litter rates are high. Developing this information has become the focus of environmental educational projects. Details are presented on a program that has been developed to conduct feral battery surveys as components of K-12 grade educational projects on the environmental implications of batteries, and to partner K-12 student teams with university research. This program offers an opportunity for hands-on education about issues such as heavy metal toxicity, environmental economics, non-point source pollution and recycling. Because this requires off-school activity at busy commercial locations where students collect and characterize what could be thought of as "hazardous" samples, implementation has not been without challenges, but the potential benefits seem to be well worth the efforts required.

Introduction

"Feral" batteries are consumer batteries (D, C, AA, AAA, 9V, etc. cells) that have "run wild" and can now be found lying on urban parking lot and street pavements releasing heavy metal contamination to stormwater each time there is a significant runoff event. This is not a well-known problem, but recent field data gathered in Cleveland, Ohio indicate that for some urban locations, battery litter can be a surprisingly important source of heavy metal contamination. The primary goal of this paper is to discuss a cooperative program of environmental education and research that incorporates K-12 field surveys into both educational programs of study on battery-related environmental issues and ongoing research to characterize the feral battery problem. However, before discussing details of this program it seems appropriate to supply more background information on the feral battery problem. Although we all use batteries, most people are unaware of the degree to which these become litter and thereby sources of heavy metal pollution to urban surface waters.

Discovery of the feral battery issue

In summer 2001, Dr. Jennings was supervising a team of NSF Research Experience for Undergraduates (REU) students in a brownfield soil sampling project. The research team searched for specific forms of "old contamination" heavy metals in brownfield soils (a specific form of pollution that can be unusually difficult to remediate), so many days were spent searching the greater Cleveland Ohio area for sampling locations. Results of this project can be found in Jennings et al. (2002), a publication to which all of the undergraduate students were co-authors. The project also required frequent shopping for consumable field supplies. On several shopping occasions, batteries were observed in parking lots. Because the project was focusing on heavy metal pollution, the team began discussing "feral batteries" as a potential source of heavy metal contamination and became more watchful for battery litter. This led to the observation of large numbers of feral batteries and to formal surveys where the team collected all the littered batteries in parking lots. The results were surprising. At one Wal-Mart, 56 batteries were recovered in the initial survey. In one small shopping center parking lot, 66 were recovered. At one urban street location, 54 batteries were recovered from a single curb and sidewalk survey. These batteries were in varying stages of decay from "like new" to "highly deteriorated", represented numerous national and international manufacturers and came from at least 10 power chemistry families. Additional details on Cleveland area survey results will be provided in a following section.

When batteries are littered in parking lots, they generally become trapped on the pavement by the curb system where they are eventually crushed (ruptured). The exposed steel "can" rusts so the color and texture of the mottled cylinder tends to blend with the asphalt background. They are easily overlooked, but they are there lying on the pavement or against the curb with the cigarette butts, disposable lighters and other litter. Few people are aware of how common this form of litter is. Unfortunately, as the batteries deteriorate, they release serious contamination (Ag, Cd, Co, Cr, Cu, Hg, Li, Ni, Pb, Sn, Ti, Zn), so they can be significantly more harmful than common litter. The type and rate of chemical release depends on size, power chemistry and deterioration state of the battery, but ultimately (if not removed), all of the internal contents will be flushed into the stormwater runoff. This is a source of heavy metal contamination that should be quantified, evaluated and (where appropriate) remediated.

Power chemistry of consumer batteries

Consumer batteries use many different electrochemical power systems. The major systems are summarized below (ref: Powerstream, 2001; Linden, 1995), but these reactions do not account for the "minor" components added to solve problems such as gas formation (the source of Hg addition) or to enhance performance under variable loading conditions. More detail can be found in battery MSDS information, but many of the subtle chemical details are proprietary and undisclosed. Feral batteries based on all of these electrochemical systems have been recovered from Cleveland pavements.

Zinc Carbon	$Zn + 2NH_4Cl + 2MnO_2 \rightarrow Mn_2O_3 + Zn(NH_3)_2Cl_2 + H_2O$
Zinc Chloride	$Zn + 2MnO_2 + ZnCl_2 + 2H_2O \rightarrow 2MnOOH + 2Zn(OH)Cl$
Alkaline-Manganese Dioxide	$Zn + 2MnO_2 \rightarrow ZnO + Mn_2O_3$
Lithium (Manganese Dioxide)	$Li + MnO_2 \rightarrow LiMnO_2$
Lithium Carbon Monofluoride	$nLi + (CF)_n \rightarrow nLiF + nC$
Alkaline Zinc-Air	$2Zn + 1/2O_2 + 2H_2O \rightarrow 2Zn(OH)_2$
Silver Oxide	$Zn + Ag_2O \rightarrow ZnO + 2Ag$
Nickel-Metal Hydride	$MH + NiOOH \rightarrow Ni(OH)_2 + M$
Nickel/Cadmium	$Cd + NiO_2 + 2H_2O \rightarrow Cd(OH)_2 + Ni(OH)_2$
Lead Acid	$Pb + PbO_2 + 2H_2SO_4 \rightarrow 2PbSO_4 + 2H_2O$
Mercuric-Cd Oxide	$Cd + HgO + H_2O \rightarrow Cd(OH)_2 + Hg$
Mercuric-Zn Oxide	$Zn + HgO + H_2O \rightarrow Zn(OH)_2 + Hg$

The alkaline-manganese dioxide battery (AKA "alkaline battery") is the most common disposable consumer battery. These batteries generally use powdered zinc (ap. 15% by weight) as the anode, manganese dioxide (MnO_2 – ap 35%) mixed with carbon as the cathode and potassium hydroxide (KOH – ap. 10%) as the electrolyte (Rayovac, 2002). These batteries have a shelf life of about 6 years. The next most common batteries are the zinc carbon and zinc chloride cells. These can often be identified by the words "Heavy Duty" or "Super Heavy Duty" used on the label. However, there is no universal convention on cell type nomenclature and these can be difficult to distinguish from one another or from "alkaline" batteries. Zinc carbon/zinc chloride batteries also use a zinc/manganese reaction, but usually contain an electrolyte solution of ammonium chloride (NH_4Cl) and zinc chloride ($ZnCl_2$), which make them more prone to leaking (Powerstream, 2001).

Battery power chemistry also continues to evolve. Panasonic and Kodak have recently begun marketing "Oxy-alkaline" batteries that are reported to have extended lives in high drain applications such as digital cameras (PIR, 2003). Oxy-alkaline batteries use an alkaline power chemistry with a modified cathode formula that substitutes nickel oxy-hydroxide for a portion of the manganese dioxide to provide a higher capacity and more voltage under heavy load. However, this blurs the line between "alkaline" batteries that are classified as non-hazardous solid waste and nickel-metal hydride batteries that generally fall under a more restricted disposal classification ("universal" waste or household hazardous waste).

Recent trends in U.S. consumer battery market

Consumer batteries come in many sizes such as lantern, multi-cell, button, button stack, K, P, R, S, J, N, AAAA, and others. Energizer currently lists 221 active battery types and over 300 discontinued battery types on its web page (Energizer, 2001a,b; Panasonic, 2003). However, the majority of consumer sales are in the "big 5" sizes: D, C, AA, AAA, and 9V. Of these, the AA size battery accounts for the largest sales volume.

D – 1.3 in. dia. x 2.4", 5V
(flashlights, boom boxes, toys)
C – 1.0 in. dia. x 1.95", 1.5V
(small flashlights, toys)
AA – 0.56 in. dia. x 1.97", 1.5V
(pagers, CD players, games)
AAA – 0.41 in. dia. x 1.75", 1.5V
(calculators, pagers, remote controls)
9V – 1.03" x 0.66" x 1.9", 9V
(radios, toys, smoke detectors)

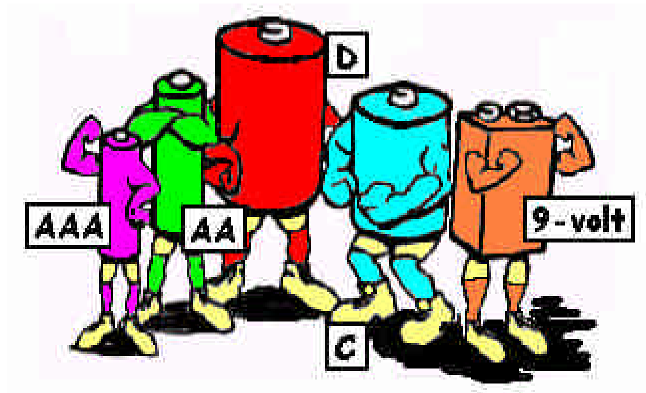

Fig. 1 – "Big 5" of Consumer Batteries

Something in excess of 10 billion dollars worth of consumer batteries are sold in the U.S. each year (Webcom Comm. Corp., 2001). The current U.S. per capita battery consumption is estimated to be 25 to 50 batteries per year (Sanyo/GE, 2003) which places the total between 7.2 and 14.5 billion batteries per year. The consumer battery market doubled during the 1990's. It grew at annual rates of 6% to 10% during 1990-98 and at 15% in 1999 due toY2K fears (Lee, 2001). This increase was driven by the general growth of consumer electronics and specifically by items such as portable CD players that have high power demands. Efforts were made during this time to introduce rechargeable consumer batteries, but it does not appear that rechargeable cells have cornered a large fraction of the (previously disposable) consumer battery market. Battery sales have not been as successful since 1999. Growth slowed to 5.2% in 2000 and may have been as low as 1.1% in 2001 (Worldofinformation, 2003). This may reflect some success in the rechargeable market, but is more likely attributable to the use of accumulated Y2K supplies and the impact of a cooler economy.

U.S. battery manufacturing is dominated by Duracell, Eveready/Energizer (uses both brand names) and Rayovac who produces batteries in the U.S. and elsewhere around the world (Canada, Mexico, China, Singapore) for import to the U.S. consumer market.

Estimated U.S. Market Share of U.S. "Big 3 Manufacturers" (Lee, 2001):

Duracell -	36.1%	(24.4 % Regular, 11.7 % Ultra)
Eveready/Energizer -	30.8%	(28.6 % Regular, 2.1% E^2 Titanium)
Rayovac -	26.9%	(7.9% Regular, 15.7% Maximum)
Total -	93.8%	

They also produce "private label" batteries. Private label batteries are batteries that carry labels such as Radio Shack, Finast, Drug Mart, Walgreens, Eckerd, Rite Aid, etc., that are made by someone else and then labeled as a store brand for a specific retail outlet. These can be made in the U.S., but are also made internationally. There are also what appear to be U.S. battery brands (e.g. Dorcy, Universal, Kodak, Polaroid) that are produced internationally for sale in the U.S. and many well-known international companies that produce battery lines for direct U.S. sale (Sony, Fuji, Panasonic, Maxell, Sanyo, Toshiba, Varta . .). There are also a large number of "anonymous" international battery brands sold in the U.S. These generally have a label written in English, but do not identify their manufacturer other than "made in -----". To date, consumer batteries manufactured in the U.S.A., plus Belgium, Canada, China, E.C.(European Community), France, Germany, Hong Kong, India, Indonesia, Japan, Korea, Macau, Malaysia, Mexico, Poland, Singapore, Thailand and the U.K. have been found in the Cleveland area.

Most recently, due to economic factors and new trade relationships, there has been an increase in the number of batteries imported from Malaysia, Indonesia and China. These can be found in dollar stores where it is common to find 16 AA batteries for $1.00. (A 4 pack of US-made AA batteries sells for about $3.50). Often dollar store batteries are lower quality, low capacity cells made with far less environmental vigilance over the quality of materials used. They claim "zero Hg added", but there is reason for skepticism about the degree to which they are Hg free. Because of their low cost, they find their way into common use, and their short lives increase the rate at which they are discarded. All types of batteries including many U.S. made batteries contribute to battery litter. However, by examining the distribution of brands in battery litter (see the following section) relative to market share statistics, one can see the disproportionate impact of lower quality, low capacity batteries. This is unfortunate because these batteries deteriorate more rapidly and release more heavy metal contamination to urban stormwater.

Results of Cleveland area feral battery surveys

Approximately 109 surveys yielding over 2,000 batteries were conducted by the CWRU Feral Battery Research Team between June 2001 and November 2002. Of these, 1,856 batteries have been classified by size, type, manufacturer and condition state. Examination of these data yield some interesting observations about the nature of the feral battery problem.

Table 1 summarizes data about Cleveland feral batteries. Over 87% of the batteries are AA or AAA cells. These sizes account for the majority of consumer battery sales, but this fraction is above the usual market share. The D, C and 9v sizes are probably underrepresented in battery litter because they are used in applications that are less mobile and are more likely to be replaced in the home. The market shares of Duracell (29.4%), Eveready/Energizer (30.3%) and Rayovac (9.5%) appear to be low. Even if one adds in some portion of the 10.9% private label batteries the total is below 80%, which appears to be well below the reported market share (Lee, 2001). This seems to reflect the recent trend in the marketing of inexpensive international batteries.

Table 1 - Summary Feral Battery By Cell type and Manufacturer

Big 5 Size	%[1]	Manufacturer	%[2]
D	3.7	Duracell	29.4
C	1.5	Eveready/Energizer	30.3
AA	69.8	Panasonic	4.9
AAA	17.3	Rayovac	9.5
9V	1.6	Misc. U.S. Private Label	10.9
Other	6.1	Misc. International	15.0

1. Percentages based on 1,856 feral batteries
2. Percentages based on 1,593 feral batteries for which the manufacturer could be identified

The average age of feral batteries can be approximated by using the "best if used by" dates that several manufacturers print on their batteries. Generally these dates (for "alkaline batteries") are based on a 6-year shelf life. Using this method, the average age of the Cleveland feral batteries sampled was 2.65 years. This appears to be quite young relative to common battery uses. As a basis of comparison, the average age of 681 datable AAA batteries that had been removed from pagers was computed to be 5.01 years by "best if used by" dating. The batteries had reportedly accumulated within the 6 months prior to the dating analysis, so they may have been as young as 4.5 years. This is still significantly older than the feral batteries collected. The "best if used by" age was also computed for 734 batteries that were removed from Adelphia remotes at their maintenance center, and from 1,262 batteries that were removed by the CWRU research team from disposable cameras awaiting recycling. The average age of these were 4.9 and 2.2 years respectively. Only the disposable camera batteries have an age profile similar to feral batteries. Based on the distribution of battery manufacturer's products in disposable cameras, which is very different from the manufacturer profile of feral batteries, it is clear that this is not the source of feral batteries. However, the nature of the disposable camera market provides another clue to the types of uses that generate feral batteries.

Figure 2 illustrates the results of feral battery surveys conducted in the greater Cleveland area between June 15, 2002 and November 21, 2002.

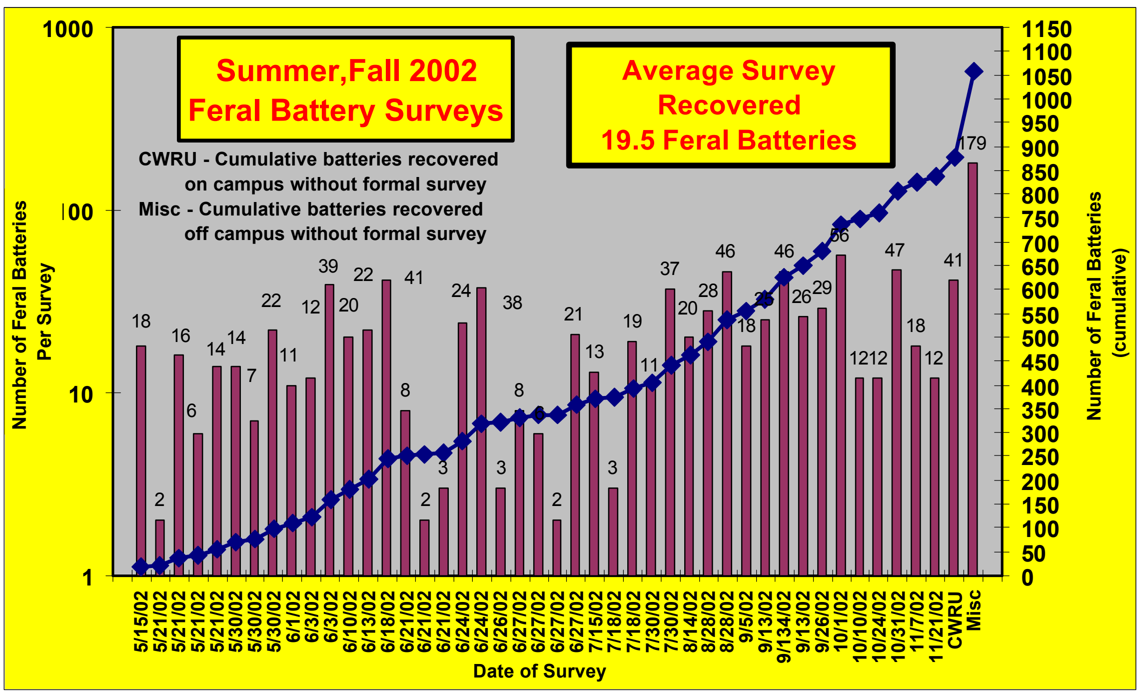

Fig. 2 – Individual and Cumulative Results of Cleveland Area Feral Battery Surveys

Note that although there is considerable site variability (recoveries varied from 2 to 56), the average site yielded nearly 20 feral batteries per survey ($\mu = 19.5$; $\sigma = 14.0$). The majority of these sites were retail parking lots, but several curb-to-curb street surveys were also conducted. The "CWRU" column represents feral batteries recovered randomly from the University Circle area and the "Misc." column represents batteries recovered randomly from off-campus locations by study team members and others. Neither of these two feral battery classes was included in the survey site average.

To help develop a more detailed understanding of the rates and patterns of feral battery generation, two survey sites were selected as case study locations and were surveyed frequently. One of these is a small local shopping center where feral batteries are recovered from the parking lot pavement. The second is centered on a busy urban street intersection where batteries are recovered from the street pavement, gutters and sidewalks.

The Church Square Shopping Center is a small shopping area on Euclid Ave. and East 79 St. in the City of Cleveland, Ohio. The site supports 19 retail outlets including a Radio Shack, CVS Pharmacy, Church Square Supermarket, Z&S Discount and Dollar Mart all of which sell consumer batteries. There are approximately 300 parking spaces in the core retail parking area.

Figure 3 illustrates the individual and cumulative results of surveys conducted at the Church Square site approximately every two weeks between Dec. 3, 2001 and Nov. 21, 2002. The 27 individual surveys yielded a total of 477 batteries. The largest number (66) recovered on March 7, 2002 probably included some batteries that had accumulated in Dec., Jan and Feb. but were hidden by snow piles. Nine different types of batteries in conditions from new to highly deteriorated were recovered. Several packages were also recovered for battery types that were not found indicating that new batteries probably went into the products from which old batteries were removed and discarded. A Panasonic C cell battery package was also recovered from which only 1 of the 2 batteries had been removed before it was discarded.

The cumulative results for the annual feral battery generation at the Church Square Shopping Center (based on 1 year of site monitoring) is 1.6 feral batteries for every retail parking space.

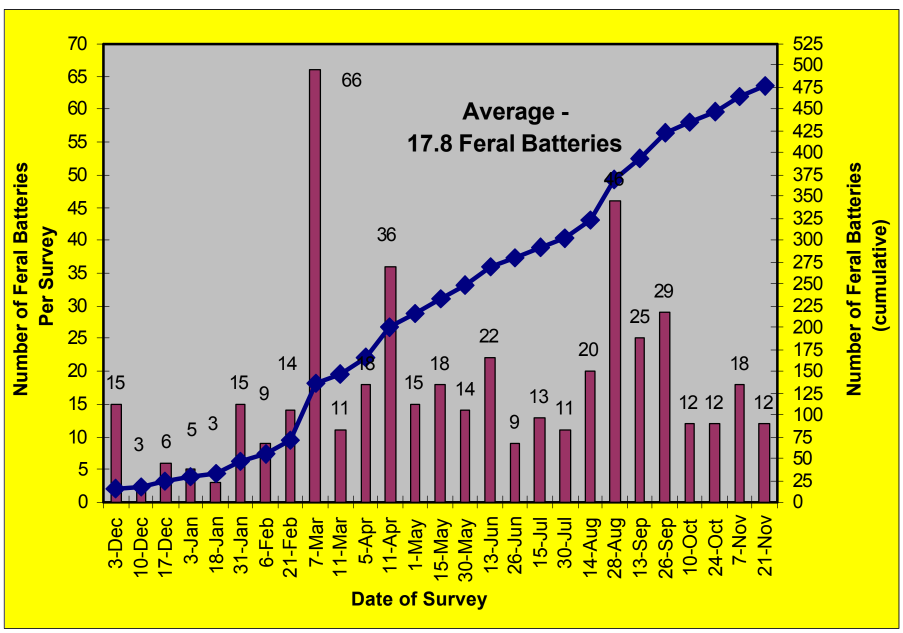

Fig. 3 - Individual and Cumulative Survey Results for Church Square Shopping Center.

The Euclid Ave./Superior Ave. case study location is centered on a busy urban intersection in the City of East Cleveland. The site is served by Regional Transit Authority rail and bus service and supports approximately 30 retail outlets including at least 4 that sell batteries. Parking is limited, but there is a large volume of pedestrian traffic at the site. Most feral batteries are recovered from the sidewalks or curbs of the public streets. There are approximately 2,880 linear feet of curb. Sampling at this site began in June 2002, but was terminated in October when the City began major reconstruction of Euclid Ave. pavement, so currently only 5 months of data are available for the site.

Figure 4 illustrates the individual and cumulative results surveys conducted at the Euclid Ave./Superior Ave. case study site. Note that the average feral battery yield (μ =38.5 ; σ =11.8) appears to be higher than at Church Square, but Church Square was sampled more frequently. If these data are extrapolated to an annual rate, the site should yield an annual feral generation of approximately 554 batteries (1 battery fort every 5.2 linear feet of curb).

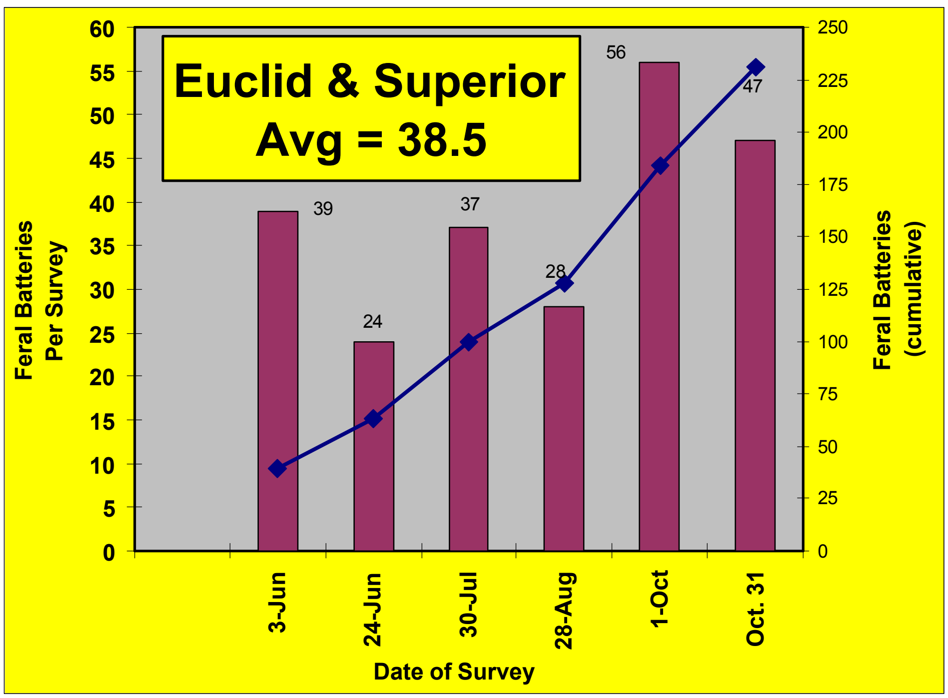

Fig. 4 - Individual and Cumulative Feral Battery Survey Results for the Euclid/Superior Site.

The fieldwork conducted in the Cleveland area has demonstrated that there is a reasonably high degree of site-to-site variability in feral battery generation, but that for some "hot spot" sites, the rate can be alarmingly high. A few of the possible indicators for "hot spot" locations seem to be emerging from the data, but it is difficult (and dangerous) to generalize without field data from a much wider area (i.e. regional, state and national variability for a much broader spectrum of U.S. communities). The dubious feasibility of generating this data in a single university research project led to the concept of using K-12 field survey teams to participate in feral battery research.

Battery deterioration rate and chemical release research

Before discussing how K-12 educational projects have been designed to participate in feral battery research, something should be said about the chemical release properties of feral batteries. This is the object of more traditional ongoing University laboratory research so it is a bit out of place here. However, it does seem important to document that feral batteries are not just litter, they are serious pollution.

For the 705 feral batteries collected between June, 2001 and May 2002, a relatively simple 5-class condition rating system was used to classify deterioration condition.

Class 1: *Like new (no signs of deterioration, freshly discarded)*
Class 2: *Slight damage (slight deformation, surface dents or abrasions, no sign of leaking)*
Class 3: *Damaged (significant structural deformation or deterioration but no obvious loss of internal integrity)*
Class 4: *Serious Damage (>50% deformation from round, deterioration, corrosion, obvious release of internal contents)*
Class 5: *Crushed (rusted, loss of structural integrity, full release of chemical contents)*

Of these 705 batteries, 63.4 % were in a "damaged" or worse (i.e. > Class 2) condition, and 40.5% were releasing their internal contents (leaking), and 18.6 % had released essentially all of their internal reactants and were little more than rusting external barrels.

Since May 2002 a more detailed system has been used to classify the physical deformation and internal/external corrosion condition of feral batteries. This system is currently being age-calibrated using battery corrosion studies conducted under controlled laboratory conditions. The initial indications are that one can use the corrosion state of a feral battery to gauge its feral age (i.e. how long it has been exposed to hostile environmental conditions). This information will be very useful in predicting annual litter rates from one-time surveys. However, corrosion studies also indicate that the feral age is not a particularly good indicator of the probability that a battery has released its internal contents. As one might expect, this appears to be much more strongly correlated with the amount of physical damage that the battery has accumulated. Studies are currently under way to quantify feral battery physical damage processes.

When alkaline batteries are ruptured, they release their internal contents, which are predominantly zinc and manganese oxides and potassium hydroxide. Of these, it is probably the zinc that has the potential for doing the most environmental damage. The Great Lakes Water Quality Agreement of 1978 (as amended in 1987) between the United States and Canada (an affirmation of both countries' commitment "to restore and maintain the chemical, physical and biological integrity" of the waters of the Great Lakes Basin Ecosystem) established a guideline of Zn < 30 μg/l to protect aquatic life (International Joint Commission, 1989). The Rayovac MSDS sheet for "alkaline" batteries (Rayovac, 2002) indicates that they contain between 11% and 16 % zinc. Using the average weight of a Rayovac Maximum AA battery ($\mu = 23.25$ g) yields between 2.56 g and 3.72 g of zinc. Using this as a rough estimate for all feral batteries, an AA battery should ultimately release approximately 3 g of zinc. Using the aquatic toxicity limit of 30 μg/l, this is enough zinc to contaminate 100,000 liters of water up to the toxicity limit.

It is clear that feral batteries release zinc. This is demonstrated by the approximately 20% of feral batteries that are found devoid of their internal reactants. This does not, however, establish that the zinc is actually released at concentrations greater than 30 μg/l. It might be possible, for example, for stormwater to carry the zinc away at concentrations more dilute than 30 μg/l. Unfortunately, this is unlikely. Solubility analysis of zinc (see Stumm and Morgan, 1996) indicates that at high pH values (pH>11) which is the native condition within the battery barrel before it is ruptured, zinc is soluble at high concentrations ([C]>>$1x10^{-4}$M) as $Zn(OH_3^-)$ or $Zn(OH_4^{2-})$. When the battery is first ruptured, this is probably the zinc form released. After the battery is ruptured and the relatively small volume of KOH is washed away, the pH undoubtedly falls. Between a pH of 11 and 8, the zinc solubility is constrained at $1x10^{-4}$M (6.5 mg/l) by $Zn(OH)_2$, but as the pH falls below 8, zinc again becomes quite soluble as elemental Zn^{2+}. Therefore, there is no solubility constraint that will prevent feral batteries from yielding high zinc water pollution levels.

As additional confirmation of this potential, laboratory batch extraction experiments and dynamic column leaching experiments have been conducted on several types of batteries under varying environmental conditions. To date, batch extractions have yielded zinc concentrations of between 18.5 mg/l and 107.1 mg/l. Dynamic column studies using a leaching flow of water at pH 4.8 indicate that when first ruptured, alkaline batteries can yield zinc at 750 mg/l in a discharge of pH = 14.5.

Educational projects built around the issue of feral batteries

The need to increase consumer familiarity about the environmental-related battery issues, and the need to generate a better understanding about the origins, patterns and solutions of feral battery generation led to the concept of building this into environmental educational projects. The idea was to educate, equip and empower K-12 study teams in major urban areas to participate in feral battery research. Study teams would conduct feral battery parking lot and street surveys, quantify battery litter rates, identify the source of battery litter at high-rate sites and implement strategies to reduce the environmental impacts of these sources. Study teams would be equipped with all of the necessary field equipment and with press kits to help them publicize the results of their activities. Detailed procedures for conducting feral battery surveys as educational projects and a series of briefing documents on battery-related issues would be supplied to the team leaders. Field surveys would be combined with educational elements that examine related issues such as non-point sources of pollution, heavy metal toxicity, the structure of the battery industry, the environmental economics of consumer batteries, environmental law and regulation, and recycling. Because feral battery surveys would be conducted as off-school activities at busy (and potentially dangerous) commercial locations where students collect and characterize what could be thought of as "hazardous" samples, a considerable amount of effort was spent on crafting and documenting a survey procedure that could be implemented with safety. Ultimately, this resulted in studies built around a study team leader and a 12-student team organized in buddy teams of two and equipped with a field kit of equipment and supplies.

> ***The Buddy Team Concept*** *- Searching the ground for batteries takes concentration. However, while concentrating on looking at the ground you become more susceptible to physical hazards in the environment around you. The best safeguard against accidents is to identify partners who will search together using the buddy system. One partner (the "safety buddy") should watch for potential dangers while the other partner (the "battery buddy") is searching for batteries. It is imperative that the partner not searching for batteries be conscientious in the duty of watching traffic so potential accidents are anticipated and avoided. This is difficult. It is fun to look for batteries. It is not as much fun to watch for traffic. Great care should be taken to make sure that the responsibilities of the safety buddy be emphasized with both partners. Partners should be encouraged to change roles so that both have the opportunity to find batteries, and both accept the responsibility for team safety. To*

help encourage these roles, we have supplied different equipment items for each role. (Jennings and Clark, 2002).

The "buddy system at work" is illustrated in Fig 5.

Fig. 5. – The "buddy team" feral battery survey approach.

The team is equipped from a survey kit that contains all of the materials necessary to locate, recover and store feral batteries (see Fig. 6). The fundamental recovery technique is to pick them up with the "Attractor" magnet and transfer them directly into the appropriate sized zip-lock storage bag. The team is also equipped with several briefing documents that address issues and procedures in detail.

Battery Industry and Power Chemistry Briefing Document – A general description of the consumer battery industry, and the power chemistry systems used in consumer batteries.
Battery Disposal Briefing Document – A general discussion of how spent consumer batteries should be classified (hazardous waste?) and how their disposal is managed.
Instructions for Conducting Feral Battery Surveys – A detailed discussion of the process of conducting a useful and safe feral battery survey.
Instructions for Classifying Feral Battery Condition – An illustrated guide to classifying the deterioration state of feral batteries.
Feral Battery Site Survey and Battery Identification Report Forms - Forms to be completed for each survey to record data on the size and condition of the site and each feral battery collected.
Guidance for Identifying Battery Product Lines – An illustrated guide to the most common consumer battery products in the U.S. market.
Team Leader and Student Participant Evaluation Forms - Forms to provide feedback on the educational properties and technical process of feral battery surveys.

These documents are supplied on CD to each survey team and will soon be available to all interested parties on a "Feral Battery Research" web page.

A. Team Leader Clip Board and Notebook
B. Team Leader Whistle and Lanyard
C. Small Battery Collection Bag (AA, AAA, 9V, . .)
D. Medium Battery Collection Bags (C, D, ...)
E. Large Site Survey Battery Storage Bags
F. Battery Tester
G. Battery Collection Gloves (medium, large)
H. Moist Wipes
I. Battery Collection/Storage Aprons
J. Collection Team Member Safety Vest
K. “Attractor” Battery Collection Magnet
L. Collection Team Member Safety Flag
M. Battery Removal Tools (screw drivers)
N. Disposable Camera

Fig. 6 – Feral Battery Survey Team Supply Kit

Field test of survey procedure

In addition to extensive field testing by the CWRU research team, the feral battery survey procedure is currently being field tested at the Brecksville-Broadview Heights High School in Broadview Heights, Ohio. The procedure is being tested by the Students Active for the Environment (SAFE) club under the direction of Mrs. Sarah Hurder.

Prior to conducting the field survey, the SAFE club was briefed on the subject of feral batteries by Jim Clark and equipped with a field survey kit that included all of the supplies illustrated in Fig. 6 plus a distance-measuring wheel. The survey team was also provided with a full set of survey briefing and result reporting documents. The SAFE club then elected to conduct feral battery surveys on the school property at the end of the school day after most of the parking lots had emptied. Working on school property resolved issues of access and transportation and allowed the work to be conducted in a reasonable amount of time as an after school project. The areas surveyed are illustrated in Fig.7. The senior parking lot has 200 parking spaces. The junior parking lot is the largest area wit 282 parking spaces and the Staff parking lot has 126 parking spaces. The total of 608 parking spaces is comparable to a modest sized retail parking lot.

The parking lots are maintained by the school's maintenance personnel and it has yet to be determined how maintenance practices impact battery litter. The plan to conduct feral battery surveys was not publicized prior to the first event so student (and staff?) battery discard practices would not be altered.

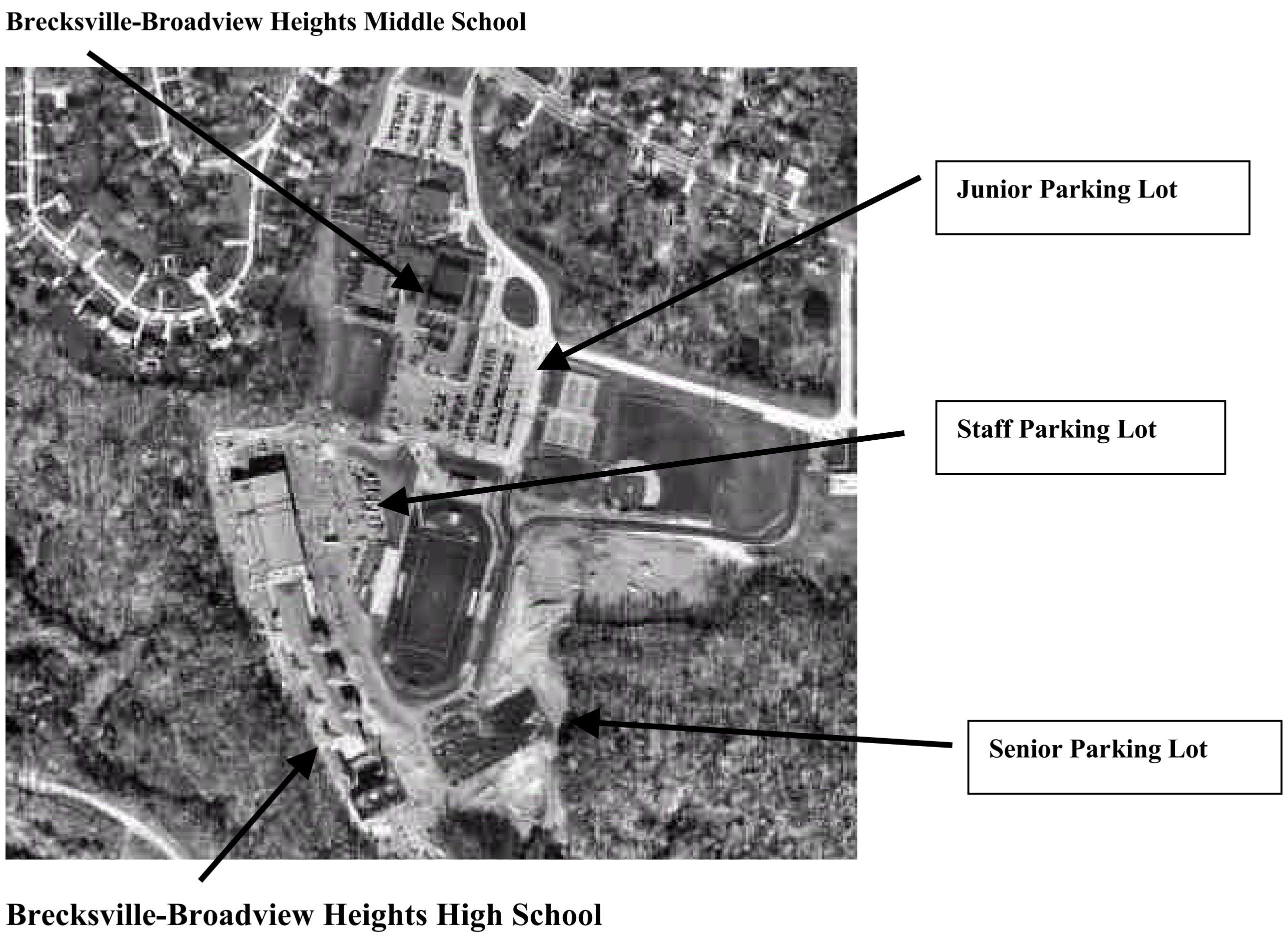

Fig. 7 – Brecksville-Broadview Heights High School Student-Conducted Survey Field Test Location

The first feral battery survey was conducted at this site on Nov. 26, 2002. The survey was conducted by 13 students, 9 of which searched for batteries while 4 were assigned safety responsibilities (flagging approaching autos). The survey was conducted at 3:00 pm, one hour after the end of the school day so traffic in the parking lots was minimized. SAFE recovered 16 feral batteries in its first survey (6 from the senior lot, 4 from the junior lot, 3 from the staff lot and 3 from the grounds between lots). The distribution by size was 13 AA cells, 2 AAA cells and 1 C cell. Duracell, Energizer, Rayovac, Panasonic, Radio Shack and Sears Diehard batteries were recovered. Although there were two batteries that could not be identified, no low-cost imported battery brands were identified. The condition of recovered batteries varied from like new to highly deteriorated. Approximately 40 % of the batteries suffered from significant external corrosion or substantial physical damage and were probably releasing contaminants.

Additional field work is planned for this site. Additional feral battery surveys would have been conducted, but winter came early to the Cleveland area. There has been an unusual amount of snowfall, which has necessitated frequent parking lot plowing. A survey was attempted on Dec. 19 during a brief break in the weather (between snowfalls), for which 3 batteries were recovered. However, it is unlikely that this represents the total accumulation since the previous survey. Batteries are probably still being littered at a higher rate, but they are hidden under snow piles and will not emerge until spring. Therefore at Brecksville (as well as CWRU's other case study locations) snow pile accumulation patterns are being documented so that snow pile melt areas can be selectively searched in the spring. Batteries recovered from these locations should help answer questions about winter litter rates and corrosion processes in the presence of additional electrolytes (salt) and low temperatures.

Summary and Conclusions

Feral batteries represent a source of surface water contamination that is not well known or understood. The significance of this source has grown with the growth of the consumer electronics industry and with recent shifts in the consumer battery market place. Field studies conducted in the greater Cleveland, Ohio area indicate that at "hot spot" sites, feral battery generation rates can be very high (approaching 2/parking space) and should probably be considered when assessing the sources of stormwater contamination.

Because so little is known about the causes for, rates of, chemical releases from and spatial distribution of battery litter problems, there is a great need for research on this subject. It will take traditional laboratory research to characterize and quantify the chemical release properties of consumer batteries ruptured and exposed to hostile environmental conditions. It will also take traditional environmental modeling techniques to predict the site consequences of battery litter because of the vast numbers of products and chemistries in the market place. However, there is also a great need for additional field research, and this appears to be an ideal topic around which exciting K-12 educational projects can be built.

The Feral Battery Research Team at CWRU has developed a program of field study based on the efforts of K-12 study teams working in cooperation with university researchers. Field teams are briefed and supplied with sufficient information and equipment to conduct safe, useful field studies. Further, study team leaders are briefed on a much wider range of battery-related environmental issues and assisted with incorporating these into their team's project. Implementation of this program has not been without challenges. There is always the problem of finding an opportunity in the curriculum for K-12 students to do field work, and always concerns about safety and supervision when students leave the classroom. However, feral battery surveys can be exciting opportunities to motivate students about a wide range of environmental study topics.

After completing field trials of the process during Spring 2003, efforts will be made to launch this program through the Great Lakes states beginning in the fall of 2003. Ultimately, the goal is to coordinate with research groups and K-12 educational programs across the country to generate national information on feral battery generation.

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