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CONTROL OF NORWAY RATS IN SEWER AND UTILITY SYSTEMS USING PULSED BAITING METHODS

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ABSTRACT: There were 1,288 sewer and 235 other utility manholes baited to control Norway rat (*Rattus norvegicus*) populations in downtown Boston using pulsed-baiting methods. About 15% of all sewer, 18% of phone, and 26% of electric manholes had rat activity. Sewer populations were most associated with residential areas with low flow, small diameter (<61 cm) brick sewers; in those circumstances, up to 38% of manholes had rat activity. Bait consumption in sewers (high risk areas) was 91% below baseline, five months after the fourth baiting period. Bait consumption and the number of active sewer holes were 96% and 87% below baseline, respectively, when seasonal maintenance baiting was last initiated. Reinfestation of phone/electric manholes was so minimal that maintenance baiting was not necessary or cost-effective. Subsurface baiting should be an integral part of urban rodent control programs.

KEY WORDS: sewer, pulsed baiting, utility system, integrated pest management, urban, Norway rat

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INTRODUCTION

Control programs for Norway rats (*Rattus norvegicus*) in urban areas characteristically are dominated by surface baiting and sanitation practices. Subsurface environments, such as sewer and other utility systems, commonly are not included when planning and implementing control measures. In part, this is because urban rodent control programs typically are reactive rather than proactive. A rat problem on the surface level is easily observable, and thus becomes the focus of pest control personnel rather than long-term strategies to manage rat populations.

Research on the ecology and control of Norway rats in sewer systems has been extremely limited in the U.S., particularly in the past 30 years. Work by Brooks (1962), Beck and Rodeheffer (1965), Barbehenn (1970), and Andrews and Belknap (1983) are examples of the limited literature available. Most information on rat control in sewers was generated by researchers in Great Britain, particularly during the 1950s and 1960s (Barnett and Bathard 1953; Bentley et al. 1955; Bentley et al. 1958; Bentley et al. 1959; Bentley 1960; Greaves et al. 1968). However, those investigations were prior to the paraffin bait formulations and active ingredients available today.

There are several reasons why there have been few studies of rat ecology and control in sewer systems and other underground utilities. These include logistics of traffic control, health and safety concerns, labor relations (union labor sometimes required to open manholes), street opening permits, and costs. These kinds of issues are not typical management concerns for field biologists.

As part of an $11 billion highway construction project in Boston, the downtown infrastructure and utility systems were extensively redesigned and construction undertaken for a new 8 to 10 lane underground highway (Colvin et al. 1990). This included relocation of 29 miles of utilities and installation of new utilities to replace numerous layers of overlapping and aging systems ranging from sewers, to phone and electric systems, cable tv, and steam and gas lines. This effort required a subsurface baiting program to eliminate rat populations prior to excavation, and concurrent control in adjoining neighborhoods to limit reinfestation of the project alignment. The purpose of this paper is to describe the baiting methods that evolved, control achieved, and recommendations for subsurface baiting programs.

RATS AND UTILITY SYSTEMS

Norway rats use sewer systems for feeding, movement, and living space. They may create burrows and excavations at cracks or breaks in sewer lines where there is soil settlement or structural movements around the pipe, pipe aging or corrosion, invasion by tree roots, or structural flaws in the system. Burrows can lead to surface level or through the foundation wall of a nearby building. Rats also can enter buildings through an open service hole in a sewer pipe inside a basement or through a toilet (usually basement or first floor). Localized accumulation of soil inside a sewer, because of rat excavations or infiltration from outside the system, also can provide a medium for burrows.

A sewer can be a combined system (storm water and sanitary flows in the same pipe) or have the storm drains and sanitary lines separate. Sanitary or combined systems have greater risk of rat activity than storm drains because of better availability of food within them. The trend towards separated storm and sanitary lines began in the 1950s because of limitations in sewage treatment capacity and water pollution from direct discharges to water bodies.

Brick was the most commonly used material to construct sewers in the early 1880s to mid 1900s; iron and wood also were used historically. However, most sewers installed in the past 50 years in the U.S. have been vitrified clay or pre-cast concrete; the use of PVC (polyvinyl chloride) became popular in the late 1980s. Because brick sewers can lose mortar and bricks, and clay pipe typically is installed in 4 to 5 foot sections, gaps for rat burrowing can occur most with those materials, especially over time.

Catch basins that provide street-level drainage can become infested or provide access into and out of a sewer system. Excessive debris or soil inside a catch basin can serve as a base for burrowing. Structural problems, such as missing bricks or cracks, provide gaps for burrows and access underneath sidewalks or into adjacent buildings through cracks in foundations.

Other types of underground systems that can be inhabited by Norway rats include phone, electric, and cable tv manholes and their ducts. Rats can live inside them and use the ducts (typically 10 cm diameter) to travel between manholes. Ducts may contain cable or be unoccupied spares. If not plugged at the building end, they can be used as access routes into basements for feeding. If structural flaws exist in a utility manhole, rats may move through excavations to surface levels. It also is feasible that rats can move between sewer and phone/electric systems underground through structural cracks in adjoining systems, particularly where utility systems are densely situated.

Rats can create or enhance structural problems in manholes and sewer lines through their excavations and gnawing. They are capable of damaging underground cable by gnawing on them (although the authors found that to be uncommon in Boston). Sudden encounter of rats by utility personnel working in a manhole creates a work environment issue. Additionally, rat-borne diseases, such as leptospirosis, are believed to be a particular concern in wet rat-infested environments and have been identified with the need for sewer baiting programs (Howard 1989).

BACKGROUND STUDIES

Preliminary to this program, manhole baiting was performed for another construction project in Charlestown, Massachusetts (Colvin et al. 1990). Baiting methods, bait formulations, and distribution of rats in sanitary and storm drains were assessed in a residential area. Sanitary sewers were 2.7 times more active than storm sewers based on bait consumption. Forty-two percent of sanitary sewer manholes and 23% of storm drain manholes had rat activity. Rats were effectively controlled by pulsed baiting with 60 g of bait (50 ppm brodifacoum, TALON Weather Blok) in storm sewers and with 100 g of bait in sanitary sewers.

Other preliminary work included live-trapping rats using Tomahawk traps (13 x 13 x 41 cm) in downtown Boston manholes during the last two weeks of October 1992 to help plan the control program and collect rats for genetic resistance testing. Traps were lowered into 74 manholes (combined sewer system; brick) using an extendable pole and attached by wire to a nail driven into the top of the manhole chimney; traps were baited and wired open for 5 to 6 days prior to live trapping. Average pipe width was 42 cm (range 20 to 76 cm); 95% were less than 51 cm.

Forty-three rats (56% juveniles) were captured; trap success was 14.7% the first night and 12.5% four nights later. Rats were not randomly distributed; 72% were trapped in 6.7% of the holes surveyed (captures were made in 20% of the holes). The presence or absence of droppings was not a good predictor of trap success, and the most active holes had small diameter pipes with low flows in residential areas. Twenty-two of the rats (4 male, 18 female) were tested by BioCenotics, Osseo, Michigan, using the WHO protocol for warfarin resistance; 13.6% (3 females) survived testing. Among 45 rats (21 male, 24 female) collected from surface areas in Boston during fall 1992, 17.8% (2 male, 6 female) were resistant. No sewer baiting programs had been conducted previously in Boston and, thus, presence of resistance in the sewer population indicated rat movement between surface and subsurface environments.

METHODS

Areas to be sewer baited were investigated using drainage maps provided by the Water and Sewer Commission. Maps identified sewer type (storm, sanitary, combined), diameters and materials, ages, and manhole locations, so that field operations could be effectively planned and tracked. Utility maps also were used to identify other manholes to be baited (phone, electric, cable tv). Data sheets were used in the field to record hole numbers, bait placed, bait consumed, water volumes in holes (none, low, moderate, high), and general observations each time a hole was opened. All accessible manholes were baited, except for those with substantial water volumes and flows (typically sewers >91 cm diameter). Baiting locations were mapped and tracked using a geographic information system (vonWahlde and Colvin 1994).

All manhole baiting was done from surface level with a two-person pest control crew assisted by a police officer (required for traffic control). All phone, electric and cable tv holes were opened by personnel from utility companies because of union and safety requirements. For more intensely baited areas, a project biologist accompanied the crew to confirm accurate mapping and record keeping, and as oversight since the work was paid on an hourly basis. Safety precautions included reflective traffic vests, knee pads, latex gloves for the baiter, and work gloves for the person pulling the manhole covers.

Manholes were tagged and each uniquely numbered using a 3 cm diameter aluminum tag (available from Forestry Suppliers, Inc., Jackson, Mississipppi). Plastic coated, galvanized, 24 gauge wire (made by Anchor Wire Corp., Goodlettsville, Tennessee) was used to suspend the bait; the plastic coating was necessary to slow corrosion of the wire and allowed for gnaw marks to be discerned to help confirm rat activity. A masonry nail was driven into the mortar or concrete at the top of each manhole, bait was attached to the end of the baiting wire and lowered to within 2 to 5 cm of the benching in the manhole base, and the wire was cut from the spool and wound around the nail so that a 15 cm piece extended from it; the numbered tag was then attached to that end of the wire. For subsequent baitings, wire loops of bait often were made in advance to facilitate field operations. The bait wire in a hole could be pulled up, the existing bait loop cut and removed to a spoil bucket, and a new loop of bait wired on and lowered back down. Orange spray paint was used to mark the street next to baited holes, to aid locating them.

Baiting was performed seasonally using pulsed-baiting methods (Dubock 1992), in a geographically sequential process beginning in 1992, matching construction staging. The baiting formula typically was day 1-14-28, indicating approximately two weeks between baiting rounds (pulses). Five TALON Weather Bloks (brodifacoum, 50 ppm, 20 g block) were used for each baiting round. In a few cases when all bait was consumed in a manhole on the first round, during the initial baiting of a new area, the bait placement was doubled from 100 to 200 g for the next round. Thereafter, and for all maintenance baiting, five bait blocks (100 g) were used each baiting round.

Activity was based on bait consumed, visually measured to 1/4 block. Gnaw marks on bait or the baiting wire were identified as rat activity. Bait with a peppered coarse appearance was recorded as cockroach (insect) activity. A wire with the bait loop void of bait, yet still in a rectangular shape as if blocks were present, was recorded as insect or water damage, depending upon insect observations and water/steam conditions. An empty bait loop stretched in an elongated manner was identified as water/debris damage, or rat activity if gnaw marks could be found.

Spring (March/April) and fall (August/September) baiting was performed for all sewers. An early summer (June) and late fall (November) baiting also was implemented in 1997 in neighborhoods where potential reinfestation and construction were greatest. Other utilities were baited independent of season. Most holes that never had activity were eliminated after a year; maintenance baiting consisted of once-active holes and a few sentinel baiting points where construction operations required it.

RESULTS

There were 1,288 sewer manholes poison baited among eight contiguous geographic sections of the project alignment (Table 1). Only one area had a separated sewer system (Area 3); others had predominately combined systems. In addition to the sewers, 235 other utility manholes (120 phone, 90 electric, 25 cable tv) were baited among Areas 4, 6 and 7. In total, 15.1% of sewer, 17.5% of phone, 25.6% of electric, and 8% of cable tv manholes had bait consumption.

Sewer activity was highly variable among the eight areas, ranging from no activity to 38% activity among manholes baited. Areas with little or no activity included predominately commercial locations (Areas 2, 5, 6, 8) and sewers built mainly with clay or concrete (Areas 2, 5, 8). Locations with high activity (Areas 1, 3, 4) predominately were residential with old brick sewers.

Bait consumption ceased each season within three rounds during initial baitings and typically within two rounds during maintenance baiting. Rat activity in sewers was 91.3% below baseline (8.7% recovery from baseline) about five months after the fourth baiting season (Figure 1), and the number of active holes had declined from 98 to 16. (That level of sustained reduction likely would have occurred much sooner if the entire system had been treated at once, rather than sequentially to match construction staging.) When the program was fully in maintenance throughout the sewer system (fall 1997), seasonal bait consumption was 96.2% below baseline, and only 13% of the holes originally active showed sign of reinfestation (Areas 4 to 7). In the oldest brick system (Area 4), the percent of manholes active declined from 33% (baseline) to 4% (maintenance).

Rat activity was more widely distributed in electric than phone manholes, but phone manholes had greater concentrations of activity (initial bait consumption 17.7 g and 34.1 g per manhole, electric and phone, respectively). Activity rapidly declined after one baiting period (Figure 2). Reinfestation was almost negligible in both systems, using annual intervals between baitings. By the third and fourth baiting periods, consumption was 97.1% and 93.8% below baseline for phone and electric, respectively.

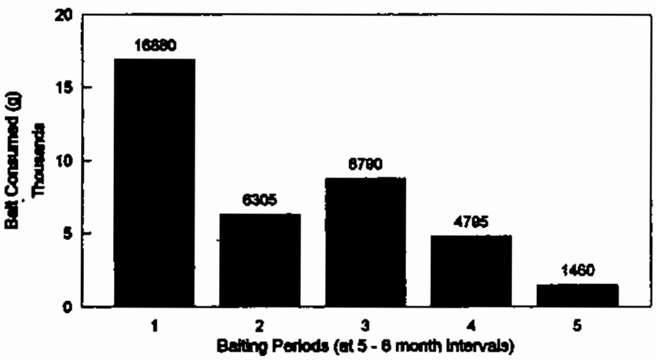

Figure 1. Changes in sewer rat activity from baseline, based on bait consumption. Baiting period 1 represents the first time that each manhole was baited, independent of season and year. Each baiting period consisted of baiting rounds at 14-day intervals until activity ceased.

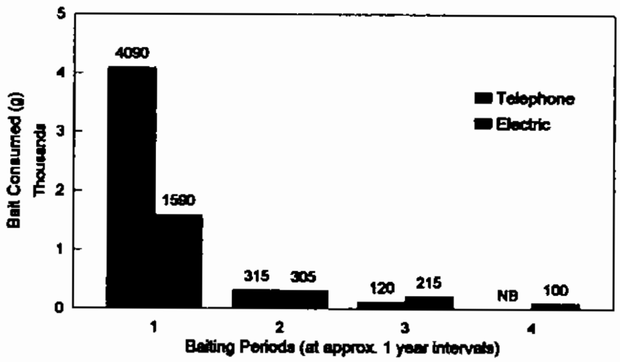

Figure 2. Changes in rat activity in phone and electric manholes, based on bait consumption. Baiting period 1 represents the first time each hole was baited, independent of season and year. Each baiting period consisted of baiting rounds at 14-day intervals until activity ceased.

Table 1. Results of sewer manhole baiting for Norway rat control in Boston, 1992 to 1997.

Area	No. Manholes		System	Dominant	
	Active	Inactive	Approx. Age	Material	Environment
1-E. Boston	38 (32%)	79	1852-1916	Brick	Residential
2-S. Boston	6 (6%)	94	1916-1937	Clay	Commercial/Industrial
3-Charlestown*	27 (38%)	45	1850-1903	Brick	Residential
4-North End	74 (33%)	148	1824-1915	Brick	Residential/Commercial
5-Leverett Crl./Govt. Ctr.	2 (1%)	146	1914-1980	Clay	Commercial/Residential
6-Financial Dstr.	22 (8%)	264	1850-1906	Brick	Commercial
7-Chinatown	25 (15%)	142	1852-1916	Brick	Commercial/Residential
8-South End	0	176	1861-1957	Clay, Brick	Commercial/Residential
TOTALS	194	1,094			

*Predominately separated sewers; other areas predominately had combined sewer systems.

The amount of bait consumed and the number of active sewer manholes steadily declined during maintenance baiting and varied seasonally. The fall period showed the greatest amount of bait consumed per manhole and percent of manholes active (Figure 3). For example in fall 1994 (Areas 4 to 7), there were 68.6 g of bait consumed per manhole, and 46% of the manholes being treated were active; whereas in fall 1997 there were only 1.8 g of bait consumed per hole (97.4% less than fall 1994) and 5% of the holes active. The 1997 fall reduction was in part achieved by instituting summer baiting of selective holes as part of the maintenance program.

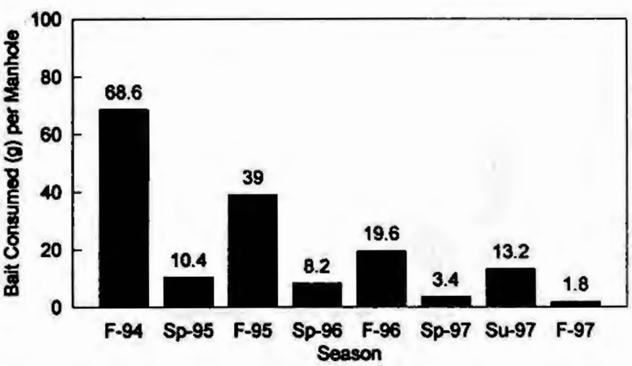

Figure 3. Changes in sewer rat activity by season, based on bait consumption.

The time interval from fall to spring consistently had less population recovery in sewers than the spring to fall interval (Figure 3). These seasonal differences suggest that rat breeding was not uniform year round, as might be expected given that sewers provide warmth and continual food availability, and relatively consistent light conditions.

Rat activity among sewers was highly non-random, considering either flow rates (Chi-square=62, 3 d.f., $P<0.001$) or pipe sizes (Chi-square=18.5, 5 d.f., $P<0.01$). Within a sample of 1,095 baited holes, flow rates were distributed as: 24% no flow, 59% low flow, 14% moderate flow, and 3% high flow. Of the holes with rat activity, 90% had low flow and 10% had moderate flow.

Pipe widths of baited manholes (Areas 4 to 7) ranged from 20 to 259 cm (mean=54.2 cm; n=723). Those with rat activity ranged from 20 to 244 cm (mean=43.9 cm; n=118), and those without activity ranged from 20 to 259 cm (mean=57.9; n=605). The percentage of manholes active was greatest among those with 51 cm pipes (31%); 90% of the active manholes had 20 to 61 cm pipes.

Observations of live or dead rats were rare. Observations of droppings were uncommon, even in manholes where bait was consumed. American cockroaches (*Periplaneta americana*) were widely, but not evenly, distributed among both sewer and utility manholes. Roaches demonstrated an ability to consume an entire bait placement, thus requiring close examination of baiting results to distinguish roach from rat activity. Fluctuating water levels and steam also eliminated bait, requiring close examination of baiting wire to prevent misidentification as bait consumption.

Baiting costs per hour were approximately $77 for a two-person baiting crew, $29 for a police detail, and $45 for a project biologist. The number of sewer holes baited per hour was approximately ten for initial placements and 15 for maintenance baiting. Costs for baiting phone manholes included two crafts personnel and a supervisor from the utility to open the holes; those costs were about $370 per hour with administrative overhead, and about ten manholes could be baited per hour. Lower utility costs per hour eventually were achieved when utilities provided one crafts-person to open holes.

DISCUSSION

The goal and methods for sewer control programs are somewhat different from that of surface programs. The intent with sewer baiting is to dramatically and cost-effectively suppress a rat population through poison baiting. Unlike surface areas where IPM principles can be fully implemented with a strong emphasis on sanitation, the nature of a sewer is that sanitation and water resources will remain available and unchanged throughout the control program. Thus, the expectation should be to effectively manage the population and not necessarily to totally eradicate it.

Random, haphazard, or reactive sewer baiting does little to actually manage a rat population or to solve localized problems. Subsurface baiting requires a systematic approach with close review and adjustments of the baiting strategy based on the quantities and geographic patterns of bait consumption. This takes time to plan, but allows for field implementation to be strategic and thus more cost effective.

The number of seasonal baiting periods performed annually should be based on the level of control necessary and the extent of the existing infestation. Where systems are infested, it is recommended that the initial program consist of three baiting periods the first year (e.g., March, June, September) to effectively dampen the population and slow the recovery rate. (Each baiting period would consist of baiting rounds at 14-day intervals until activity ceases.) Inactive holes should be culled from the program at the end of the second baiting period (season), except for a few sentinel holes maintained in locations of potential future risk (e.g., near restaurants, residences). Thereafter, the baiting regimen should be customized annually, centers of activity targeted, and holes prioritized based on baiting histories (Forbes 1990). The seasonal timing chosen was intended to eliminate adults prior to onset of peak periods of parturition or weaning, further slowing recovery rates.

A maintenance program could include the following: March/April and August/September—pulse bait all holes that once were active, and possibly a strategic/limited number of sentinel holes, until activity ceases. For high risk areas where heightened control is desired, also pulse bait in June and November, but only those holes active the previous season. Over time, holes never active can be culled or periodically treated on a sentinel basis. In this work area, the number of sewer manholes baited was reduced from 1,288 to less than 225 necessary to maintain monitoring and control (>90% reduction in rat activity over baseline at all times). The maintenance budget, for a two-person baiting crew, concurrently was reduced to <$10,000 per year for a five square mile area.

Recovery of sewer populations is likely within six months (or less) if they are not effectively baited (Bentley et al. 1959; Brooks 1964). Baiting programs that use single bait placements (e.g., annual or twice annual), without follow up, simply crop a portion of the population and enhance the rate of population growth. Key to an effective sewer program is to reduce the population to minimal levels (e.g., >90%), so that it remains at the low end of the sigmoidal growth curve until the next baiting period; otherwise recovery will be rapid and little achieved. The benefit of pulsed baiting is that it can dramatically lower a subsurface population, best ensuring a slow rate of population recovery.

Pulsed baiting is especially important in sewers because of their dynamic nature (loss of bait from changing water levels, steam, roaches). Repeated baitings and checks over a short period of time (e.g., six weeks) help ensure delivery of bait to the population and determination of necessary baiting points. Otherwise, baiting continues to be random and costly, and animals may be "over killed" by use of excessive amounts of bait. Importantly, the pulsed strategy allows time between baiting rounds for rats living between manholes to redistribute, expand their tubular territories, and thus encounter bait placements.

The effectiveness of a control program and the needed intensity of baiting can be determined by calculating the rate of recovery each baiting period. If control has been broadly achieved in the system, the rate of reinfestation will be low. Data from this study indicate that broad control was achieved over the entire sewer system by strategically pulse baiting.

Sewers greatly differed from other utilities in their ability to sustain rat populations. The lack of population recovery and reinfestation of phone/electric manholes indicated that those systems held relatively closed populations with limited food resources. Control programs for such utilities do not appear to require much on-going maintenance once control is achieved.

Environmental factors such as excessive availability of food and harborage have been associated with development of genetic resistance to some anticoagulant rodenticides (Jackson and Ashton 1992; Greaves 1994). Thus, sewer environments should be considered ideal for nurturing resistant strains of rats and potentially could enhance spread of genetic resistance in an urban area if baited inappropriately. For these reasons, as well as efficacy and labor costs, the authors do not recommend the use of first-generation anticoagulants or saturation baiting in sewers. The second-generation material selected should not have documented resistance problems.

The kind of bait that is recommended for sewers would be a single-feeding, highly palatable, paraffin block formulation. The block would have homogeneously distributed ground grain, rather than whole seed or cracked grain. The latter type of formulation appears to absorb moisture and deteriorate more quickly. The recommended size for a bait block (second generation anticoagulant, e.g., brodifacoum) would be about 100 to 125 g, with one block used each baiting round in a pulsed-baiting strategy. Larger blocks of second-generation anticoagulant bait (e.g., 450 g) appear unnecessary and wasteful.

Subsurface populations can serve as a reservoir to potentially infest surface areas or adjacent buildings, and surface populations may retract into sewers, especially with the onset of winter in middle-latitude climates. These factors are important when evaluating localized rat infestations on surface levels and timing control efforts. It was found that the presence of a rat population on the surface level does not necessarily mean that rat activity exists in the sewer system below. However, where surface problems are present or chronic, sewers should be test baited.

Several factors appear to contribute to rat infestations in sewers. Sections of combined or sanitary systems with low flow and small diameters (< 61 cm) built with brick were most susceptible in the work area (Figure 4). Land use most commonly was residential or mixed residential/commercial (restaurants) where activity was found, and the brick sewers were 85 to 175 years old. Better feeding opportunities for rats exist with low flows because solids tend to drop out of the water column. Small diameter lines also are more stable for rat survival because of less flooding. Brick sewers potentially provide more gaps for living space than concrete or clay lines.

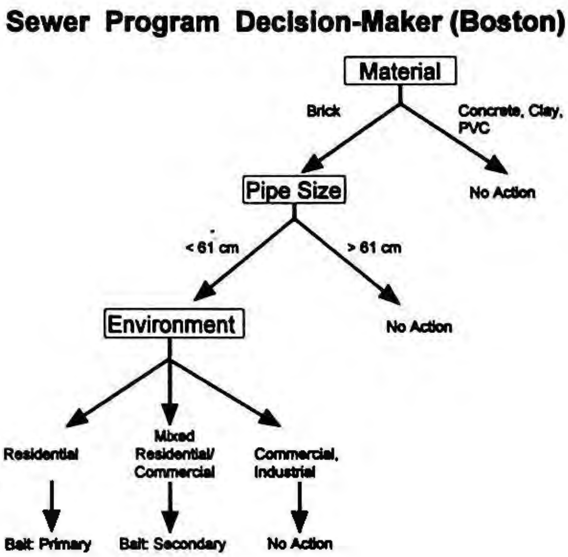

Figure 4. Decision-making flow chart for planning and prioritizing a sewer baiting program.

Topography may also influence rat distribution patterns. Within the sewer collection system for Areas 4, 6, 7 and 8, Area 4 was the highest point and Area 8 was the lowest. Potential flooding of the system during rainfall events, as a result of topographic differences, possibly could have contributed to the lack of rat activity in Area 8. Additionally, utility (phone/electric) workers that were interviewed described shifts in rat activity from manholes near the waterfront to those at higher elevations, during flooding or high tide events.

Engineers should consider the Norway rat to be an indicator species, helping to determine sewer locations in need of structural evaluation and priority for repair. Baiting results and maps should be discussed with the local Water and Sewer Authority, and major centers of rat activity can be inspected by the Authority using remote cameras. This process may identify locations that need to be flushed or cleaned to remove a build-up of sediment/soil used by rats for burrowing or, more commonly, locations in need of repair. Smoke tests also can be used in sewers to evaluate breaks leading into basements or to surface level.

Good inspection, maintenance, and installation of a sewer system are important for limiting rat populations from inhabiting them. Several methods are used today for sewer rehabilitation including pipe replacement with cut and cover trenching methods, filling the existing system with grout and micro-tunneling, installing a pipe liner using pipe bursting technology, or using a cured-in-place plastic-resin lining.

Many myths exist about rats in sewers, from unconquerable numbers to blind populations, contributing to inappropriate control methods and mis-education of the public. Myths also have included assumptions that any construction or vibration near a sewer line will cause rats to flee the system. Barnett and Bathard (1953) observed that rats will continue to inhabit sewers while they are under construction, and the authors believe, based on observations, that direct excavation is necessary to cause displacement. In fact, rats will readily inhabit cut-and-cover trench excavations during utility construction.

Subsurface control programs should be an integral component of any Integrated Pest Management (IPM) program in urban environments. However, many municipalities and pest control operators in the U.S. are unfamiliar with, or poorly understand, sewer baiting principles and needs. Sewers can be viewed by pest control personnel as undesirable work environments, logistically difficult to access, an unknown best left alone, or potentially expensive to treat. These factors illustrate the need for a cultural change in many urban pest control programs that only will occur through training and experience.

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