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Authors
von Wahlde, Matt
Colvin, Bruce A.

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USING GEOGRAPHIC INFORMATION SYSTEMS FOR TRACKING AN URBAN RODENT CONTROL PROGRAM

MATT von WAHLDE, and BRUCE A. COLVIN, Bechtel/Parsons Brinckerhoff, Central Artery/Tunnel Project, One South Station, Boston, Massachusetts 02110.

ABSTRACT: Geographic information system technology is being used to help coordinate an urban rodent control program initiated as part of the Central Artery/Tunnel Project in Boston. Databases with neighborhood survey data, surface and subsurface baiting data, sanitation code violations, and public complaints are linked to base mapping, land parcel, and utility graphics. This integrated approach helps Project biologists plan control strategies and evaluate the relatedness of rodent activity to environmental conditions. Spatial querying techniques and the ability to graphically display and map variables, such as bait stations and sanitation deficiencies, help ensure that control resources are effectively targeted and tracked. This technology application and the design principles involved provide a model for managing urban rodent control programs.

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INTRODUCTION

Successful vertebrate pest control programs require a sound design, which should be a synthesis of both technical and administrative considerations. Once defined, efficient implementation of a program becomes dependent upon effective tracking, review, and analysis of control procedures. For an urban rodent control program, one of the greatest challenges is efficiently coordinating and integrating the various survey, sanitation, educational, and baiting elements over diverse areas and neighborhoods. Furthermore, managing the large quantities of information associated with such an effort becomes increasingly difficult as program elements progress.

The use of geographical information systems (GIS) has been integrated with various ecological studies as part of data analysis and tracking, and it can provide extensive mapping, display, and analytical capabilities for geographic evaluation (August 1993, Johnson 1993). However, GIS has not yet been established as a tool in vertebrate pest management and has never been used previously as part of an urban rodent control program.

The purpose of this paper is to describe the use of GIS technology as part of a large-scale and comprehensive rodent control program designed and implemented for the Central Artery/Tunnel Project (CA/T) in Boston, Massachusetts. The unprecedented scope of this program and diversity of the geographical space encompassed requires use of innovative rodent control techniques in context of an urban infrastructure, location and time-specific requirements, public concerns, and administrative and contractual procedures.

GIS technology functions as a management and decision-making tool by providing the ability to track the important geographical component of information gathered; thus allowing, for example, accurate targeting of baiting and survey efforts. It also provides a means to evaluate relationships among infrastructure (e.g., sewer and other subsurface utilities), sanitary conditions, and program data on rodent activity and poison baiting. GIS further enhances program efficiency and decision- making by providing spatial query techniques, trend analysis, and predictive capabilities.

BACKGROUND

The Central Artery/Tunnel Project is a $7.7 billion construction project that is committed to minimizing construction-related impacts to adjoining neighborhoods during its ten-year term. It entails depression of the existing interstate highway that bisects downtown Boston (I-93) and construction of a new harbor tunnel to Logan Airport (I-90). Thus, the current elevated I-93 roadway will be replaced by an eight to ten lane highway underground, and I-90 will be extended via a four-lane tunnel to the airport. More than 50 major construction contracts will be awarded for this Project, that extends over 12 kilometers of mainline highway. Construction does not proceed simultaneously or linearly from one end of the Project alignment to the other, but instead proceeds in sections based on environmental constraints, construction methodology, and engineering requirements.

The CA/T rodent control program involves integrated pest management (IPM) applied under construction management principles (Colvin et al. 1990, 1992). The program was established to help prevent displacement of Norway rats (*Rattus norvegicus*) and house mice (*Mus musculus*) from construction areas into adjacent neighborhoods, and also to help keep rodents from infesting construction sites. These objectives are being accomplished by locating rodent activity and causative factors, such as sanitation and rodent-proofing deficiencies, and then applying appropriate control resources to affect resolution. Rodent control may begin more than a year before construction at any particular location, and construction contractors are not allowed to mobilize until rodents have been eliminated from work sites. Control activities extend outward about two to four blocks from every construction area. Timing of pest control operations remains flexible to match ever-changing construction schedules and events. Control and monitoring practices include pre-, during, and post-construction surveys; extensive public education involving door-to-door distribution of literature, community meetings, and neighborhood displays; enforcement of sanitary codes; poison baiting on both surface and subsurface levels; rodent-proofing; and a garbage container distribution program. Data are collected on all program elements and, to date, that includes over 18,000 addresses and over 20,000 baiting records. Over the life of the Project, up to a half-million individual baiting, sanitation, and rodent activity records are anticipated.

GEOGRAPHY OF THE PROJECT AREA

The existing Central Artery (I-93) is the major north-south interstate running through downtown Boston, while the I-90 portion of the Project extends east-west. Both roadways cross diverse residential and commercial districts, and the harbor tunnel breaches waterfronts in East and South Boston. Urban features range from high-rise office towers and densely populated residential buildings and stores, to open commercial land and waterfront industries. Underground, there are subway tunnels and a maze of utility systems that include sewerage, electric, gas, telephone, steam, and street and traffic lighting. The downtown Boston environment can be characterized as having historic, crowded, and complex infrastructure both above and below ground.

The potential for supporting rodent populations varies widely among each of the districts or neighborhoods affected by CA/T construction, because each area has its own biotic and abiotic features. Environmental conditions not only vary among areas, but they also vary over time as sanitary enforcement and seasonal conditions change. Open markets, aging infrastructure, underground utility systems, refuse storage, vacant lots, and densely planted landscapes contribute to rodent problems. Furthermore, because Boston is an old seafaring city, the extensive waterfront also provides food and harborage resources for rodents.

The CA/T rodent control program encompasses six major geographical areas. The need and ability to track geographic features within each area ranges from landscapings to garbage storage locations to sewer systems. For example, in many areas, soil available for burrowing appears to be an important limiting factor for rats because little exposed soil is available in the concrete and asphalt environment downtown. The ability to track exposed soil areas, especially in relationship to nearby sanitation deficiencies, provides an important capability for targeting survey efforts and anticipating rodent problems. In the case of sewers, most in the Project area are combined systems (i.e., they have both sanitary and storm water). Rats are not randomly or equally distributed in the sewers; most commonly they are found in sanitary or combined systems. Additionally, rat activity is greatest in those sewers located in residential areas, in sewer lines with low to moderate flow rates (e.g., 46 to 61 cm diameter pipes), and in older sewers with cracks or breaks that allow burrowing. Thus, tracking and evaluating surface infrastructure, pipe dimensions, and conditions in the sewer system can facilitate planning and targeting of subsurface baiting operations.

PROGRAM RESOURCES

To successfully implement an urban rodent control program on the scale of the CA/T Project, adequate human and technical resources must be assembled and integrated. The Project employs five biologists to manage this effort and six pest control companies are contracted by the Project to perform baiting and neighborhood surveys among the geographical areas encompassed. Additionally, four City of Boston health inspectors and a code enforcement officer also are assigned to the Project. These City employees play a critical role by performing comprehensive pre-construction (baseline) surveys and by enforcing State and City sanitation codes. Rodent activity and sanitation deficiencies observed on private property are referred to those officials for investigation and possible court action. Project biologists perform quality control surveys in the field and also review all data entered into the program's databases. The distribution, phasing, and scheduling of pest control resources are re-evaluated weekly based upon construction schedules and environmental need.

The rodent control GIS/database is a cooperative effort involving many CA/T employees. Computer programmers, computer aided drafting and design (CADD) experts, GIS specialists, network analysts, utility engineers, and many others contribute technical expertise to the program. This helps ensure integration with Projectwide operations and databases.

In addition to human resources, various management tools and field equipment are used. This includes a communication system consisting of two-way radios and base station, pagers, voicemail, faxes, and electronic mail to coordinate daily activities and to quickly respond to public complaints or incidents. Additionally, a multi-platform computer network is used for the GIS and other data management efforts. Vehicles, bicycles, and an array of field equipment provide mobilization, response, and field evaluation capability throughout the geographic area served.

APPROACH TO GIS ON THE CA/T PROJECT

A universal definition of what constitutes a GIS is somewhat illusive. The basic definition applied here is a system that allows storage, manipulation, and analysis of spatially referenced data. Geographical information systems typically are composed of two types of data, attribute and graphic. Attribute data are stored digital information (e.g., number of rat burrows surveyed on a parcel, diameter of sewer lines, etc.) pertaining to specific graphics entities. Attribute data usually are stored and manipulated by data management software (e.g., dBase, ORACLE). Alternatively, graphics data are stored digital representations of real-world features (e.g., buildings, sewers, parcel outlines) that can be displayed and manipulated by computer graphic software such as CADD or dedicated GIS software. Linkage of attribute data with graphics data establishes the core of a GIS (Figure 1). Many dedicated GIS packages (e.g., ArcInfo) provide an already integrated data/graphics environment; other systems, such as the CA/T GIS, are custom-designed and linked database/CADD systems.

Hardware and Software

The CA/T rodent control GIS uses a modular multi-vendor approach to system design and implementation. In this approach, several software and hardware tools are integrated. The two primary software components are Graphic Design Systems (GDS, version 5.3) dynamically linked to the relational database management system ORACLE (version 7). GDS was selected because it is the CADD software tool on which all CA/T engineering and base mapping graphics are stored and managed. These Project drawings are constantly updated to reflect changes in design and construction.

CA/T RODENT CONTROL PROGRAM

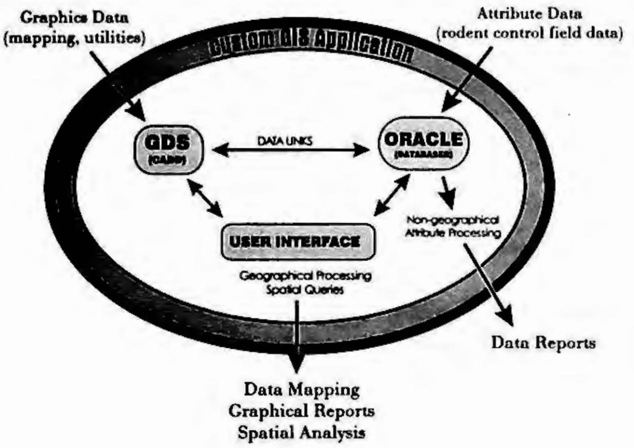

Figure 1. Functional diagram of the geographic information system designed for the CA/T rodent control program.

GDS communicates with ORACLE through a bi-directional link provided by GDS called SQL*CAD. This link allows dynamic interaction of graphic and attribute (rodent control) data. At the CA/T Project, GDS functions under the VMS operating system running on a local area VAX cluster. Most graphics input, manipulation, and analysis is performed using GDS on VAX 4000 workstations. ORACLE is installed on a Digital ALPHA server. Attribute data is entered into ORACLE on both VAX and DOS/WINDOWS based workstations. Much of the conventional non-geographical processing of data (such as bait consumption calculations) is performed by ORACLE. Some pre- and post-processing is done in custom programs written in the C and BASIC languages. All workstations are networked in a client-server configuration to minimize network data traffic for improved performance. Because the rodent control office is geographically remote from the main computer facilities, a T1 data line has been installed to provide remote access to all Project data. Many other remote sites contribute graphics data, such as survey and design engineering drawings, which the rodent control program uses.

A pen-based, weatherproof mobile computer (Tusk SuperTablet) with Fieldnotes GIS software is used for direct field entry of spatially referenced data. This unit is capable of handwriting recognition and storage of all Project base mapping for field reference. This limits the need to carry unwieldy maps into the field and allows graphics data to be annotated while in the field. This unit also offers basic spatial query capability. Data can be read directly into ORACLE through a cable connection.

Output is obtained through a variety of devices including a high resolution 28x43 cm (11x17 inch) postscript laser printer for immediate field reference use. Color plots are obtained using a 91 cm (36 inch) format electrostatic plotter. Plot files can be exported to various graphics enhancement software packages for the production of presentation graphics.

DATA SOURCES

Attribute Data

The CA/T rodent control program collects attribute data of two principal types: poison baiting and survey data. Several other miscellaneous databases also are maintained, such as public complaints, sanitary code violations on private property, and referrals made to City agencies for code enforcement. All data are recorded in the field on standardized forms designed by the Project.

Baiting data is divided into categories of subsurface (sewer, catch basin, and other utilities) and surface baiting (burrow, bait station). Records are maintained on location, type, and amounts of bait applied by the pest control contractors. The contractor also records information such as insect and water damage to bait, and any signs of rodent activity at the bait site such as droppings. The use of multiple bait types at a single baiting point can also be tracked if needed.

Several different kinds of field surveys are conducted to evaluate sanitation conditions and rodent activity throughout the Project duration. The most comprehensive is the baseline neighborhood survey performed by the City's Inspectional Services personnel. This survey, modelled after that described by Davis et al. (1977), was conducted on all properties within two to four blocks of the construction alignment to document conditions in the early phase of program activities. This survey provides broad documentation of neighborhood conditions and will be systematically repeated upon each completed round (e.g., every two years). A second type of survey is conducted weekly by the pest control contractors within each of their assigned areas. This survey provides up-to-date information on specific areas with pending or active construction nearby. These weekly surveys primarily document active rodent signs and chronic or serious sanitation violations. Much of the baiting and enforcement efforts are based on the results of these weekly surveys. Other types of survey data include quality control surveys performed by Project biologists and site inspection records on specific properties. Additionally, systematic surveys of catch basins are conducted periodically to determine the need for cleaning, since dirty catch basins can provide excellent burrowing substrate for rats.

Other attribute data maintained for Projectwide operations include those on utilities and land parcels. The utility databases contain such information as diameter of lines, year built, materials, owner, and depth. The parcel database was compiled from information provided by the City of Boston Tax Assessors Department and from the field surveys. This database contains a list of all addresses in Boston including ownership, commercial/

residential status, and other descriptive information. Multiple units or suites in downtown office towers also are included.

Graphics Data

An expensive and difficult task in most GIS efforts is the collection and input of the graphics data. The use of GIS with the CA/T rodent control program is largely feasible because of the quantity and high quality of survey and graphics data already inputted into GIS for direct support of CA/T engineering and construction. Project graphics data were collected from several sources including field survey, aerial photography, electronic files provided by the City and utility companies, and by digitized printed drawings.

Three main groupings of graphics data used extensively by the rodent control GIS are base mapping, utility inventory, and City of Boston parcel mapping. The CA/T base mapping graphics are categorized into eight feature families: 1) Control (grid lines, state plane coordinate ticks, etc.); 2) Hydrologic (waterways, harbor boundaries); 3) Lot features (building outlines, walkways, fences, etc.); 4) Railroad; 5) Road (edge of pavement, street names); 6) Topographic; 7) Surface utility structures (e.g., manhole lids, utility poles); and 8) vegetation (planters, trees, shrubs, etc.). In addition to base mapping, the Project maintains several families of detailed utility graphics including gravity, pressure, electrical, and signal systems. Graphics from each of these utility inventories is linked to its own attribute database. The third main graphics group is that defining the City of Boston tax assessor parcels. These parcels are defined as closed polygons in GIS and also are linked to their corresponding attribute database. Individual utility structures or parcels can be selected or queried for any attribute that is linked to it by positioning a computer pointing device (i.e., mouse) on it. Utility structures, parcels, or building outlines are represented as closed polygons and can be highlighted or filled with patterns or colors to represent the results of such queries. Because all utility structures and parcels have unique number identifications, they can be linked to rodent control baiting and survey data for specialized query and analysis.

In addition to base mapping, utility, and parcel graphics, the Project's GIS system contains all the engineering drawings for the proposed construction of the new Central Artery and Harbor Tunnel. This includes new utility lines as well as tunnels, buildings, and landscaping. Also, special categories of graphics data for the rodent control program were created, such as bait stations for individual tracking. The mapping and utility inventory information stored in the CA/T system is considered to be the highest quality information of its kind available for Boston.

GIS/ORACLE DESIGN

For the rodent control GIS to be effective, it had to enhance management and analytical capabilities compared to conventional data management approaches and also fit well into the Project's existing organizational and procedural framework. To accomplish these objectives, design planning was approached from four perspectives: 1) human interface and data entry; 2) data management; 3) graphics interaction, analysis, and reporting needs; and 4) program management. Actual design of the system was approached in four major phases: 1) prototype/proof of concept; 2) needs analysis; 3) database design; and 4) GDS integration and graphical user interface and design. Assumptions made during each design phase determined the system capabilities and limitations.

To demonstrate functionality and prove the concept of an application based on a linked GDS-ORACLE model, a prototype was designed and built. This prototype confirmed that data could be entered from any remote terminal and automatically produce updated thematic maps. A graphical user interface and basic spatial query also were implemented and tested. This model served as the basis for subsequent design work.

Because the system was intended to be used by a variety of participants with varying computer experience, the human component was a primary consideration in the needs analysis. For software/human interface, this included ease of use and data accessibility. Substantial effort also was devoted to data integrity and the design and implementation of database forms. Because most data errors occur at the data entry stage, and because data entry is a tedious and time consuming process, data forms that prevent errors and that are efficient were recognized as important.

Also considered in the needs analysis during system design were the management requirements of Project biologists. These considerations included the ability to:

1. Accurately track and map bait placements and consumption for accountability, planning, and directing personnel to specific locations requiring baiting.
2. Easily produce accurate maps showing locations of key survey conditions including sanitation, rat burrows, complaints, and resolved and unresolved cases referred to City agencies.
3. Automatically generate data forms and maps for pest control contractors and City personnel to use in the field while performing baiting, survey, and code enforcement work.
4. Manage geographic information on locations that do not have street addresses such as parks, vacant lots, and railway right-of-ways.
5. Generate maps for presentations, reports, and field personnel in a flexible manner that allows many factors to be viewed simultaneously.
6. Facilitate quality control/assurance review of pest control contractor work performance. This could include queries as to when an area was last surveyed, when a site was last baited, or how long it took a contractor to gain control in a specific area.

The needs analysis for the GIS also included graphics interaction, analytical, and reporting requirements such as the ability to:

1. Flexibly interact with data and graphics, including definition and placement of graphics representing dumpsters, bait stations, and chronic infestation sites so they can be interactively queried for status.

2. Provide conditional query and basic spatial query capabilities including selection by radius, rectangle, line buffer, polygon, line intersection, and entity.
3. Calculate bait consumption at surface and subsurface bait sites and display summary information as graphics for a specified location and date range.
4. Help evaluate spatial relationships between rodent activity and abiotic factors such as construction activity, sanitation conditions, utility system characteristics, residential/commercial ratios, and topographic features.
5. Help evaluate changes in environmental conditions over time, including the effectiveness of program elements such as sanitation, baiting, code enforcement, and public education within and among different geographical areas of the city.

FINAL DESIGN AND IMPLEMENTATION

Final design of the GIS was based on both the needs analysis and practical considerations. Limitations imposed by the hardware and software tools discovered in the implementation phase required several design modifications, but the overall GDS/ORACLE combination proved powerful and flexible.

Definition of entities, database tables, and relationships between entities and tables required the most substantial design effort. Because certain GIS analytical capabilities were dependent upon the database structures, database design was approached first. The overall approach was to establish or utilize global Project databases; these are centrally created and maintained datasets from which all Project databases retrieve information. In this way, reliable relationships between attribute data and graphics could be maintained more easily.

The most important aspect of global database development was the design and creation of the master address database. The ability to retrieve addresses from a predefined and centrally-maintained list eliminates redundant addressing and provides consistent links to graphical entities such as buildings or parcel outlines. Addresses were defined by unique combinations of City ward, street name, street number, and street type (street, circle, boulevard, etc.). Street addresses, however, are not always adequate geographical identifiers for field work. Many sites with rodent activity are in parks, vacant lots, construction boundaries, and other vaguely defined areas not easily handled by conventional address descriptions. The ability of a GIS to manage such unaddressed entities by use of base mapping and coordinate systems makes it an extremely useful extension of database technology for pest management field activities.

The dissection of processes and procedures used by the rodent control program resulted in several entity-relationships, and table relationship diagrams, that served as the "road-maps" for the GDS/ORACLE integration process. The dissection process involved analyzing how baiting and surveys are conducted in the field and then breaking that information into discrete data entities. This process was important because it defined the essential information required to manage the program and to create predictive analyses. By establishing the relationships between entities, the way in which information would eventually be queried, combined, and analyzed was defined. The implementation phase began when consensus was reached on the entities to be managed and their relationship to each other.

Computer data-entry forms were programmed with extensive look-up and error-trapping capabilities. These forms also were designed to maximize ease of data entry and to minimize redundant data entry. A validation check on addresses, baiting data, and other information was built into the system at the point of data entry to help maintain integrity of important data sets required for graphics linking. Additionally, a processing capability was established for baiting data, so that bait consumption values could be calculated over irregular time intervals.

Once the database structures were defined and implemented, data from existing dBase tables were mapped into the new ORACLE structures. For locations with established addresses in the master address database, the link to rodent control data was automatically established. For locations with no readily discernible addresses, linking was performed interactively by using a computer pointing device to click on parcel graphics and then link them to text records. Every address in the master address database was linked to one parcel. Because large parcels can contain several addresses (i.e., buildings, apartments), linkages also were established between building outlines and single addresses. Subsurface baiting sites were linked directly to manhole graphics, which in turn were linked to utility attribute datasets. Surface baiting locations were linked to graphics defining individual bait stations.

DATA QUERY, ANALYSIS, AND REPORTING

One of the major benefits of developing a GIS is the ability to retrieve information in a flexible, task specific, manner. Data can be retrieved using standard logical database queries or with interactive graphical (spatial) queries. Logical and graphical queries can also be combined, as needed, to provide the required output. Query results can be represented in a variety or combination of formats, including standard text-based reports, graphical representations, and data files for statistical analysis.

Because of the relational database structure provided by ORACLE, complex logical queries can be built that join the various tables and filter the data based on either pre-defined or ad hoc selection criteria. Pre-defined queries are included in the customized menu and are grouped according to data type, such as baiting and survey data. Pre-defined queries include those for active bait sites (i.e., with recent consumption), locations with current sanitation violations, and properties with both chronic rodent activity and sanitation violations. The selection of data can be further refined through use of an ad hoc query utility.

Ad hoc queries allow the user to impose relational operations (<, >, =) or conditional restriction (if, then) on data elements. In the simplest examples, the user needing information on baiting or consumption at a specific area and time would input the date range and pest control area of interest to produce the required information. Bait consumption or bait type criteria could also be imposed to select only those sites where large amounts of a specific type of bait are being consumed.

Because data records are linked through street addresses in the master address database, cross-category queries can be constructed to provide information related to a specific address. For example, an address can be queried to produce all baiting, survey, or other data collected on that property. Many other cross-category queries can be defined, such as baiting results for properties that have over a certain number of burrows.

The power of GIS application lies in its ability to provide enhanced spatial query and analysis capabilities over conventional database approaches. Conventional databases do not provide a convenient or natural method for visualizing or analyzing geographically related data. Even the most basic of mapping capabilities required for any GIS are powerful tools for managing an urban rodent control program. By simply entering text-based records into a database, the GIS can automatically generate maps showing all currently baited manholes, unresolved complaints, or any other information needed to manage the program (Figure 2). Such maps can help personnel visualize the geographical relatedness of various entities. For example, the distribution of bait stations that a pest control contractor places throughout an area can be evaluated for coverage or effectiveness when compared against survey results or other criteria such as complaints. Unnecessary clumping of bait stations can be quickly detected and corrected to manage resources more efficiently. Similarly, maps of public complaints can be used when evaluating the relatedness of complaints to construction disturbances, inadequate baiting, or neighboring sanitation deficiencies.

In addition to automated mapping, a GIS allows more intuitive and sophisticated queries of data than possible with logical queries alone. Data related to a specific address can be queried directly from graphics by first selecting the parcel outline with a computer pointing device, specifying the data type (baiting, survey, etc.), and then selecting the output type. The output type can be a text based report sent to a printer or screen, annotation applied directly to any graphic, or a variety of graphical techniques such as polygon cross-hatching or color coding.

Although data can be retrieved through direct selection of graphical entities such as clicking on parcel outlines, other GIS techniques can be applied to geographically select data. Polygon selection can be used to select records in an irregularly defined area meeting any specified attribute criteria. In this mode, the user draws a series of connected lines to "corral" an area. This can be important for selecting features in areas with temporary boundaries, such as construction sites. A related technique involves buffer selection where the user defines a polygon and then specifies a buffer distance around that polygon. Any data entities within that buffer region will be selected. Line buffers also are useful for selecting data points recorded at a specific distance from a line defined by a linear structure such as a sewer. In this way, all surface rodent signs can be selected and highlighted within a specific distance of a sewer line with rodent activity. Point buffers can be similarly applied to point entities, such as bait stations, to select data records within a circular region of a specified radius. Data retrieved by any of these graphical techniques can be further filtered by imposing the standard pre-defined queries or applying ad hoc criteria. A useful example of this would be highlighting all chronic or serious sanitation violations within a 50-meter buffer of a complaint address. That information could then be used to effectively prioritized rodent control around that location.

Another technique, polygon overlay, involves superimposition of different data layers. By layering one data set upon another, areas of coincidence can be determined. For example, human activity layers (e.g., construction or land use) can be compared with rodent activity to look for spatial relationships. Additionally, proximity tests can be performed on any property to determine the closest recorded sanitation violation or rodent activity. Proximity queries can be made that ask questions such as "show all properties that have at least one other adjacent property with rodent activity" or "show all locations with rodent activity that are adjacent to a construction site." Such techniques allow Project biologists to quickly respond and formulate effective control strategies.

When a sanitation violation or baiting observation is recorded, it is referenced to a particular property. Although this may have important legal significance, rodents do not observe socio-political boundaries such as property lines or neighborhood boundaries. Because the GIS allows survey, baiting, and property lines to be placed on separate data layers, and each can be turned on and off, the data can be viewed independently to review spatial relationships that property information may obscure. As shown in Figure 2, it may be that, in terms of rodent populations, activity in certain bait stations in parcel "A" may be more spatially related to activity in parcel "B" than to other bait stations within parcel "A". A conventional database report on these properties would not show such relatedness between parcels.

One of the most basic, but useful, reporting techniques implemented with this GIS is the ability to produce thematic maps of results for display or printout. For example, maps showing different colors representing various levels of bait consumption can be used to target additional enforcement and education efforts in areas showing high consumption rates. Indices combining baiting activity with survey data (e.g., consumption, droppings, burrows) are being developed to provide overall measures of rodent activity for every property; these indices will also be displayed or printed as different colors or patterns. Similarly, sanitation indices are being developed that combine several measures of sanitation conditions to characterize sanitation in a neighborhood or district. By looking at time sequences of these maps, patterns of change should be detectable as enforcement and education efforts are emphasized. Clusters of properties with severe or chronic problems may indicate infrastructure defects or other factors related to rodent movement or abundance.

GIS maps also can be used during the planning phase of a rodent control program to help predict problem

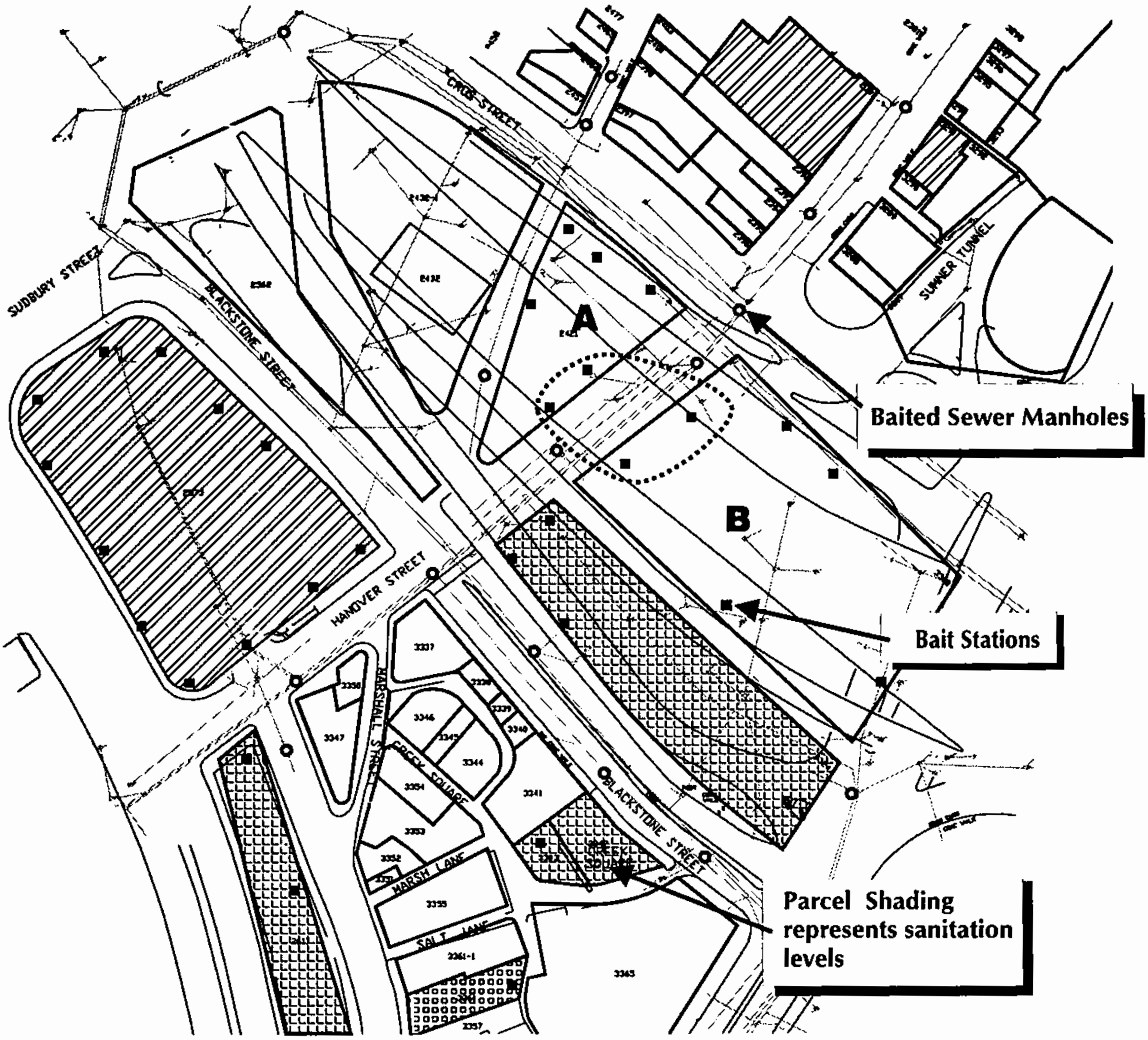

Figure 2. Example map from the CA/T geographic information system showing parcels and utility structures.

areas, and thus to prioritize work tasks. Because rodents are not randomly distributed in an urban area, utility structures, landscaping, and properties most predisposed to have rodent problems (e.g., restaurants/markets) may require early identification and priority. This allows available control resources to be distributed most effectively. For example, although thousands of manholes can be located within an urban area, only a subset may actually require baiting. This is because some utility structures (e.g., small sewer lines) are intrinsically more conducive to rat activity than others. The GIS used for the CA/T Project can identify and map certain types of utility systems or land parcels, as queried, when planning and estimating work.

Maps produced by the GIS not only have management and analytical value, but also serve as a practical tool for field personnel. For example, the capability to specify a date range and graphically display consumption values for specific bait stations and manholes can be used to direct pest control operators to those baiting locations requiring more frequent service. Similar maps can be generated on chronic sanitation problems for use by health inspectors and code enforcement personnel in the field.

Maps also can be used by field personnel to track bait locations, thus better ensuring monitoring and bait removal after all operations have been completed. Other examples of map use include tracking right-of-entry for private properties and resolving public concerns about exposure to poison baits. Accurate and consistent mapping also helps various groups participating in the CA/T program to coordinate and share information. For example, observations by pest control operators on sanitation conditions can be transmitted to City health inspectors; these inspectors subsequently can investigate effectively because the violation location is clearly identified.

Maps produced by the GIS also can be used effectively as part of community education efforts. Presentations using thematic maps can easily emphasize problem locations or improvements that have resulted from control activities within a particular neighborhood. Visual representation allows community members or the news media to clearly see where issues exist and what has been accomplished. Similar maps can be transmitted to regulatory or cooperating agencies to help ensure effective communication and cooperation.

CONCLUSIONS

The CA/T rodent control program GIS is a flexible tool ideally suited to a modern urban rodent control program. Because it is modular in design, new data or analytical features can be added as the rodent control program matures. The operational goal of the GIS will be to maximize program effectiveness and efficiency. Although custom tailored to the specific needs of Boston's CA/T Project, similar capabilities and management strategies could be adapted to other rodent control programs.

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