MAPPING THE URBAN INFRASTRUCTURE

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BIOGRAPHICAL SKETCHES

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R.G. (Glenn) Ritchie obtained his B. Ed. degree from the University of Alberta in 1971. He furthered his studies for one year in the Survey Engineering (Cartography) Program at the University of New Brunswick. He returned to Alberta in 1973 and was employed as the Supervisor, Urban Mapping, Alberta Transportation until 1978. He then joined the City of Edmonton as the Supervisor, Drafting Services, Engineering Department and is presently the General Supervisor, Mapping and Graphics for the Department.

ABSTRACT

Urban administrations, faced with increasingly complex problems in the expansion, upgrading and maintenance of the urban utility network, are seeking new and innovative means of obtaining fast, accurate and up to date facilities data. The development of modern electronic surveying and computer mapping capabilities have provided powerful tools to meet these challenges without major increases in human resources. This paper discusses a solution to this problem which is currently being implemented jointly by the Province of Alberta and the City of Edmonton. It briefly describes the urban survey and mapping program being carried out by the province and discusses the development of an urban utility cadastre, which is a sub-system of the City's Geographic Base Information System. Included is an evaluation of the benefits of the technological and procedural approaches adopted.

INTRODUCTION

The development of computerized mapping and land information management systems has been facilitated in Edmonton, as in other areas of Western Canada, by the existence of a homogeneous, structured system of land subdivision. This system of land (i.e. cadastral) surveys, commonly called the "township system" was established prior to settlement, and in conjunction with the land titles system of registration, has provided one of the best documented systems of land subdivision in the world. In recognition of the growing need for coordinate referencing of land information, the Alberta Bureau of Surveying and Mapping has developed a comprehensive surveying and mapping program, commencing in the late 1960's. The scope of this program now includes:

- the establishment of a survey control (i.e. geodetic) network
- the determination of co-ordinates for all points in the land survey system
- the determination of co-ordinates of photogrammetric control points in aerial photography, and
- the development of a base mapping system.

Since the majority of land information records are linked to or described relative to the land survey system, the program has been designed to make the maximum use of that system in order to optimize the development of land information management systems.

This paper is divided into two sections. The first section gives an overview of the urban component of the province of Alberta's surveying and mapping program. The second section briefly describes the development of the City of Edmonton's Geographic Base Information System (GBIS), which has used the framework provided by the Bureau's provincial program to implement an urban information management system, and discusses the development of the Utility Cadastre sub-system of the GBIS.

URBAN SURVEYING AND MAPPING PROGRAM

The Intergovernmental Agreement. Alberta was one of the first provinces in Canada to recognize the need, and accept the responsibility, for providing assistance to urban municipalities to develop a surveying and mapping framework. This assistance is formalized through an intergovernmental agreement which defines the area of coverage and sets out the respective responsibilities of the urban municapality and the province, which are, in summary, for the municipality to:

- locate and install survey control markers,
- maintain the survey control network in perpetuity, and
- make ties from the survey control network to the land survey system,

and for the province to:

- perform survey measurements on and compute coordinates of the survey control markers,
- compute coordinates of the land parcel corners,
- establish a photogrammetric control data base, and
- produce and periodically revise standard map sheets to cover the municipality, consisting of cadastral (land survey), contour and orthophoto components.

The municipality provides partial funding for the last step. Once the coordinates for the survey control markers are published, the area covered by the Agreement is declared a Survey Control Area. The Surveys Act requires that any subsequent land surveys within such an area be tied by survey measurements to the survey control network. This provides the mechanism for on-going maintenance of the cadastral component of the base mapping system.

The intergovernmental agreements with Alberta's two major cities, Edmonton and Calgary, differ in several key areas from the standard agreement. These cities have significantly greater technical and fiscal resources than the smaller cities and towns of the province, and this is reflected in the level of assistance provided under the urban surveying and mapping program. The major changes include the deletion of the photogrammetric control data base and the contour and orthophoto components of mapping coverage. In addition, a modified cost and work-sharing approach has been adopted for the production of cadastral mapping.

The Production Process. Once both parties have signed the agreement to formalize their respective intents to establish and maintain the urban surveying and mapping system, the work proceeds as described in the following paragraphs.

A. Survey Control. Once the municipality has located and installed the survey control markers, conventional triangulation, trilateration and traversing techniques are used to establish their relative positions and tie the municipal network to existing first and second order markers of the national geodetic network in the area. Field procedures are designed to yield positions of the markers to third order accuracy standards, as defined by the Federal Surveys and Mapping Branch. Additional measurements are made to tie at least one monument in the land survey system to each new survey control marker. The survey field work is contracted to surveyors in private practice, with limited in-house staff resources being used for reconnaissance and quality control checks on contract returns. The field data are processed through a least squares adjustment program on the Alberta government mainframe computer, an IBM 3033, to produce final coordinates for the survey control markers. Subsequent computation provides coordinate values for the tie points in the land survey system.

B. Land Survey. A map manuscript is used as the primary source document for the computation of land survey co-ordinates. This manuscript shows all surveyed property boundaries from which stems current title to land, and is compiled from such source documents as plans of survey, certificates of title, judges' orders, and gazetteers. The objective of the computations process is to assess the data in the same manner as a registered land surveyor would assess evidence on the ground, and to distribute errors accordingly. Staff survey technologists use a computer system of interactive programs to compute coordinates on mainframe CRT terminals, with the coordinates previously determined for the tie points and the survey measurements shown on plans of survey as input data. Each coordinate point is given a unique code number, which is stored in the computer file and is shown on the map manuscript. The land survey coordinates are used for cadastral mapping purposes, and under certain conditions defined by legislation, for the re-establishment of lost survey monuments in the field.

C. Photogrammetric Control. Vertical aerial photography of the municipality (normally at a scale of 1:8 000) is obtained under contract with a private mapping firm. Survey control markers are targetted prior to photography, and serve as the basis for establishing the positions of artificial photogrammetric control points marked on the aerial photos. The controlled photography and coordinates of the photogrammetric control points establish a photogrammetric control (or aerial survey) data base, which is used primarily for the production of mapping but is also made available for such special applications as digital terrain modeling or computational analysis projects within the municipality.

D. Base Mapping. The base mapping system for urban municipalities includes cadastral (land survey) orthophoto, 1m contour components. The Three Degree Modified Transverse Mercator (3TM) projection system is used, with 1:1 000 and 1:5 000 being the standard map publication scales. The 1:1 000 map shows detailed cadastral information, while the 1:5 000 maps include various combinations of the generalized cadastral, the contour and the orthophoto components. Examples of the typical 1:1 000 and 1:5 000 map sheet contents are shown in Figures 1 and 2, respectively.

Urban base mapping is achieved through a combination of contract and in-house production. The orthophoto and contour components are supplied by mapping contractors, usually on a project basis, which also includes the establishment of the photogrammetric control data base. The cadastral map components are produced by staff cartographic technologists from the coordinates previously computed on the mainframe computer, using the Bureau's Geodigital Mapping System (GMS). The GMS consists of an 8-station Intergraph Corporation interactive graphics system and an off-line photo-plotter supplied by Gerber Scientific Instrument Company. The GMS was acquired with the objective of establishing a provincial digital mapping system composed of several data bases to fulfill large, medium and small scale mapping application requirements. The large scale data base, being developed through the mechanism of the urban surveying and mapping program, currently consists of cadastral and contour data, with other topographical and cultural information being captured in hard copy form as orthophoto imagery.

Program Maintenance. The utility of the surveying and mapping system as a basic framework for land information management is largely dependent on the currency of the data. The urban program has been designed to have this very critical on-going maintenance function built in. The municipality is committed to maintaining the survey control network by replacing disturbed or destroyed markers and increasing the network density in urban fringe areas as development occurs. As previously indicated, land surveyors are required by legislation to tie all new land surveys to the control network, which facilitates the Bureau's on-going revision of land survey coordinates. The municipality and the Bureau are jointly committed to periodically revising the mapping coverage, with improved cost efficiency being provided by the existence of the photogrammetric control data base. The GMS has not only enhanced the Bureau's ability to meet the demand for a wide variety of graphical outputs, but has also greatly improved turnaround on map revision.

Products and Services. Although the urban surveying and mapping program is primarily designed to meet the needs of urban administrations, the available products and services are also used widely by such groups as land surveyors, engineers, planners, land developers and computer service bureaus. Survey control products include individual marker identification (ID) cards, and coordinate listings in hard copy or magnetic tape format. Adjustment statistics are also available for more scientific uses. The standard land survey product is a hard copy or magnetic tape coordinate listing, with computer-generated line connections to become available within the next year. Although the Bureau's copies of photogrammetric adjustment data and controlled photo diapositives are available to users, a system is currently under development which will provide a more formal service for users of the photogrammetric control data base. This will include access to an onsite point transfer device for transfer of control to the user's own photography, and provision of photogrammetric control point coordinates as a hard copy computer printout or on magnetic tape. The standard mapping products are diazo copies of 1:1000 and 1:5 000 cadastral maps and lithographed copies of 1:5 000 orthorphoto-line maps. Digital copies of GMS files of cadastral and contour data are also available on magnetic tape. In addition, a service is available for the municipalities to obtain various combinations of the data on film, in a range of scales, at the cost of materials. All products are available at nominal costs, with access restrictions limited to ensuring that users acquire the most current data and use it within normal accuracy limitations.

An Evaluation of the Program. The urban surveying and mapping program being carried out by the Alberta Bureau of Surveying and Mapping is expensive. The typical average implementation cost for a small municipality covering approximately 9 square miles is $200 000, with the Bureau and the municipality funding 87% and 13% of the total, respectively. Justification of the program from a conventional cost/benefit perspective is virtually impossible, since many of the benefits are long range and are either non-quantifiable, or at best, very difficult to quantify.

During the initial planning stages of the program, considerable effort was expended in evaluating alternatives and in analyzing similar programs in Europe, and in other parts of North America. The long term value of coordinate referencing, and of integrated surveying and mapping systems, had been widely known and accepted for decades in many European countries, but North American examples of such systems were relatively few at that time. One alternative to the approach, was ultimately adopted, would include the production of uncontrolled or semi-controlled aerial mapping, on a local datum, and the development of cadastral mapping by the manual compilation of survey data. This approach has been implemented in other areas, and while having the advantage of increased economy, it has generally suffered the major disadvantages of very limited application and short term benefits. Fortunately the planners of Alberta's urban surveying and mapping system possessed the foresight to identify the shortcoming of such a program, and the perseverance to secure the level of funding necessary to develop the program to its present form.

Some of the major benefits of the program are as follows:

1. The integrated system has the necessary accuracy to be used, not only for planning and land management, but also as an engineering design tool.
2. It substitutes one accurate standardized map base for large numbers of non-standardized urban maps and plans, many of which are often of unknown origin or accuracy.
3. The survey control network provides an accurate, stable framework of points which can be used for the location or relocation of property boundaries and for a large number of municipal engineering and surveying projects in the field.
4. The existence of the mapping data base in digital form provides the basic component required for the development of computerized urban utility, assessment and taxation cadastres.
5. The surveying and mapping system reduces revision costs by establishing the necessary key elements to facilitate on-going maintenance. Long term commitment to program maintenance is ensured by the joint signing of the intergovernmental agreement.

For any program to maintain its effectiveness, it must be subject to periodic reviews in the light of changing user requirements and new technology. Alberta's urban program is reviewed on an ongoing basis and has been improved in several areas during the past twelve years. From the surveying viewpoint, survey control markers have been improved in design, their spacing adjusted to meet changing needs, and the methods of their positioning updated to take advantage of modern developments in EDM, satellite and inertial positioning technology. From a mapping perspective, cartographic production has evolved from manual, through semi-automated to fully automated plotting of output, and significant improvements have been experienced in the accuracy and reliability of photogrammetric mapping. Standards and specifications have been amended and upgraded for both in-house and contract surveying and mapping work. A recent major revision of the intergovernmental agreement document has significantly improved the overall funding and administration of the program, as well as clarified the parties' roles and responsibilities. Further innovations, such as the use of "black-box" survey positioning technology and digital terrain modelling, will be implemented as required to ensure that the program continues to provide the necessary basic framework for the planning of Alberta's urban development.

EDMONTON'S GEOGRAPHIC BASE INFORMATION SYSTEM PROJECT

Background. The benefits of the accurate, up-to-date digital cadastral mapping system provided by Alberta's urban surveying and mapping program can be readily seen by providing a brief synopsis of the Geographic Base Information System (GBIS) currently being developed in the City of Edmonton. In 1977 a Metric Task Force recommended to City Council that a geographic base be developed with the framework for this system being the urban surveying and mapping program developed by the Province of Alberta. The data base system would coordinate all civic departmental metric conversion activities, develop metric standards for City maps and utilize computer-assisted mapping technology for conversion applications. In 1978 City Council approved a capital budget program for the Geographic Base Information System. The City of Edmonton commenced negotiations with the Province of Alberta to extend the urban surveying and mapping program, divide map production responsibilities and agree on suitable cost-sharing arrangements.

In order to complete the program by 1982, the City, through the G.B.I.S. Branch, purchased an automatic mapping system from Intergraph Systems Incorporated, consisting of a DEC 11/70 Central Computer Processing Unit, three graphics work stations and a Calcomp 960 plotter. Today the GBIS configuration consists of four networked systems and forty (40) workstations spread over eight City Departments, and capital funds have been approved to expand the project to five networked systems with over fifty (50) workstations by late 1982. Systems are currently operational in the Departments of Water and Sanitation, Edmonton Telephones, Edmonton Power and the central G.B.I.S. Branch. The Engineering Department has acquired a precise Cartographic Drafting System from Gerber Scientific Instrument Company in February of 1981 and in the late fall of 1982 will be installing a standalone graphics system for integrating geometric roadway design, engineering surveys and land-related information with the cadastral mapping data base.

The Utility Cadastral. The Geographic Base Information System encom passes a variety of graphical and informational sub-systems various stages of development. These include engineering design, tax assessment, street addressing and land-use and demographic mapping applications.

However, the foremost sub-system is the Utility Cadastral, which is being developed with input from Edmonton Power, Edmonton Telephones, the Water and Sanitation Department and the Engineering Department. Also, as of May of 1982, Northwestern Utilities, the privately owned gas company, has become an active participant in the project.

One of the most frequent problems in land-related information management systems has been the absence of accurate location of data. Consequently, the benefits of precise postional coordinates in a digital cadastral mapping system are numerous. One such benefit for the City of Edmonton is the accurate mapping of utility infrastructure data. The term infrastructure, as used in context of the Geographic Base Information System, applies to all man-made features of the landscape, including all of the "physical plant" necessary for the urban community - water, sewer, power and telecommunications facilities, oil and gas pipelines, buildings and transportation networks. Since location is the common attribute by which all infrastructure elements may be correlated, the large scale digital cadastral mapping system, developed by the City of Edmonton jointly with the Province of Alberta, provides the essential fabric for the development of the GBIS Utility Cadastre.

In order to effectively fulfill the corporate utility mapping requirements, the G.B.I.S. Project is structured along the following committee lines. A Steering Committee, comprised of Senior Management Levels in those civic departments with primary input responsibilities, was established to ensure that corporate planning and direction is maintained. To ensure that the policy decisions are effectively coordinated and implemented by all participants in the project, an Implementation Committee comprised of mid-management personnel was struck. This committee oversees the three working committee levels of Finance, Standards, and individual Departmental committees. Committee representatives established utility cadastre implementation procedures and schedules and developed protocols and levelling assignments for the layering of information. A special symbol and linework library for utility map products was also created. The major departments then proceeded to input utility data on the cadastral base from their existing records.

One of the problems foreseen in this method of implementation was the relative positional accuracy of each infrastructure element being entered. Since all departmental records were not uniform nor were they necessarily oriented to the provincial coordinate system, there existed the need for the corporation to strengthen its record system utilizing the highly accurate cadastral mapping base as the common tool. Towards this end, the Engineering Department researched several methods of acquiring, processing and displaying various types of digital infrastructure data on the cadastral base.

To achieve a more accurate and complete picture of the current infrastructure situation in the City of Edmonton, the Engineering Department proposed that the basis for the system must be surveyed location of the various utilities. Although it was recognized that many other important features of the utility such as material, capacity, installation and maintenance records were integral to the information management process, only the precise location of the physical plant would permit proper correlation of all data in an unequivocal manner.

An assessment of City utility records indicated that several of the common errors made in the acquisition and use of survey data were evident. In order for the survey community to provide a responsive need to engineering projects, it is most critical that the available human resources for surveying activities are utilized in the most cost-effective manner. Although surveying must be undertaken for every engineering project, the cost of the survey is generally a minor portion of the total project cost. However, if engineering projects are not supported by reliable survey data, delays and errors quickly escalate the total project cost. In addition, surveys should not be performed for single-purpose use without adherence to adequate geodetic support and accuracy specifications. If surveys are performed in a hapharzard manner, the results are never recoverable and the municipal taxpayer ends up paying handsomely for redundant surveys on the same project.

A more serious problem arising from the lack of systematic performances of survey can be seen when civic authorities must attempt to manage all aspects of the highly complex urban environment without accurate infrastructure information on the location, condition, and other related features of particular utility installations. If, for example, gas or pipeline explosions occur, as has been the case in several North American cities including Edmonton, there is a vital need to respond with prompt and highly correct emergency measures. Accurate mapping of the urban infrastructure permits technical staff, engineers, and civic administrators to utilize their time dedicated to a particular engineering project in the most efficient and effective manner.

With these important considerations in mind, the Engineering Department has embarked on new surveying, mapping and record system development projects to acquire and graphically display various types of infrastructure data. These projects are being implemented with a view towards utilizing the various human resources of private industry and the municipal government sector to their maximum potential. One such project, which utilized a combination of aerial mapping and modern ground survey techniques, is described in some detail hereunder.

Infrastructure Mapping - The Production Process. In order to create a utility map product which could be utilized for a variety of engineering and planning activities, the Engineering Department has established mapping specifications for the input of infrastructure elements to the cadastral mapping base. Survey specifications of data call for coordinates to be published using the 3^{o} Transverse Mercator Projection with the usual 0.9999 scale factor at the reference meridian. Accuracy requirements are for features to be within 5 to 8 centimetres of their true position relative to the Alberta Survey Control system. These requirements allow both photogrammetric and land surveyors to acquire various sets of infrastructure data to be correlated with the cadastral framework. One surveying and mapping contract recently awarded in the City of Edmonton calls for the complete acquisition of digital data for utilities, buildings, curbs, hydrography and topography in a 2400 hectare area (2- 1:5 000 map sheets). The following briefly describes the surveying and interactive computer-assisted mapping procedures used in this infrastructure mapping process.

Prior to photogrammetry being performed, the survey company made a careful inventory of the street hardware that was known to exist. This was done by transferring the approximate location and type of data from existing City of Edmonton record plans to composite work sheets. With these sheets placed in a clipboard, the survey technologist then walked along each street checking off existing hardware and painting targets on selected items of hardware that were too small to be visible or may be obscured on a photograph. At this time, the control markers required for aerial triangulation were also targetted. Control markers, water valves, or buried street hardware were located using an electronic pin finder. Hardware not shown on the composite work sheet but clearly existing on the ground was added, while hardware not existing on the ground but shown on the sheets was noted.

New aerial photography was undertaken to C.A.A.S. (Canadian Association of Aerial Surveyors) specifications and at a scale of 1:3 000. The digitization of the street hardware, building, curbs, contours, and hydrographic features was undertaken using semi-analytical stereoplotters and the digital data stored on a 9-track magnetic tape along with added codes or identifiers for each set of requested information. The magnetic tape was then turned over to an engineering services sub-contractor whose interactive graphics hardware configuration closely matched that of the City of Edmonton. All cadastral base map files covering the project area were forwarded to the sub-contractor to separate the survey data into the appropriate files and levels. The City of Edmonton also made the firm familiar with all naming conventions, symbol or cell libraries, utility label definitions, working units, control parameters, and line weights and styles.

After the initial preparation of the graphics file by the mapping technologist, a ball point plot was returned to the survey firm for corrections. Additional survey work, if required, was performed using a "total station" surveying instrument consisting of theodolite, electronic distance measuring unit and digital data recorder. A revised plot was then forwarded to the Engineering Department who in turn edited the sheet for survey accuracy and completeness. Once again discrepancies were noted and returned to the survey firm where supplemented ground survey or additional field checks were performed. Corrected data was returned to the Engineering Department, interactive edit modifications were completed, and additional linework and annotation attached by the individual utility departments. A final photo light beam plot was then generated by the Gerber Cartographic Drafting System and photomechanically reproduced for record purposes. Examples of final utility maps are shown in Figures 3 and 4.

Evaluation of Infrastructure Mapping Project. The results of this and all other digital surveying and mapping projects undertaken as part of the corporate Geographic Base Information System have conclusively demonstated the need for future infrastructure acquisition, information processing and map creation projects to be continued using similar types of methods and procedures. The inherrent value to engineering projects can be summarized as follows:

1. All infrastructure data can be accurately captured terrestrially (ground survey) or photogrammetrically and can be supplemented by conventional field survey to provide 100% completion of utility information. This information should be surveyed to third order accuracy specifications which enables the infrastructure coordinates to correlate within acceptable survey deviation with the property (cadastral) boundaries.

2. Using automated survey practices which require the derived coordinates of the utilities to be connected to the survey control network means that this information can be accurately related to any other information on the city fabric which may be integrated at a later date.

3. Future changes to the urban infrastructure, whether they be for a minor or major undertaking, can always be surveyed to the same common specifications and result in new sets of data which can be easily integrated into the Utility Cadastre Sub-System.

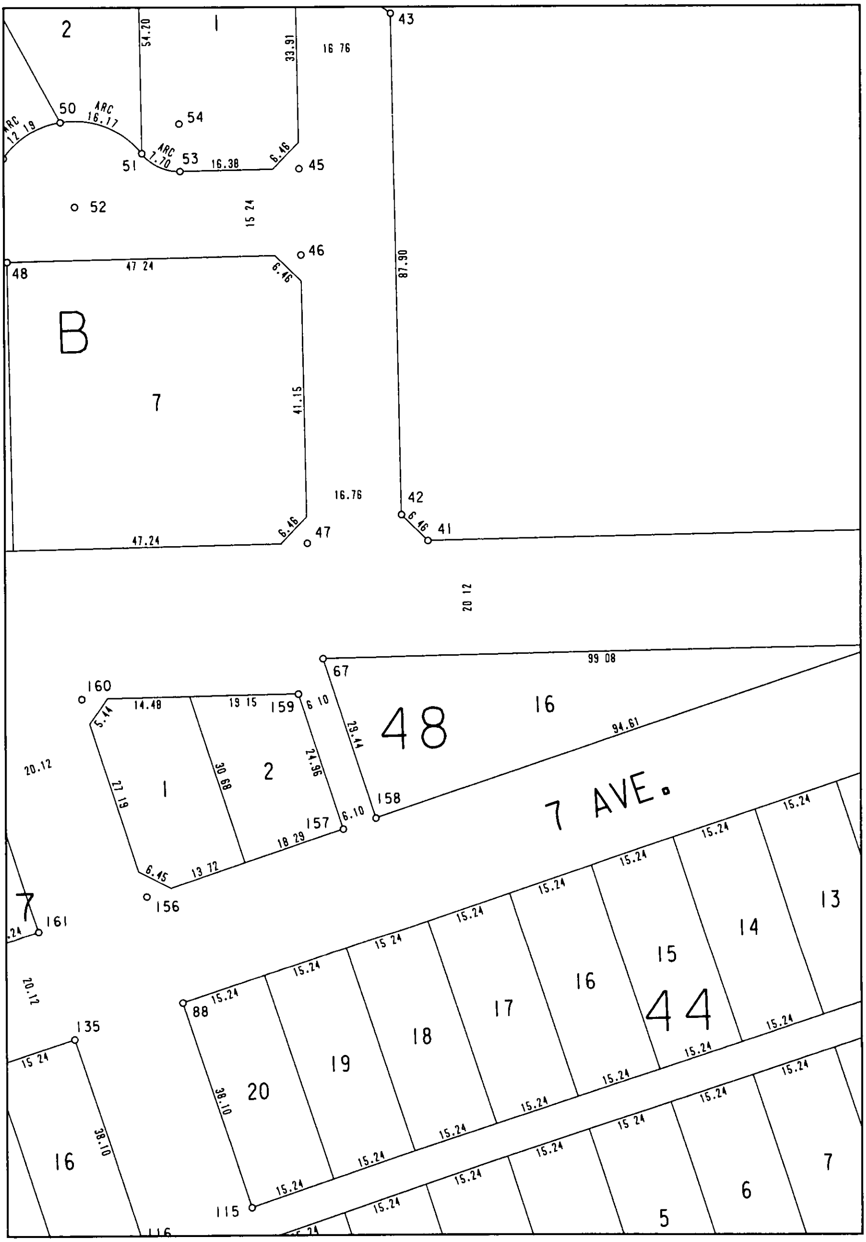
4. The primary role of the interactive graphics system is to process and eventually store the vast amounts of utility data which must be collected in the City of Edmonton. The computer graphics system also enables the municipality to simplify the production and maintenance (updating) of utility maps.

   The computer graphics system can readily accept large amount of data which can be quickly disposed into graphics files for rapid access and retrieved by technicians, designers, cartographers,or engineers to complete any pre-determined project function. This function may be related to mapping and/or engineering activities such as record system development or geometric roadway design. The graphics terminal operator can easily manipulate various types of information to conform to the requirements for the user.

5. The computer plotting and drafting system provides the most modern, "state-of-the-art" technology for the generation of various types of maps, engineering plans,and utility drawings. The system accuracy, speed and flexibility combine to provide a most efficient drafting tool for engineering utilization.

5. By utilizing the services of private survey firms and engineering companies engaged in similar interactive mapping applications, the compatibility of systems makes possible the smooth transfer of data with only minor software development required. This minimizes the quality control required of the municipality and enables mapping personnel in the City to complete the massive undertaking of utilily record conversion in a shorter period of time.

In summary, it is recognized that the total acquisition of complete utility infrastructure data utilizing the innovative techniques described above is very costly. However, it is much more economical to perform one survey to capture large amounts of information rather than extracting redundant survey data for single applications. A key to the continual development of the digital Utility Cadastre Sub-System in the City of Edmonton is to ensure that technical legends or accuracy codes are available to inform the user of the reliability of the information or from what source it is derived. As part of the total input in the Utility Cadastre Program for the G.B.I.S. Project, the Engineering Department is committed to achieving many of these goals. This will involve the active inter-relationship of personnel in both the surveying and mapping community and all engineering project staff in the City of Edmonton. Interactive graphics and computer drafting systems have provided a most powerful tool to effectively deal with the much sought after dynamic information system that is indespensible to rapidly growing municipalities. The involvement of man conversing with machine optimizes the capacity of both towards achieving higher levels of productivity within the complexities of rapid technological growth in the surveying and mapping industry.

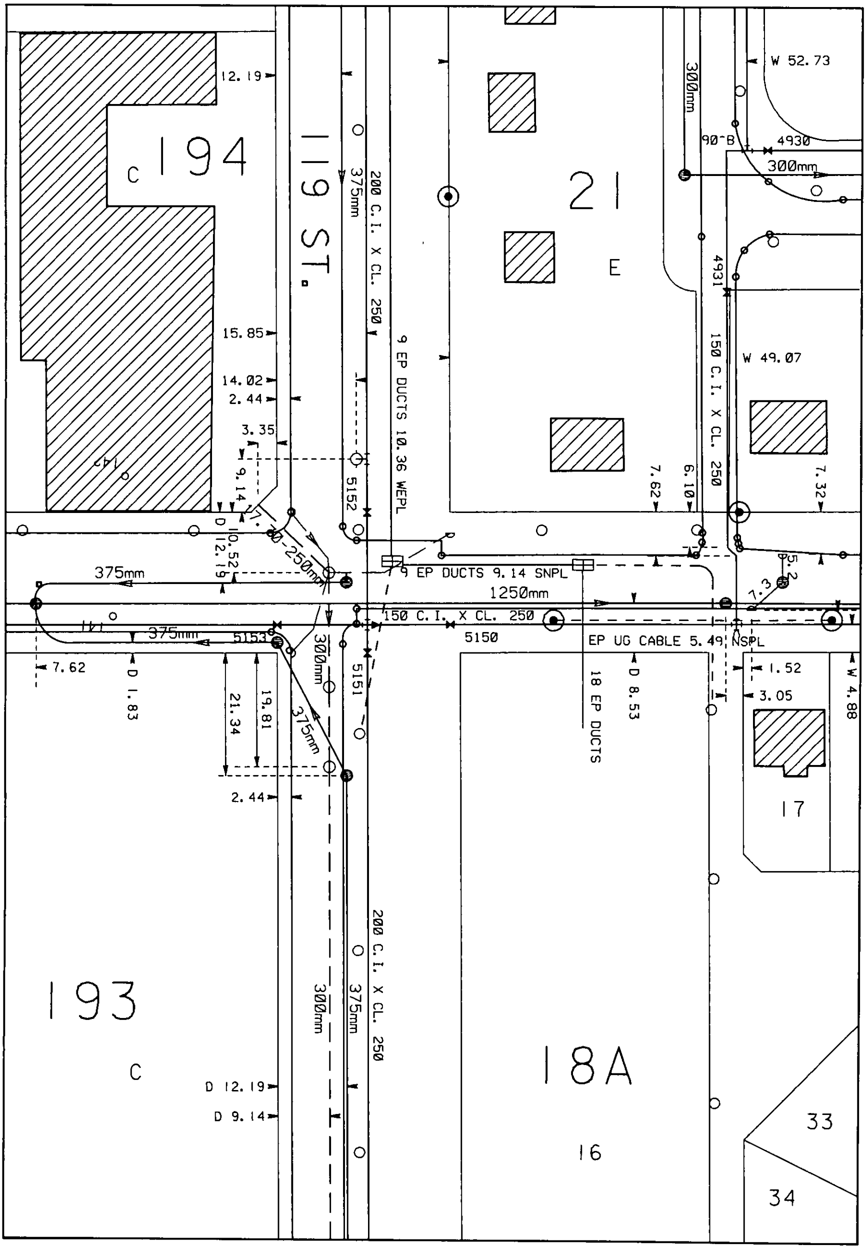


PORTION OF A TYPICAL 1:1 000 CADASTRAL MAP

FIGURE 1

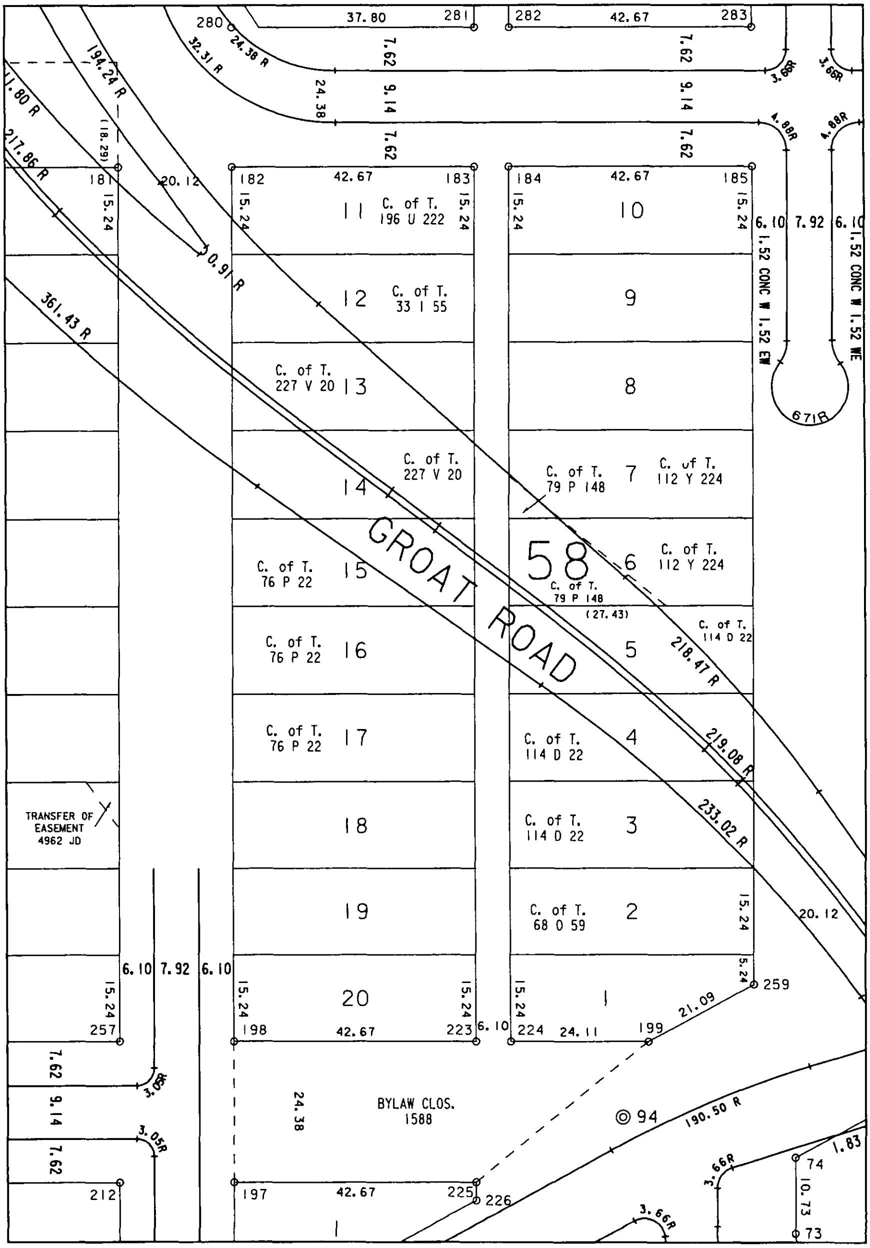
PORTION OF A TYPICAL 1:5 000 ORTHOPHOTO-LINE MAP

FIGURE 2



PORTION OF 1:1 000 UTILITY CADASTRE

FIGURE 3



PORTION OF 1:1 000 CADASTRAL STREET INVENTORY

FIGURE 4