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The Millimeter Legal Coordinated Cadastre

Carlton A. Brown

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THE MILLIMETER LEGAL COORDINATED CADASTRE

By

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A THESIS

Submitted in Partial Fulfillment of the

Requirements for the Degree of

Doctor of Philosophy

(in Civil Engineering)

The Graduate School

The University of Maine

May, 2011

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ACCEPTANCE STATEMENT

On behalf of the Graduate Committee for _____, I affirm
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committee members are on file with the Graduate School at the University of Maine,
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THE MILLIMETER LEGAL COORDINATED CADASTRE

By Carlton A. Brown

Thesis Advisor: Dr. Raymond J. Hintz

An Abstract of the Thesis Presented
in Partial Fulfillment of the Requirements for the
Degree of Doctor of Philosophy
(in Civil Engineering)
May, 2011

Land ownership is an important part of a nation's wealth. Land value is determined by information about the land and about property rights that exist over the land. The Cadastre is the primary means of providing information about property rights, providing the private and public sector with: information identifying those people who have interests in parcels of land; information about those interests; and information about the parcels.

The definitive cadastre would require anyone looking for information about a parcel of land to only go to the cadastre to find everything there is to know about the land such as:

- the exact, true location on the ground of all boundary corners of the parcel;
- the exact, true measurements, such as direction and distance of all boundary lines of the parcel and the exact area and geometry of the parcel as it exists on the ground;
- the exact, true information on every interest (and all interests) that exists over the parcel, including the person who owns the interest and the exact nature and extent of the interest.

Examined in this thesis are issues surrounding the design of such an ultimate cadastre. One conclusion is that the ultimate cadastre should be based on the legal coordinated cadastre in which geodetic coordinates are used to define boundary corner locations. Also, since it is difficult to quantify what is meant by “exact”, this thesis will make the assumption that the smallest error of concern is 1 mm and thus the ultimate cadastre is the millimeter legal coordinated cadastre.

Other conclusions are that the cadastre should be based on the Torrens system of land registration, but where all property rights are registered rather than just the ownership right known as the fee-simple estate.

The millimeter legal coordinated cadastre is compared and found to be superior to other existing cadastres.

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I would like to thank my parents, Mr. and Mrs. Hazen Brown, my sister, Debra Constantino, and my son, Nathan Brown for all the support they have given me after moving so far away from home to live in Maine and go to graduate school. I remember that day on July 4, 2000 when we all talked about the possibility of going back to school.

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FOREWARD

When I, a greenhorn from the city, moved to Maine, one of the first things I was told was what to do if, while walking in the woods, I stumbled upon a cute little bear cub. Rather than start taking pictures or going up to scratch behind the cub's ears, I was told to immediately turn around to see if I was between the cub and the mother bear (who was surely close by). If so, then I was cautioned to hope that since I wouldn't be able to outrun the enraged mother bear, I could at least run faster than other members of the surveying crew I was with. I have seen similar protective instincts in the human race (certain moms and dads at soccer (baseball, basketball) games when their six-year old (10-year old, 17-year old) children were "slighted" by a coach, opposing player, opposing player's parents, etc). However, it all pales when compared to the protective nature that humans have with their land. Humans want to know the exact boundary location of their land. Humans want to know the exact boundary rights attached to their land. I grew up as did my father and grandfather before me in a small suburban city in Massachusetts. For almost 30 years I was a land surveyor for a small firm located in that city and many of my clients were my friends, my father's friends, my grandfather's friends, my relatives and my neighbors. I saw firsthand how protective (compulsive, irrational) people can be over their land. One Saturday I met with a potential client who was having a boundary dispute with his neighbor. I knew the neighbor, an archbishop for a major religion, to be a pious, sincere, kind person. However, as I was standing with the future client on his land, his neighbor came charging out of his back door, telling my client in no uncertain terms to "stay off my land". I don't know if I was more shocked by the neighbor's

uncharacteristic yet proficient use of profanity or by the red-faced rage that I was afraid would turn into an apoplectic fit.

In another survey, I was staking a boundary line for two neighbors who had lived next to each other for decades. Every weekend they would mow their respective lawns, including the lawn between their houses over which the said boundary line ran. When I staked the front boundary corner with an iron pipe one neighbor said, “Oh, that’s not right. The corner should be over there,” pointing a couple of feet into his neighbor’s side. The other neighbor said, “No, no, no, it should be over there!” pointing a couple of feet into his neighbor’s side. Even though they had each mowed their lawns over that general area for decades, it was not until I “fixed” the location of the corner that they had problems (which resulted in two fences marking the boundary line, each of the neighbors setting their own fence on the line that I staked).

Finally, I was involved in a survey where the deeds were ambiguous and vague making it difficult to determine where a boundary line was located on the ground. My client and I met with his neighbor and his neighbor’s surveyor to discuss the issues. Both owners were friendly to each other, had lived next to each other for years, and had children who went to the same school. The other surveyor and I, hoping for a boundary agreement between parties, gave a mutual presentation of our results, after which my client said amicably, “I only want what’s mine. I don’t want any of my neighbor’s land, but...”. At this point his face turned hard, he put his hands on the table and leaned across the table saying “...I won’t give up one millimeter of my land!” That case eventually went to court.

Most countries are striving to create a cadastre that closely models land parcels as they exist on the ground. Many cadastral models will allow for more accurate data to be continually added so that as time passes the cadastre will more accurately model the reality that exists on the ground. One question often asked is how accurate should the models eventually be? Most of my clients wanted me to show them their “exact” boundaries, with no error. Most of my clients wanted what was articulated so well above: “I don’t want any of my neighbor’s land ... but I won’t give up one millimeter of my land.” I believe that the accuracy required of cadastres is that they be “exact”, but since that is not possible, then to have an error of 1 mm or less. Thus this dissertation will discuss the ramifications of having a millimeter cadastre.

Land ownership is an important part of a nation’s wealth. In 2002 the U.S. Census Bureau reported that about 68% of U.S. households owned their own home, and the equity in those homes made up about 42% of the net worth of those households. (U.S. Census Board 2008) To protect this asset, it is important for land owners to know not only where the land is located on the Earth’s surface, but also to know exactly what rights they have to their land, and what rights others have over their land. Developers need to know what rights, restrictions and regulations affect a parcel of land before acquiring and developing the parcel. They also would like to have these questions answered instantly or “right now” because the more time it takes to determine what can and cannot be built, the more money is spent in monthly land option costs and investment loan fees. Thus, this dissertation will also discuss the ramifications of creating a cadastre for which all rights, interests, restrictions and regulations over a parcel are known “right now”, are current and up-to-date.

1. THE PROBLEM AND ITS SETTING

Parcel location, ownership, usage and display of those concepts is a dynamic application of the theory, mathematics and science of land surveying. Advances in technology have created a demand for a more unique way to apply the concept of a seamless cadastre capable of growing with those technological advances.

1.1. Statement of the Problem

A Cadastre is normally a parcel based, and up-to-date land information system containing a record of interests in land (e.g. rights, restrictions and responsibilities). It usually includes a geometric description of land parcels linked to other records describing the nature of the interests, the ownership or control of those interests, and often the value of the parcel and its improvements.

The Cadastre is the primary means of providing information about property rights. More specifically, the Cadastre provides the private and public sector with:

- *information identifying those people who have interests in parcels of land;*
- *information about those interests (e.g. nature and duration of rights, restrictions, and responsibilities);*
- *information about the parcels (e.g. their location, size, improvements, value).*

(FIG 1995)

A cadastre is a parcel based land information system that provides information on who has interests in parcels of land, what those interests are, and the size, shape, and location of the parcels themselves. The vision of a single seamless cadastre to cover an entire nation is being studied by the International Federation of Surveyors in their Cadastre 2014 (Kaufmann and Steudler 1998), and by the United States Department of the Interior, who through the Federal Geographic Data Committee (hereafter called the FGDC) Subcommittee for Cadastral Data and the Bureau of Land Management Cadastral Survey, has a goal of creating a seamless cadastre for the entire United States. This

United States cadastre will be known as the National Integrated Land System (NILS) (Bureau of Land Management 2006).

An “ultimate” cadastre might be envisioned as one in which an interested party looking for information about a parcel of land would only have to go to the cadastre to know “everything” there is to know about the lot such as:

- the exact, true location on the ground of all boundary corners of the parcel;
- the exact, true measurements (such as direction and distances) of all boundary lines of the parcel (and thus the exact geometry of the parcel as it exists on the ground);
- the exact, true area of the parcel;
- the exact, true information on every interest (and all interests) that exists over the parcel, including the person who owns the interest and the exact nature and extent of the interest.

For example, a person sitting in front of a computer monitor anywhere in the world would be able to query such an “ultimate” cadastre and without ever setting foot on or near a particular parcel of land, would be able to access definitive information such as where the parcel is definitively located on the ground, its exact geometry, and all information needed to be able to determine all the uses for which the parcel could be used, and all interests that others have over the parcel.

One difficulty in designing such an “ultimate” cadastre is in determining what is meant by “true” and “exact” and the similar concepts of “zero error” or “no error”. Since it is difficult to quantify these concepts (“true”, “exact”, “zero error”, and “no error”), this dissertation will make the assumption that 1 mm will be the smallest error with which to

be concerned when describing the location of a boundary corner or when describing the measurement of a boundary line, and thus any location or measurement whose error is 1 mm or less will be assumed to be “exact”, “true”, and with “zero error”. (Thus the “true” and “exact” legal coordinated cadastre becomes the “millimeter legal coordinated cadastre”.)

Throughout the world the paradigm for describing the definitive location of parcel boundary corners is through the use of physical monuments set in the ground and where the land surveyor (either public or private) is charged with determining where parcels of land are located through the use of these definitive physical monuments. Land surveyors typically create plans showing the results of their survey of a particular parcel of land. Such plans show what physical monuments were found or set to definitively locate a boundary corner on the ground, and the measurements (such as direction and distance) of boundary lines between corners as determined by the land surveyor. When defining an error to be 1 mm or greater, these boundary line measurements determined by land surveyors will probably have error and will not be the “exact” boundary line measurement. Thus in such a case, even land surveyors’ plans of a parcel of land may just be models and may not show the “exact” boundary line measurements. In the vision of the seamless cadastre, the land surveyor will also measure a coordinate so that the location of the parcel boundary corner shown on the cadastre can be referenced to the national coordinate system. Since the coordinate will be measured, it will have error and will not be the exact coordinate of the location of the definitive physical monument. Thus a cadastre based on the current paradigm of using physical monuments to describe the definitive location of boundary corners will only be a model of reality as the cadastre

will use information from the surveyor's plan, which is itself only a model of reality, and will use coordinates that also only model the location of the actual location of the definitive physical monument.

Cadastre 2014 (Kaufmann and Steudler 1998) uses a fixed boundary system in which parcel boundary locations are modeled by coordinates that are determined by land surveyors (and not for instance by coordinates determined by boundary features observed on an orthophoto or other image). These coordinates will have measurement error associated with them, with the accuracy of the coordinates of the fixed boundary system being determined by the cadastre creator before the cadastre is built. NILS will also use coordinates that are determined by land surveyors and that will have measurement error associated with them. However, NILS will have the ability to take record data from various other and future surveys to create new coordinates that will have less error through a least squares mathematical adjustment. Thus the survey fabric ((Arctur and Zeiler 2004) page 234) of all the parcels in a cadastre will change over time as new survey data is added, with the anticipation that more survey data will result in more accurate coordinates. However, both cadastres will only be a model of reality.

A better cadastral system is the legal coordinated cadastre in which the location of a boundary corner of a parcel of land is definitively described only by a coordinate of a national reference system and not by a physical monument set in the ground. (As explained further in the dissertation, the cadastre used by Singapore comes close to being such a legal coordinated cadastre). In this case, the coordinate location of a parcel boundary corner is not just a model of the actual location; the coordinate location shown in the cadastre *is in fact the actual, definitive boundary corner location*. The model (the

computer monitor on which the cadastre is viewed) becomes reality, in a process much like that which Baudrillard calls “hyperreality” (Baudrillard 1983). The problem with this system is that land owners cannot “see” such a definitive coordinate on the ground. When defining an error as being 1 mm or greater, the location of a physical monument set in the ground by a land surveyor to mark such a definitive coordinate will have error associated with it. Also, since all locations in a legal coordinated cadastre are by coordinates, a land surveyor will have to measure a coordinate of location of any physical object such as a building corner before that building corner can be shown in the cadastre. All measurements have error associated with them, and thus it is probable that the coordinate entered into a cadastre showing the location of a physical object in the ground will have error.

Another issue is that most cadastres do not show “all” the rights and interests that might exist over a parcel of land. This dissertation will include rights and interests usually included in cadastres such as fee simple estates (“ownership”) and easements but will also assume that regulations and restrictions created by governmental agencies are also rights and interests that should be included in a cadastre.

This thesis will propose two possible designs for a millimeter legal coordinated cadastre for the United States based on the land registration system of the Massachusetts Land Court and the use of National Spatial Reference System coordinates to definitively locate parcel boundaries. This thesis will also analyze the legal, social, and technical aspects of such a legal coordinated cadastre for the issues presented above as well as other issues that are not as obvious.

The design of the first legal coordinated cadastre (LCC1) will include:

- a Torrens system of land registration much like that used by the Massachusetts Land Court;
- the use of geodetic coordinates to define the true location of boundary corners;
- the setting by land surveyors of (subservient) physical monuments in the ground that approximately mark the true location of boundary corners;
- the creation by statute of a “de minimis” zone within which there can be no encroachment or zoning violation for those owners who rely on these approximately located physical monuments;
- the smallest unit of LCC1 will be the individual land parcel in which definitive location, size, and shape, and fee simple owner are determined;

Technical issues that must be addressed and new policy, regulations, and statutes that may have to be enacted will be discussed.

The design of the second legal coordinated cadastre (LCC2) will be more radical than LCC1. Arguably, the ideal cadastre is one with which someone who is located at any place in the world may instantly determine the following current, definitive, and up-to-date information about any parcel of land:

- all entities that have interests in the parcel (including who has “fee ownership”);
- what those interests are (duration, restrictions, responsibilities, and the nature of the interests);
- location and size of the parcel.

LCC2 will provide information on all interests and rights that exist for any point in the cadastre. Through the concept of the *cadastron* (Brown 1999), LCC2 will differ from LCC1 in the following ways:

- The Land Court will decree the definitive owner, location, size, and interest of each *cadastron* rather than the present method of decreeing only the fee simple interest, owner, location, and size of the parcel of land.
- The Land Court will be responsible for maintaining a data base of *cadastron* information containing the following data:
 - i. What entity holds the interest or estate.
 - ii. What the interests or estates are.
 - iii. The location of the land over which the interest or estate exists.
 - iv. The time interval over which the interest or estate exists (or is effective).

The Land Court will only be responsible for maintaining the data base and not for creating the actual cadastre. Instead, the data base information will be made available to the public, and it will be left up to private enterprise to create methods and software programs that will compile information from the data base into useable cadastres for the specific needs of their clients.

- The concept of level (or scale) of measurement (Stevens 1946) will be modified and included in LCC2, which will allow imprecise or estimated locations of certain interests to be added to the cadastre. (For instance,

regulated wetlands and wildlife habitat are interests that can restrict development. The locations of these areas are often estimated or imprecise and may require a further investigation to determine their definitive locations. The modified concept of “level of measurement” will allow these types of interests to be included in the cadastre.)

1.2. Overview of Key Components Explored

The premise of my proposed solution to creating a “timeless” cadastre discusses the various components that are necessary to create such a product. I have separated my discussion into sections that provide the necessary background information, current paradigm and future applications/research.

1.2.1. Discussion of the Role of the Surveyor

Section 3.3.2. will discuss the two roles that land surveyors will have in the legal coordinated cadastre.

- The first role is as a retracing surveyor, setting physical monuments in the ground to mark the surveyor’s professional opinion as to where the official geodetic coordinate, decreed by the Land Court, is located. Liability issues and significance of these physical monuments will be discussed.
- The second role is as the Surveyor for the Land Court, preparing the plan from which the Land Court will decree a parcel of land or cadastron for the first time. Liability issues and significance of physical monuments set in the ground both prior to and after the final decree will be discussed.

1.2.2. Comparison of Five Cadastre Systems

Section 5.1. will discuss the advantages and disadvantages between the five cadastres (Cadastre 2014, NILS, Singapore Co-ordinated Cadastre, LCC1 and LCC2)

1.2.3. Findings

Section 5.2. will discuss the findings with a conclusion discussed in 5.3.

1.2.4. Future Research/Application Implications

Section 5.4 will discuss the implications of the findings of this dissertation and their relationship to future research topics.

One research topic, wireless sensor networks, is currently being performed in many fields, such as in monitoring volcanic eruptions (Werner-Allen, Johnson et al. 2005) and the study of plate tectonics and earthquakes (Earth Scope® - EarthScope: An Earth Science Program, 2010). Suggestions will be made about how wireless sensor networks might be used to monitor physical monuments set in the ground at the locations of those SPC that definitively mark boundary corners. Another suggestion will be on how augmented reality can be used.

1.3. Statement Of The Hypothesis

The hypothesis is that a cadastre can be designed for the United States of America in which an interested party looking for information about a parcel of land would only have to go to the cadastre to know “everything” there is to know about the lot that exists at that time (the “current” time, or “right now”) such as:

- the exact, true location (including the location on the ground) of all boundary corners of the parcel;

- the exact, true measurements (such as direction and distances) of all boundary lines of the parcel (and thus the exact geometry of the parcel as it exists on the ground);
- the exact, true area of the parcel;
- the exact, true information on every interest (and all interests) that exists over the parcel, including the person who owns the interest and the exact nature and extent of the interest.

2. LITERATURE SEARCH

To date there have been multiple attempts to create the “perfect” cadastre, that will provide a seamless interface among multiple applications. Technology continues to provide opportunities for development of more time-relevant products that are capable of changing as technology changes. However, many countries have only just begun to understand the need for such a product as they emerge into the 21st century. A literature review of current cadastres reveals that all of those reviewed have deficiencies which will be discussed further throughout this research.

2.1. Introduction

A legal coordinated cadastre (Surveyor's Board of Tasmania 2000) is one in which boundary corners of parcels of landownership are definitively located only by coordinates (and not by physical monuments set in the ground). People from around the world who are involved in cadastres have started to investigate whether legal coordinated cadastres will be feasible and desirable. While research (for instance, see (Ballantyne, Khan et al. 2000)) has uncovered several of the obvious advantages and disadvantages of a legal coordinated cadastre, a systematic investigation of the legal and technological aspects of such a cadastre is lacking. In order to determine whether a legal coordinated cadastre is feasible and desirable, a systematic study of the following items is required:

- A thorough understanding of the concept of land ownership that exists in the United States
- The ways in which a legal coordinated cadastre could be designed to complement this concept of land ownership.

- Shortcomings and problems that must be overcome during the design process before a viable legal coordinated cadastre can be created.

Cadastrals may be grouped into two classes based on how the locations of boundary corners are identified: physically monumented cadastrals; and legal coordinated cadastrals¹. A physically monumented cadastre is one in which boundary corners are definitively located on the ground by called-for physical monuments actually set in the ground, but are described in the cadastre by their coordinates as determined by survey. In such a system, title and boundary records may use coordinates to show the location of boundary corners and describe the parcel, but these title and boundary records will have unavoidable errors introduced because of measurement errors in the survey process. Thus the coordinates described in deeds and plans of record will be somewhat different than the true position of the called-for monuments set in the ground. (Surveyor's Board of Tasmania 2000) Examples of this system are Cadastre 2014 used in Europe and NELS used in the United States.

A legal coordinated cadastre is one in which boundary corners are definitively located only by coordinates, and such registered coordinates are indefeasible. Title and boundary records that use coordinates to define the location of boundary corners and describe the parcel are definitive. In this case, any monuments set in the ground to describe the location of a boundary corner will be somewhat different (because of unavoidable errors introduced by measurement errors in the survey process) than the true position of the definitive coordinate. At this time there appears to be no jurisdiction that

¹ The use of "legal coordinated cadastre" is described in Newsletter No. 5 June 2000 of the Surveyors' Board of Tasmania, Office of the Surveyor General, Tasmania. (Surveyor's Board of Tasmania 2000).

uses such a legal coordinated cadastre in which once a boundary corner is decreed to be located by a specific coordinate, the location of the boundary corner is thereafter definitive and unchangeable. (Note that the new Singapore cadastre, introduced in August 2004 (Singapore Land Authority 2004), was created to be the first legal coordinated cadastre in the world, however registered coordinates of boundary corners are not absolutely infeasible and may be corrected or adjusted under certain situations, and therefore do not meet the requirements and characteristics of the legal coordinated cadastre as defined in this dissertation. See further discussion below.)

Perhaps the most thorough investigation to date of the concept of a legal coordinated cadastre was performed by Brian Ballantyne et al (Ballantyne, Khan et al. 2000) in a report submitted to the Canadian Council of Geomatics (CCOG) in August 1999 entitled: “Coordinates in context: Technical, social & legal implications of using coordinates-only to define boundaries”. Ballantyne investigated whether a Canadian legal coordinated cadastre would be technically feasible, socially acceptable, or legally permissible, and discussed proposed legislation that might be necessary before such a cadastre could be instituted. Some of Ballantyne’s conclusions are:

1. Boundary corners may be definitively defined by either a coordinate or a monument set in the ground, but not by both. Thus monuments are not placed in the ground to mark boundary corner locations that are definitively defined only by coordinate.
2. There is a difference between defining a coordinate based on a national horizontal datum (e.g. The Canadian Spatial Reference System) and defining a coordinate expressed relative to regional or local control (e.g.

coordinates relative to existing township, section and quarter section monuments).

3. Integrated surveys are prescribed for many areas of Canada. Integrated surveys are those in which the position of all new monuments set in the ground to definitively define boundary corners are also described by coordinate. (In this dissertation, such an integrated survey is defined as a physically monumented cadastre.)
4. In a legal coordinated cadastre, a coordinate marking a boundary corner cannot be subservient to the monument, but such a coordinate may be subservient to the boundary. For instance, water bodies are features commonly used as boundaries. Since water bodies (such as “the water’s edge” or “the thread of the stream”) have a temporal dimension (i.e. their spatial location may change with time), coordinates can only be used to define the location of such a feature for a given point in time.
5. The quality of a legal coordinated cadastre depends on the quality of the national datum to which it is tied. Coordinates in a legal coordinated cadastre will be determined relative to control monuments the coordinates of whose locations have been previously determined by some geodetic governmental agency. The accuracy of coordinates marking boundary corners can be no better than the accuracy of the coordinates marking the location of the control monuments.
6. The use of GNSS to define coordinates may not be feasible in urban canyons. In urban areas large buildings may shield GNSS receivers from

parts of the sky, thus making it difficult for the receiver to communicate with GNSS satellites.

7. Owners of land whose boundary corners are defined by coordinates may attempt to determine the location of the boundaries of their land with their own GNSS receivers.
8. The action of plate tectonics on the Earth's surface must be monitored. Coordinate systems introduced in a legal coordinated cadastre must take plate tectonics into account, both for movement of the entire plate as well as relative deformation between points on the plate.
9. Through his research and investigations Ballantyne concluded that landowners want boundary corners marked on the ground with visible monuments.
10. Land surveyors may have reservations about the institution of a legal coordinated cadastre. Land surveyors may perceive that their role will be lessened in the retracing of boundary lines if a legal coordinated cadastre is introduced.
11. Land surveyors may support the institution of a legal coordinated cadastre. Cost savings to the consumer may mean more land surveying opportunities. The use of title insurance in place of using the services of a land surveyor may be reduced.
12. Even with the current paradigm that boundary corners are definitively marked by existing undisturbed monuments that are set in the ground and then are called-for in conveyance, the fact is that many boundary corners are

not marked on the ground with a monument. Such unmonumented corners are instead referenced by measurements to other controlling features or monuments.

13. The hierarchy of evidence and the action of prescriptive rights and adverse possession should not preclude the use of coordinates in a legal coordinated cadastre.
14. Boundary corners will be just as much “fixed” by coordinates in a legal coordinated cadastre as they are by called-monuments in the present paradigm.
15. In a legal coordinated cadastre, physical monuments set at boundary corners are merely the professional opinion of the land surveyor as to where the legal coordinate is located on the ground.
16. Tolerances of boundary lines are important. Some Canadian court cases have stated that a small encroachment of a building over a boundary line was of no consequence. Landowners must be aware that there is a difference between an encroachment in fact and an encroachment in law. Boundaries defined by coordinate in a legal coordinated cadastre will have some error and thus “ ...there will be a very thin, finite zone within which the boundary will lie.” (Ballantyne, Khan et al. 2000) page 2

2.2. Current Paradigm of Land Ownership And Location

Before designing a new legal coordinated cadastre, it is important to understand the current paradigm of land ownership and location.

2.2.1. Present Concept Of Land Ownership

The term “land” includes not only the soil and everything attached to it, but also the space beneath and above the surface. The classic concept is that ownership of land includes not only the surface of the Earth but extends infinitely upward and downward. (See Figure 1)

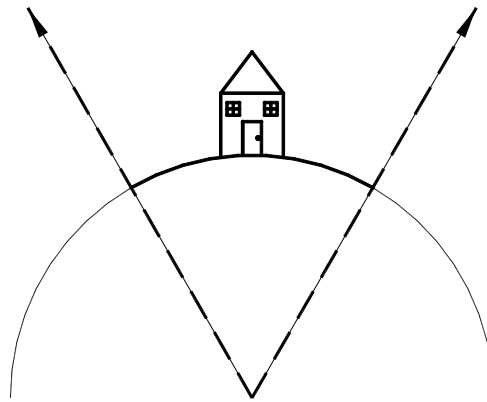


Figure 2.1 Concept Of Land Ownership Is Three-Dimensional

This concept has been modified in recent times so that ownership of land includes the space above and below the Earth’s surface, but only to the extent necessary for the enjoyment and exploitation of the property (Creteau 1977). Thus planes flying over a parcel of land are not encroaching on the rights of the landowner because the planes are flying above where the landowner might reasonably be expected to have actual control. For instance, in the Code of Federal Regulations, 14 CFR- Chapter I Part 91 Section 91.119 states:

Except when necessary for takeoff or landing, no person may operate an aircraft below the following altitudes:

...

(b) Over congested areas: Over any congested area of a city, town, or settlement ...an altitude of 1000 feet above the highest obstacle within a horizontal radius of 2000 feet of the aircraft.

(c) Over other than congested areas: An altitude of 500 feet above the surface, except over open water or sparsely populated areas. In those cases, the aircraft may not be operated closer than 500 feet to any person, vessel, vehicle, or structure.

...

The creator of a cadastre must therefore determine the limits of ownership above and below the Earth's surface. For instance, a reasonable limit might be 500 m above and below the surface of the Earth. (See Figure 2.2)

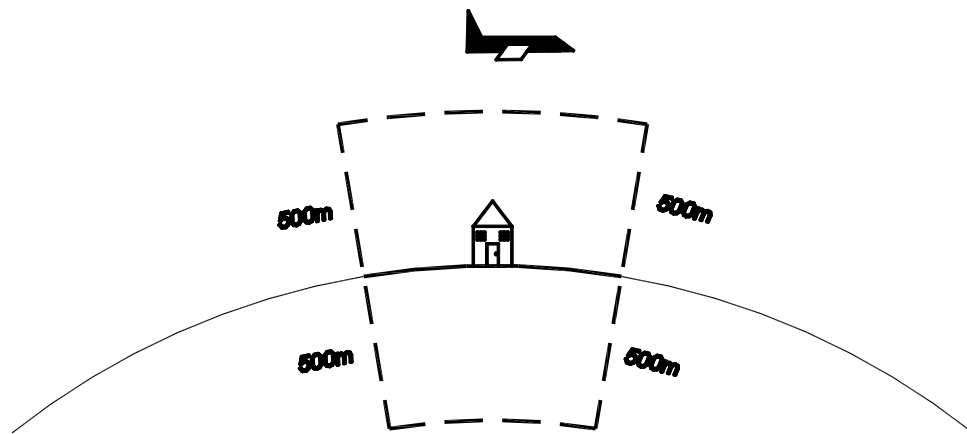


Figure 2.2 Vertical Limits To Land Ownership

Land ownership therefore consists of a volume or wedge of land. Such a wedge may be described through the use of two-dimensional surfaces that intersect the volume of ownership. Four surfaces that may be used are the terrain (or Earth's) surface, the horizontal plane, the ellipsoidal surface and the developed surface of the State Plane Coordinate System.

The terrain or Earth's surface is the most visible part of a parcel of land and therefore is arguably the most important surface on which to describe the volume of ownership. The current paradigm of parcel location is to set physical monuments such as

an iron pipe or IP) in the terrain surface at boundary corners or along boundary lines.

(See Figure 2.3)

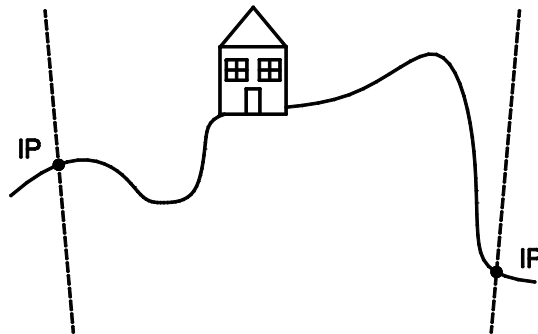


Figure 2.3 Terrain Surface

The horizontal plane is used when describing a parcel's dimensions and area.

American Jurisprudence (12 Am Jur 2d Boundaries § 53) (Lawyers Co-operative Publishing Company 1962) states:

In the absence of any specific statutory provision governing the manner of measurement of distances, distance is to be measured along the shortest straight line, on a horizontal plane...

Webster's dictionary (Gove 1986) has the following definitions:

Horizontal: *of or relating to the horizon*

Horizon: *1b2) The circle in which a plane perpendicular to the direction of gravity intersects the celestial sphere. 1b3) The plane tangent to the Earth's surface at the observer's location.*

Vertical: *2a) Perpendicular to the plane of the horizon*

Combining the two definitions of “horizon” gives the definition of “horizontal” as “of or relating to the plane perpendicular to the direction of gravity at the Earth’s surface”. (See Figure 2.4)

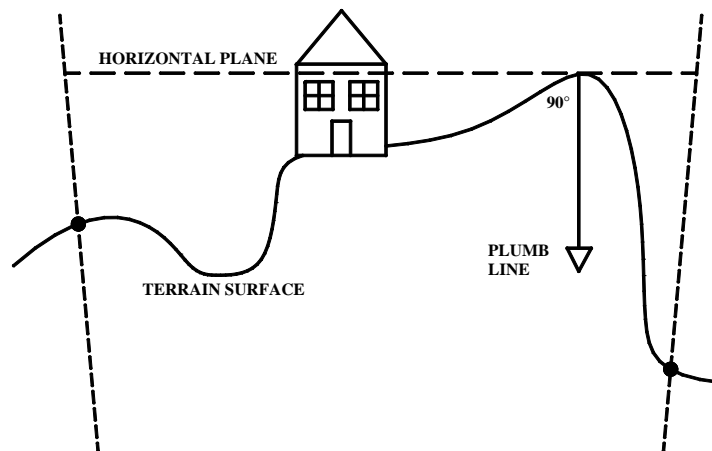


Figure 2.4 Horizontal Plane

For large parcels of land it is necessary to consider a third surface that models the curvature of the Earth. In the United States this surface is modeled by the GRS80 ellipsoid. The horizontal datum of geodetic latitude and longitude that was established using this ellipsoid is the North American Horizontal Datum of 1983 (NAD83). (See Figure 2.5)

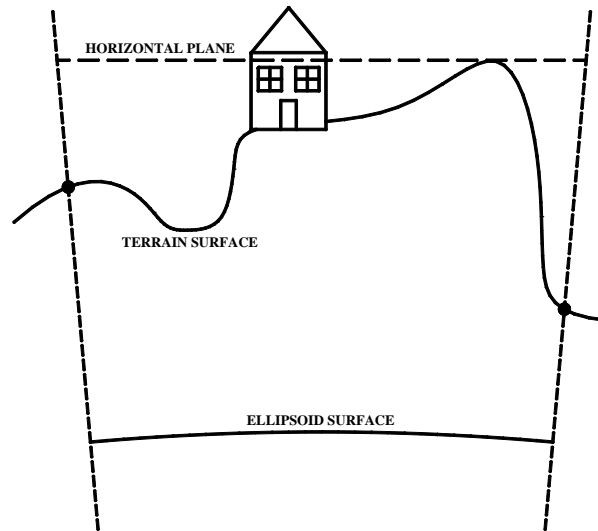


Figure 2.5 Ellipsoidal Surface

Determining positions, directions and distances using the ellipsoid surface involves lengthy and complex calculations. In the United States, the State Plane Coordinate System of 1983 (SPC83) was created to convert geodetic positions on the ellipsoid surface into plane rectangular coordinates. Computations can then be made by much simpler coordinate geometry formulas. The importance of this fourth surface is that in many U.S. states, the location of a parcel of land can be legally determined by a State Plane Coordinate (See Figure 2. 6). For instance, Massachusetts General Law Chapter 97 §17 states:

For the purpose of describing the location of any ...land boundary point in the commonwealth it shall be a complete, legal, and satisfactory description of such location to give the position of said...land boundary point on the Massachusetts Coordinate System.

Also Maine Revised Statutes Title 33 Chapter 13 §803-A states:

For purposes of describing the location of any survey station or land boundary corner in the State, it shall be considered a complete, legal, and satisfactory description of such location to give the position of the survey station or land boundary corner on the system of plane coordinates defined in this chapter.

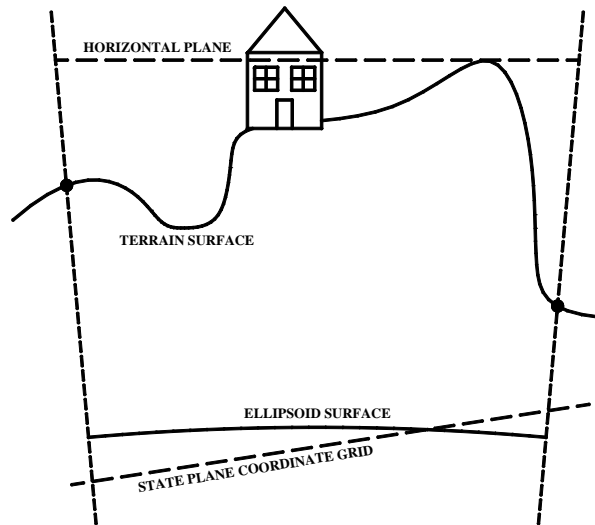


Figure 2.6 State Plane Coordinate Grid Surface

2.2.2. Proving Ownership

As land becomes more valuable, proving ownership is paramount for both location and usage of a parcel of land. Methods that have worked successfully in previous cadastres may no longer be as useful or interface well with technological advances. To understand this evolution, we first need to examine current methods of proving ownership.

2.2.2.1. Registration of Evidence of Title

One system of land ownership practiced throughout much of the Western world is where registration of evidence of title (deeds and other instruments of conveyance) is recorded at a Registry. To prove title requires that these evidences of title be used to show that all prior owners in the chain of title from the present owner back to the sovereign had good title for that parcel. This system of registration of evidence of title dates back to the time of the Norman Conquest of England by William the Conqueror.

William, Duke of Normandy, conquered England in 1066 and was crowned King of England and supreme lord of the land. During the next twenty years the Normans succeeded in expropriating the lands of the conquered English aristocracy but by 1088 the ownership of land in England was in chaos. While William had given land specifically to some of his Norman supporters, other land had been violently and unjustly seized by members of the Norman occupying forces. Many disputes over ownership of land erupted, especially between Normans who had rival claims to the same parcel of land. Many Normans attempted to take as much land as they could and then try to have the courts of that day legitimize their claims. William was forced to act because of the

confusion over land ownership and the many land disputes clogging the court system (Wood 1986). One purpose of the Domesday Book was to legitimize and settle the ownership of land in England. William had his clerks investigate and determine three things: who owned the various parcels of land at the end of the English reign in January 1066 just before the Norman conquest; when did the present owner take possession of the land; and who possessed the land as of 1086 when the Domesday Book was written. Normans claiming land were able to plead their case in court with the outcome being an “official” judgment on who owned the land in question. The Domesday Book listed all the Norman owners and described the land. Possession of land was approved only where William's authority had authorized it, whether directly or indirectly. The importance of the Domesday Book was that it legitimized all the land holdings in England. All the courts thereafter upheld the ownership claims of those named in the Book. In other words, to prove title an owner simply had to show that he had an unbroken chain of title (i.e. he could list all the prior owners and show that they all had good title to the parcel) back to the Norman listed in the Domesday Book. This tradition is still used today: to prove title to a parcel of land means to show an unbroken and good chain of title back to the sovereign. (Wood 1986)

Thus to prove title of ownership to a parcel of land requires that there be an unbroken and good chain of title back to the sovereign. In the colonial states between 1620 and 1789 the sovereign was the King of England, and after 1789 has been the individual US state in which the land is located. In states where land was patented by the GLO the federal government was the sovereign. Proof of title thus requires a determination of whether there is a “good” chain of title back to the sovereign. This

proof uses the evidence of title (deeds and other instruments of conveyance) that is registered at a Registry of Deeds.

2.2.2.2. Title by Registration

Another system of land ownership is one of title by registration rather than registration of evidence of title. This system is currently in operation in most of the British Commonwealth, including the six Canadian provinces (Service New Brunswick 2002) and Singapore, and in the United States in Massachusetts, Hawaii, and Minnesota. Three important principles of the system of title by registration are:

1. The Mirror Principle. The title register is a mirror that reflects accurately and completely the current facts about the title to a parcel of land: with certain overriding exceptions, the title is free from all adverse rights and qualifications unless they are mentioned in the title register.
2. The Curtain Principle. The title register is the sole source of information necessary to determine what rights an owner has to the parcel of land in question. These owners need not (and in fact should not) look beyond the curtain to determine rights that they or others have in the land.
3. The Assurance Principle. If the mirror fails through human frailty to give an absolutely correct reflection of the title and a flaw develops in the title, anybody who suffers loss as a result must be put in the same position, so far as money can do it, as if the reflection were accurate.(Service New Brunswick 2002)

Thus the difference between the title by registration system and the register of evidence of title system is that under the former, historic searches to determine adequacy of chain of title are not required, the government guarantees good title, and if the system makes a mistake the government will pay the injured party.

2.2.3. Location Of Boundary Corners

Proving ownership is not the only dilemma that faces the creator of a modern cadastre. Definitive locations of boundary corners are described by physical monuments set in the ground or by geodetic coordinates, each of which have advantages and disadvantages.

2.2.3.1. Physical Monuments as Boundary Corners

In the United States, the current paradigm is that physical monuments set in the ground by the original surveyor definitively locate boundary corners. The mere fact that a monument is set, and then is called for in a conveyance is enough to exactly locate that boundary corner.

“A monument set by the original surveyor and called for by the conveyance has no error of position. It is legally correct, in that only the description may be in error.”

(Robillard, Wilson et al. 2006) page 284

The public domain was originally vacant land in the United States that was held in trust by the government for the people. Perhaps three-quarters of the real property in the United States can be traced back to the public domain. Monuments set by duly appointed surveyors during the survey of the public lands definitively determined boundary corners.

“From...congressional legislation it is evident:

First. That the boundaries and subdivisions of the public lands as surveyed under approved instructions by the duly appointed surveyors, the physical evidence of which survey consists of monuments established upon the ground, and the record evidence of which consists of field notes and plats duly

approved by the authorities constituted by law, are unchangeable after the passing of title by the United States.

Second. That the original township, section, quarter-section, and other monuments as physically evidenced must stand as the true corners of the subdivisions which they were intended to represent, and will be given controlling preference over the recorded directions and lengths of lines.”

(Bureau of Land Management 1973) Section 1-20.

2.2.3.1.1. Unambiguous Location-Physical Monuments

Monuments set by the original surveyor and called for in a conveyance definitively locate that boundary corner and have no error. Problems arise if in the future this original monument is disturbed or destroyed, and thus the definitive location of the boundary corner is put in doubt. Another situation that may put the definitive location of the boundary corner in doubt is if there are several monuments in the general area, and it cannot be determined which of those monuments is the original, definitive monument and which is not. Therefore it is imperative that those monuments that locate definitive boundary corners be massive enough so that they are difficult to disturb, lose or destroy and descriptive enough so that other monuments will not mistakenly be used.

If physical monuments delineate boundary corners, and are so massive that they cannot be destroyed or are so descriptive that other physical monuments will never be mistakenly assumed to mark the boundary corner, then no other descriptor of the boundary corner is required (For instance, the highest point of the top of the bald ledge at the top of a mountain such as Mount Chocorua in New Hampshire might be such a massive, descriptive boundary corner physical monument.). However, few physical monuments are so massive or have such a unique description that their existence alone is sufficient to delineate a boundary corner location for all people for all time. Other descriptors rather than just the monument themselves are required so that interested

parties will know whether the monument still exists or whether a particular monument is the one that actually describes the boundary corner location. Historically, this has been accomplished in two ways: by the early method of conveying land ownership by livery of seisin, which used the ritual of “beating of the bounds”; and by the later method of land conveyance using descriptive words in written deeds.

The earliest method of transferring the ownership of land in our English heritage was by livery of seisin. To transfer land ownership, the grantor and grantee would go to the site with witnesses who were usually abutting owners and other neighbors. The grantor would, in a loud voice, describe the land being conveyed and what type of estate was being conveyed, and then would point out the boundaries of the property being transferred. The grantor would then formally “give” or “deliver” the seisin (or possession) to the new owner by handing him a twig or clod of earth as a symbol of the transfer (no formal written document was required). This symbolic delivery of the land would consummate the transfer of possession. (Creteau 1977)

With livery of seisin, the only way to know which physical monuments were boundary corners was to create “expert witnesses” who could remember and perpetuate which physical monuments were the boundary corners. These people would perambulate the boundaries of the parcel of land being conveyed through the method of livery of seisin and would ritually “beat” the physical monument with willow sticks. In order to ensure that successive generations would know the exact location of these boundary corners, young boys were brought along the perambulation and were imprinted with which monuments marked boundary corners. This imprinting was caused by performing some traumatic act on the child, such as holding the boy upside down and bumping his

head on the monument, switching the boy with the willow stick, or throwing the boy over hedges, into brambles or into ponds. (Cholesbury & St Leonard's Local History Group 2005)

In the sixteenth century the English Parliament enacted the “Statute of Uses”, which changed the method of land conveyances. Rather than having the parties meet at the site for a symbolic delivery of the seisin, a simple written deed could be executed. The parties could convey land without going on or even near the site. While monuments still were used to define the location of parcel boundary corners and lines, it was not necessary to view them in order for a conveyance of land to take place. Instead, a deed was used to model (in words) the parcel of land being conveyed. Rather than viewing a monument, a deed described the monument in words. Rather than walking alongside and viewing a boundary line, a deed described the boundary line with bearing, distances and calls for abutters. Rather than walking over the entire parcel to get a sense of its size, a deed described the size of a parcel in words by giving an area. (Creteau 1977)

Thus, regarding the location, shape and size of a parcel of land, the words in a deed had two purposes: to describe the monuments that marked boundary corner locations and to describe the parcel of land attributes of size and shape. Not only did the words in the deed describe the physical monument (material, shape, size, etc) but they would also provide evidence of the location of the monument by tying it to other physical monuments through the call for directions and distances in the deed. Thus if the boundary corner location were ambiguous because two monuments were found close to each other that each met the description provided by the words in the deed, then the

direction and distance to other called for monuments might give enough evidence to determine which of the two monuments did in fact mark the boundary corner.

2.2.3.1.2. Uncalled-for Monuments “Pincushion Corner”

The land surveying community has long known about the possibility of multiple monuments existing for a boundary corner for which the original surveyor did not set a monument and thus for which no monument was called for in the first conveyance of the parcel. Because of measurement errors and differences of professional opinion on the location of such an unmonumented corner, a surveyor may determine that the location of the boundary corner is different than the locations of uncalled-for monuments that already exist in the area. In general, land surveyors are divided on what to do in such a situation. Some feel that land surveyors should always set a monument marking their professional opinion of the location of the “not set” corner no matter how many other uncalled-for monuments exist in the general area. Others just as passionately advocate not setting a second (or third) monument if there is an existing uncalled-for monument in the general area of the location determined by their professional opinion.

2.2.3.1.3. Uncalled-for Monuments-National Integrated Land System

The FGDC Cadastral Data Content Standard addresses the issue of uncalled-for monuments and how to show them in the National Integrated Land System (NILS):

“...in some jurisdictions there are multiple monuments at corners while in other locations significant effort has been committed to establishing and maintaining a single monument for any corner. In these two cases, the first will use the three entities as described in this standard for a corner while the second would be able to collapse these three entities into one.”
(Federal Geographic Data Committee 2003) page 7.

The Bureau of Land Management further addresses this issue by the following definition of a “representative corner” (Bureau of Land Management 2000) page A-12:

“A *measured feature*, which has been chosen to be the corner position over other *measured features* in the immediate vicinity. (e.g. multiple, theoretical, porcupine)”

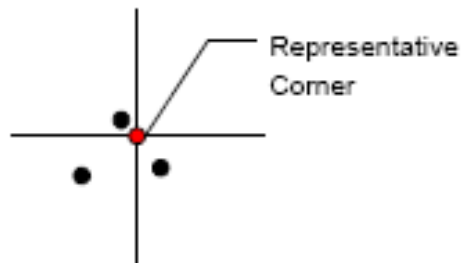


Figure 2.7 Representative Corner

Environmental Systems Research Institute, Inc., (ESRI), has partnered with the Bureau of Land Management to help create the NILS application software (Bureau of Land Management 2006). In its design of geodatabases to be used by NILS, ESRI has recognized that while there is only one boundary corner, there may be more than one monument marking that corner, and each monument may be described by more than one coordinate.

“This parcel model accommodates multiple monuments for corners and multiple coordinates for each monument. That is, a corner may be marked by more than one monument and a monument may have more than one coordinate.” (Arctur and Zeiler 2004) page 178.

2.2.3.1.4. Special Case: Monuments Set By Decree

Certain parcels of land in Massachusetts were originally created by the King of England in the early 1600s. For almost 400 years these parcels have been conveyed, subdivided, re-subdivided, combined, and recombined to their present owner and lot configuration. It is therefore reasonable to assume that the Land Court should be capable of guaranteeing the location of boundary corners of parcels of land for perhaps 1000

years or more after creating registered parcels. Since boundary corners are currently definitively located on the ground by physical monuments, the Land Court must be capable of guaranteeing the location of boundary corners for 1000 years through the use of such physical monuments. However, the Land Court realizes that these monuments may only exist for 20 years without being disturbed or destroyed (“A permanent monument is a monument that can reasonably be expected to remain stable for at least 20 years.” §2.1.3.5.2 2005 Manual of Instruction). To help perpetuate the location of definitive boundary corners through the use of physical monuments set in the ground, the Land Court uses a system in which the chain of the history of each record monument can be documented and a system in which if an insufficient number of undisturbed record monuments exists, a so-called S-Petition can be submitted in which a new judgment is issued by the Court, in effect re-registering the parcel.

Through the use of a chain of the history of record monuments and the S-Petition process, the Land Court perpetuates the location of record physical monuments that definitively locate boundary corners of registered parcels of land. While performing surveys for new registration or for the division of existing registered land, land surveyors will locate and use existing record physical monuments shown on prior Land Court plans. If such undisturbed monuments are deteriorating or in danger of being disturbed or destroyed, new physical monuments can be placed to replace the older monuments. The Land Court has realized the importance of describing the physical monument that marks the definitive location of a particular boundary corner as the monument has existed over the years.

In order to minimize the confusion and ambiguity of how and when existing physical monuments are located by land surveyors over time, the Land Court requires a statement on the status of existing monuments found by land surveyors. Any monuments shown on a plan submitted by a land surveyor must have one of the following statuses associated with it (§2.1.3.5.7.1):

- Found. A monument that was found and accurately located.
- Set. A monument that was set by the land surveyor as part of the current project.
- Disturbed. A monument that was found and located by the land surveyor, but that does not appear to be in its original location.
- Found-Not-Located. A monument that was observed to exist in the field, but was not accurately located.
- Not-Found. A monument that was known to exist in the past, but could not be recovered after a physical search of its purported location.
- Record. A monument that was known to exist in the past but whose existence was not confirmed because a physical search was not made.

Thus a land surveyor who has been surveying and locating the same physical monument over the years might report on the monument's status as follows (§2.1.3.5.7.2):

Stone monument: Set 04 May 1990; Found 15 July 1995; Found 12 February 1997; Found Disturbed 12 June 1999; Not Found 10 September 2002.

This method allows the Land Court to track the existence or non-existence of those physical monuments that locate definitive boundary corners.

Ultimately an insufficient number of undisturbed monuments may cause doubt concerning the proper location of boundary corners of registered parcels of land. In such cases the Land Court may require that an S-Petition be submitted, and if the Court allows the S-Petition, then a new plan will be allowed showing the boundary corners being definitively located on the ground by new physical monuments (§3.2). In many ways, the S-Petition process is much like the process used when registering land for the first time.

In summary, the Land Court realizes that while physical monuments may exist for 20 years, the requirement is that boundary corner locations must be guaranteed for much longer. The Court has instituted a process where the existence of such monuments may be tracked over the years as land surveyors locate that particular monument as they prepare surveys and plans for new registration of adjacent land or for subsequent divisions of existing registered land. In cases where an insufficient number of record monuments exist, there is a process where the Court may issue a new judgment to allow new monuments to definitively locate boundary corners. In any case, undisturbed physical monuments that mark the location of boundary corners through an order of judgment show definitive locations of the said boundary corners. Such undisturbed physical monuments show the exact, true location of a boundary corner and have no error.

2.2.3.1.5. Monument Survival in Urban Settings

Definitive boundary corners are currently located on the ground through the use of physical monuments set by the original land surveyor. If such an original physical monument is destroyed or disturbed, then the location of that definitive boundary corner is in doubt. Since a cadastre might be expected to last and be maintained for hundreds of

years, it is important to know how long such definitive physical monuments might exist undisturbed in an urban setting.

In early 2001 the Alberta Land Surveyors' Association (ALSA) commenced a study of the rate of destruction of monumented urban lot corners through field investigations of subdivisions in Calgary and Edmonton. (Alberta Land Surveyors' Association 2002) A total of 26 subdivisions were inspected, 15 in Calgary and 11 in Edmonton. Of these 26 subdivisions, 11 were subdivisions where monuments were immediately set prior to development and 15 were subdivisions where the setting of monuments was delayed to some later stage of development. All of the subdivisions had been registered between 3 and 12 years before the investigation. Approximately 750 lot corners were searched for. A typical search involved measuring to the lot corner and scanning for the monument using a metal detector. A positive scan was recorded as a "detected" monument. Monuments that were obviously problematic for scanning were exposed for confirmation. About 20-30% of the detected locations were exposed and inspected to determine monument condition and to look for evidence of disturbance.

Of all the lot corners investigated, 74% were "detected" and 95% of those detected monuments that were exposed and inspected were deemed to be "acceptable" or "intact". Assuming the 5% judged disturbed holds for the entire sample, ALSA estimated a global "reliability" rate of 70%. ALSA found the reliability rate for the delayed setting of monuments to be 68% in Edmonton and 78% in Calgary.

Assuming that the average age of these physical monuments was 10 years (the age range was in fact 3 to 12 years), then the rate of destruction of monuments set after development was 22% in 10 years for Calgary and 32% in 10 years for Edmonton.

Assuming further that these rates are constant over time, then the time it will take for half of the original monuments set after development to be destroyed will be about 30 years for Calgary and 20 years for Edmonton. (This compares favorably with the Massachusetts Land Court assertion that a permanent monument can be expected to remain stable for at least 20 years, if the definition of “expected to remain stable” is assumed to be that 50% of permanent monuments will still exist 20 years after being set.)

2.2.3.2. Geodetic Coordinates As Boundary Corners

In the previous sections, we discussed some of the ramifications encountered with traditional methods of boundary corner location. We will now discuss an application of the use of mathematical monumentation , applying both current technology and proposed future technology to define boundary corners based on geodetic coordinates.

2.2.3.2.1. Proposed Use Of Geodetic Coordinates

Within the past fifty years, the concept that a geodetic coordinate could be used to definitively mark the location of a boundary corner was introduced. Model statutes were written that could be used in the United States by individual states that wished to have a State Plane Coordinate System (Stem 1983). For instance, the Commonwealth of Massachusetts is a state that used the model statutes to create Massachusetts General Law Chapter 97 §17, which states:

For the purpose of describing the location of any ...land boundary point in the commonwealth it shall be a complete, legal, and satisfactory description of such location to give the position of said...land boundary point on the Massachusetts Coordinate System.

States that have enacted statutes that closely paraphrase the model statutes are:

Connecticut	Delaware	Kentucky
Louisiana	Maine	Massachusetts
Michigan	Mississippi	New Mexico
North Carolina	Rhode Island	South Dakota
Tennessee	Vermont	Virginia

Table 2.1 States With Statutes

(Several other states imply that geodetic coordinates may be used in marking boundary corners without specifically saying that the coordinate is a “complete, legal, and satisfactory description of such location”, while others allow geodetic coordinates to be used to define boundary corners, but not if in conflict with a corner created by the US Public Land Surveys.)

If geodetic coordinates definitively mark the location of boundary corners, then there is no need to use any other descriptor other than the coordinate. The geodetic coordinate is “massive” in that it can never be destroyed, and is “descriptive” in that it can never be confused with any other geodetic coordinate. Unlike for physical monuments, there is no need for descriptive words of distance and direction to help determine which geodetic coordinate is the boundary corner: the geodetic coordinate alone is adequate. However, there are certain problems that might arise by using geodetic coordinates instead of physical monuments to definitively mark the location of boundary corners.

2.2.3.2.2. Current Use of Geodetic Coordinates

While many US states allow by statute the use of a SPC to definitively describe the location of a boundary corner, there is no indication that this is being done. SPC (or geodetic coordinates) are not being used (except in the Singapore legal coordinated cadastre, which has technical and legal issues that will be explained further in the dissertation) to definitively describe a boundary location if it is possible to instead describe the location by using a physical monument set in the ground. The only actual use of a geodetic coordinate to definitively describe a boundary corner has been in regions where it is physically impossible to set a physical monument in the ground (such as where the ground is covered by the deep ocean). For instance, one such use has been to describe the maritime boundary in the Gulf of Maine between Canada and the United States of America.

In 1984 the International Court of Justice was charged with creating the line of delimitation by a single boundary for the continental shelf and the exclusive fishing zones between Canada and the United States in the Gulf of Maine (International Court of Justice 1984). Both Canada and the United States proposed to use physical monuments (such as the coasts of Maine, Massachusetts, and Nova Scotia, the Northeast Channel, Georges Bank, and “the line of greatest depths” of the ocean) in defining the line of delimitation. The Court however determined that:

“... given the unity and uniformity of the sea-bed, there are no geomorphologic reasons for distinguishing between the respective natural prolongations of the United States and Canadian coasts in the continental shelf of the delimitation area: even the Northeast Channel, which is the most prominent feature, does not have the characteristics of a real trough dividing two geomorphologically distinct units... the {Court}, however, is not convinced of the possibility of discerning, in so fluctuating an environment as the waters of the ocean, any natural boundaries capable of serving as a basis for carrying out a delimitation of the kind requested... The {Court} considers that, having regard to all those considerations, it must put forward its own solution independently of the Parties.”

The International Court of Justice in its judgment used geodetic coordinates to definitively describe the line of delimitation of the maritime boundary in the Gulf of Maine area (International Court of Justice 1984):

“That the course of the single maritime boundary that divides the continental shelf and the exclusive fisheries zones of Canada and the United States of America in the Area referred to in the Special Agreement concluded by those two States on 29 March 1979 shall be defined by geodetic lines connecting the points with the following co-ordinates:

<i>Points</i>	<i>Latitude North</i>	<i>Longitude West</i>
A.	44° 11' 12"	67° 16' 46"
B.	42° 53' 14"	67° 44' 35"
C.	42° 31' 08"	67° 28' 05"
D.	40° 27' 05"	65° 41' 59"

Table 2.2 Points Delimiting Maritime Boundary Between Canada & U.S.

While it may be possible to legally describe a definitive boundary location only by using a SPC or geodetic coordinate, research indicates that this method is not being used if instead it is possible to use a physical boundary that is set in the ground. Geodetic coordinates have been used to definitively describe a boundary location in the deep ocean.

2.3. De Minimis Encroachment Over Registered Land

Under Title by Registration systems of land ownership, the Mirror Principle states that the title register is a mirror that reflects accurately and completely the current facts about the title to a parcel of land, and that unless they are mentioned in the title register, the title is free from all adverse rights and qualifications. The Curtain Principle states that an owner need not look beyond the curtain to determine rights that others may have to the land. As noted above for the Massachusetts Land Court Title by Registration System, every owner of registered land holds the land free from all encumbrances except for those noted in the Certificate of Title (M.G.L. c. 185, §46). No person may gain title or an easement or other right in another person's registered land by prescription or adverse possession (M.G.L. c. 185, §53). Thus it would appear that no encroachments over registered land would be allowed, and such encroachments would be ordered to be removed.

However, there are a category of "exceptional cases" where an order to remove the encroachments was not mandated. These exceptional cases may arise "...where the unlawful encroachment has been made innocently, and the cost of removal by the defendant would be greatly disproportionate to the injury to the plaintiff from its continuation, or where the substantial rights of the owner may be protected without

recourse to an injunction, or where an injunction would be oppressive and inequitable...” (Goulding v. Cook, 422 Mass. At 277 n.3, quoting Peters v. Archambault, 361 Mass. 93 (1972)). Included in the category of exceptional cases is where the encroachment is “trivial” or de minimis in nature (Capodilupo v. Vozzella, 96-P-1788 Massachusetts Appeals Court).

Massachusetts and Hawaii have taken different approaches to de minimis encroachment over registered land. The Hawaii legislature has enacted a statute to deal with de minimis encroachments over registered land, while Massachusetts has relied on case law.

2.3.1. De Minimis Encroachment over Registered Land: Hawaii

Hawaii has legislated the definition of de minimis encroachment over registered land, and what the ramifications of such an encroachment are:

- In the statute, de minimis encroachment is known as “de minimis structure position discrepancy”. The definition of “de minimis structure position discrepancy” is:
 - “For commercial property, industrial property, and multi-unit residential property, 0.25 ft;
 - For all other residential property, 0.5 ft;
 - For agricultural and rural property, 0.75 ft;
 - For conservation property, 1.5 ft;

between the locations of an improvement legally constructed along what was reasonably believed to be the boundary line and the actual location of the

boundary line based on the most recent survey.” (Hawaii Revised Statutes Annotated §669-11)

- This statute applies “...to all structure position discrepancies without regard to when the facts or actions giving rise to the discrepancy occurred.” (1997 Haw. Sess. Laws, Act, 131, § 5, as amended by 1999 Haw. Sess. Laws, Act 185, § 4)
- “A de minimis structure position discrepancy shall not be considered an encroachment or a basis for zoning violation;” (Hawaii Revised Statutes Annotated §669-12)
 - However: “If real property subject to this section is owned by a county, any improvement within a de minimis structure position discrepancy shall be removed at the expense of the property owner who constructed the improvement...” (Hawaii Revised Statutes Annotated §669-13)

Thus a structure position discrepancy can happen at any time and will not be considered an encroachment if it exists within a minimum of 0.25 ft of the registered land boundary line.

2.3.2. De Minimis Encroachment over Registered Land: Massachusetts

Encroachments over land that have been decreed as de minimis are described in various Massachusetts Appeals Court and Supreme Court decisions (as described in Capodilupo v. Vozzella, *supra*):

1. Encroachment was not insignificant, but plaintiff only had a short time left on his lease. (Lynch v. Union Inst. For Sav., 159 Mass. 306, 310 (1893))

2. Bulge of a building encroached by only one-eighth to one-quarter inch. (Tramonte v. Colarusso, 256 Mass. 299, 301 (1926))
3. Encroachment of a sewer pipe under a six-inch strip of plaintiff's land did not affect plaintiff's beneficial use of the property. (Loughlin v. Wright Mach. Co., 273 Mass. 310, 315-316 (1930))
4. A few bricks imbedded in the defendant's wall encroached only a few inches into plaintiff's wall. (Triuzi v. Costa, 296 Mass. 24, 28 (1936))
5. The maximum encroachment was four inches. (Goulding v. Cook, *supra* (1996))
6. The maximum encroachment was 4.8 in. (Capodilupo v. Vozzella, *supra* (1999))

In Capodilupo v. Vozzella, the encroachment was over registered land. The decision was that even though the encroachment was over registered land, and by statute, every owner of registered land holds the land free from all encumbrances except for those noted in the Certificate of Title (M.G.L. c. 185, §46), in this case the encroachment of 0.40 ft (4.8 in.) over registered land was determined to be de minimis. (Note that in Massachusetts it is still necessary to have the court determine whether an encroachment is de minimis on a case by case basis.)

2.3.3. De Minimis Encroachment: Summary

In summary, under the Mirror and Curtain Principles of Title by Registration, encroachment over registered land is not allowed. However, by case law in Massachusetts and by statute in Hawaii, a land owner abutting a registered parcel of land does have certain unwritten rights over that abutting registered land within a small

distance of the boundary line. In Massachusetts this right is for encroachment of up to 0.40 ft (4.8 in.) (However, each encroachment must be litigated to see if it meets the de minimis criteria.). In Hawaii an abutting land owner has the right to encroach over registered land by between 0.25 ft and 1.5 ft.

2.4. Cadastre 2014

Cadastre 2014 moves beyond the current system of creating a land cadastre and incorporates use of both physical monuments and coordinates to define property of land parcel corners. However, it is still only a model of what actually exists on the ground.

2.4.1. Description

Cadastre 2014 is an improvement over traditional cadastre systems. In Europe, most countries have a land recording system consisting of cadastre and land registration components, with the land registration component being much like that practiced by the Massachusetts Land Court. In these European systems, the land surveyor creates a plan of the boundary parcel being registered. The parcel is located on the ground through the use of physical monuments that are set in the ground to mark the definitive locations of boundary corners on the parcel. These physical monuments have either been previously decreed by the an earlier registration process in which case the land surveyor will have found and located them for his plan, or the monuments will be newly set by the land surveyor and their locations will become definitive boundary corners of a newly registered parcel of land after being duly decreed by the Court.

As previously discussed, the surveyor's plan will not in itself show the definitive location of the registered parcel, instead it will describe the physical monument whose

location on the face of the Earth is the definitive location of a boundary corner.

Boundary measurements between these definitive physical monuments as shown on the surveyor's plan are also a model of reality.

In the traditional cadastre systems, the cadastre would be created by compiling these individual surveyor's plans into a large-scale map showing the outlines of the properties. Some problems with this system were in keeping the cadastre current and up-to-date, and in having cadastre maps in a format (e.g. scale) that would be useful for all users. Another problem was that the land registration component and the cadastre component were often separately administered by different governmental agencies.

Cadastre 2014 improves on the traditional cadastre systems. The location of boundary corners of registered parcels of land will still depend on the decreed physical monuments set by land surveyors as part of the land registration. The land surveyor will still create a surveyor's plan of the parcel to be registered, which again is still only a model of the reality of the parcel. However, Cadastre 2014 will add the requirement that during the process the land surveyor must determine coordinates of the boundary corners on the parcel (Both for boundary corners whose definitive locations are marked on the ground by decreed physical monuments, and for boundary corners whose definitive locations are not marked on the ground by physical monuments.).

This requirement will not be foreign to land surveyors. As discussed previously, most surveyors use coordinates as part of the analysis of survey field work and the determinations of boundary parcels, the only difference being that the coordinates required for the cadastre must be referenced to the national coordinate system on which the cadastre is based. As discussed previously, these coordinates will merely model the

location of the parcel boundary corners, which will be definitively located on the ground by decreed physical monuments. There will be error in the coordinates.

After creating coordinates through the analysis of field data and determination of boundary corners of parcels, the land surveyor typically will create a plan of the results of the survey. Distances and directions of boundary lines will be calculated mathematically by using these coordinates. This plan will be used in the land registration process. In a traditional cadastre the plans would then be compiled into a large scale map. Cadastre 2014 is proposing instead to create a database of coordinates, and instead of creating a map of the cadastre will instead create a model of the cadastre. The model will consist of the database of coordinates. Users will be able to create their own maps for a specific instant in time, at any scale desired, for any portion of the cadastre by querying the database for official coordinates and having software that will mathematically calculate distances and directions of parcel boundary lines and parcel areas. Cadastre 2014 will therefore be a digital model of the cadastre from which users will be able to create their own maps. Land parcels created and described in the land registration process can easily be related to the cadastre, effectively allowing one governmental agency to combine the tasks of administering the land registration process and the cadastre.

Cadastre 2014 is based on the “fixed boundary system” [(Kaufmann and Steudler 1998) page 29], which means that boundaries are located by coordinates that are surveyed and not by a description of the decreed physical monuments (whose locations on the Earth’s surface will still be the definitive locations of boundary corners). Thus Cadastre 2014 is a model of the registered land parcels that exist for a country. The true, actual reality of the registered land parcels still depends on the location of decreed physical

monuments set in the Earth's surface that mark the definitive location of boundary corners.

2.4.2. Example of Cadastre 2014: The Austrian Cadastre

(Pfahler and Meixner 2007)

The history of the Austrian cadastre started as far back as 1817. The current surveying law was introduced in 1969 and since 1989 the cadastre has been modeled by the digital cadastral map. The Austrian cadastre covers about 84,000 square km (a little less than the area of the State of Maine). Within this cadastre there are about 8 million inhabitants, 10.5 million land plots, 3 million registration units, 139 land registration courts that administer the land registration process, 41 federal surveying offices that administer the cadastre, and about 300 chartered surveyors (referred to as chartered engineers in the law). Each year about 30,000 new parcels are created by the subdivision process.

Most changes to the cadastral model are the result of subdivisions of land plots, determination of boundary lines that are being contested by adjoining owners, and reestablishment of boundary corners by setting new physical monuments to replace those official physical monuments that have been lost, disturbed or destroyed. Much of this work is performed by the private sector (the chartered surveyors) rather than by the public sector (the land registration courts). This reduces the cost to the state agencies and shifts the cost to the users who hire a private chartered surveyor to perform the survey and create the surveyor's plan that eventually is used to change the cadastre.

The procedure starts with the need to redefine parcel boundaries, for instance by subdivision of existing registered parcels, by determining the location of a boundary line

between adjoining owners when there is a conflict in where the boundary line is located on the ground, and by reestablishing official physical monuments marking the definitive boundary corners of registered parcels when such monuments are lost, disturbed or destroyed. A chartered surveyor is contracted by the client to perform a survey of the parcel and prepare a surveyor's plan showing the parcel resulting from the survey. In a process much like the ancient procedure of livery of seisin, all the interested parties (adjoining owners and others) are required to meet at the land in question, at which time the chartered surveyor presents his findings on the boundary situation. Visible boundary marks (those physical monuments that are either found and marked or set and marked) allow the interested parties at the meeting to see where the proposed boundary lines or boundary corners are located on the ground. The interested parties must then agree to the boundaries on the ground and to the parcel of land as established by the chartered surveyor and shown on the surveyor's plan, and sign such an agreement that is then witnessed by the chartered surveyor. The plan must also include coordinates for boundary corners so that the parcel may be placed into the digital cadastral model. The plan and signed agreement is then submitted to the federal agency for surveying, which will use the surveyor's plan to change the cadastre. A copy is also registered with the land registry. Such a surveyor's plan with the signed agreement has the same authority as if a judge at the land registration court had decreed the parcel through a court hearing. Chartered surveyors are liable without limitation for all damages resulting from mistakes in the content of the surveyor's plans and other authoritative documents. If an agreement is not signed by all the participants then the case will be heard at court and a judge will decide the issue.

Thus in Austria the cadastre is a digital model of the registered parcels of land. Official physical monuments set in the ground definitively mark the location of boundary corners. In the cadastre these boundary corners are modeled by coordinates determined by chartered surveyors. While the geometry of the registered lots (directions and distances of boundary lines and area of the parcel) are the same as that decreed by the land registration courts (the courts use the surveyor's plan in the registration process), the coordinates shown in the cadastre only show the approximate location of boundary corners. (As previously discussed, the boundary lines shown on the surveyor's plan also are approximate, and since the surveyor's plan is used in the registration process, the decreed boundary lines and area are also approximate, even though they are decreed by the courts).

2.5. National Integrated Land System²

In the United States, NILS uses a similar approach to Cadastre 2014. While there is no land registration component in the Public Lands Survey System, a process was used in which public lands were subdivided into lots that completely tiled the region so that every point in that region had to be located within one and only one lot. When created, the lots were definitively marked on the ground with physical monuments. The Bureau of Land

² In September 2009, the Bureau of Land Management informed the Department of the Interior of its decision to retire the National Integrated Land System. In 2009, BLM conducted a functional Gap Analysis to determine whether NILS meets the BLM's core business requirements and performs efficiently. The BLM concluded that given significant problems with functionality, data performance, and usability, NILS was not ready for production and failed to meet BLM's business needs. The BLM decided to immediately start the process of retiring NILS, to develop a new national integrated system that would meet BLM's Land and Minerals requirements, and to continue to support the GeoCommunicator until a suitable replacement system could be found to meet the BLM's business requirements. (This information was found on the Federal IT Dashboard, an official website of the United States Government, which showed that the Department of the Interior had downgraded the status of the BLM-National Integrated Land System. See http://it.usaspending.gov/?q=content/eliminated-downgraded&agency_id=010 that was accessed on August 18, 2010.)

Management administers the PLSS, which includes administering rights given to others over the public lands such as mining rights, grazing rights, etc. NILS was created as a digital model of the PLSS. Users can make their own maps from this model. The locations of corners of lots are modeled in NILS by coordinates stored in the NILS database (although definitive locations are still marked on the ground by physical monuments). The coordinates in the NILS database are continually updated through a least-squares adjustment using survey data of the locations of decreed physical monuments as they become available. The result is that the model coordinates of boundary corners will continually become a more accurate representation or model of the actual locations of the decreed physical monuments that definitively mark the locations of boundary corners. NILS is a cadastre in which information on licensing rights to use public lands is stored in a database and locations of lots is administered through the use of a data model of coordinates stored in a database, both of which are combined to relate the licensed rights to a specific parcel on the ground.

NILS is a parcel based cadastre that uses the concept of a “fabric” in which the collection of parcels shares geometry at common corners and boundaries to create a seamless model of parcels. When features are edited, a change to one geometric element such as a point or line will affect the shape and location of all parcels topologically connected to the edited feature. Thus as new feature data acquired by more accurate techniques is added, the accuracy and reliability of the cadastral model should increase. The cadastre will never be finished, as the location of parcel boundary corners and distance and direction of boundary lines continually change as new data is added.

NILS does not change the way cadastral surveys of public lands are performed. The Manual of Surveying Instructions, first printed in 1855 with the 2009 edition being current, describes how physical monuments set in the ground control boundary corners, and the procedure on how lost or obliterated corners are restored to their original location. The procedure to create and update NILS starts with those physical monuments that control boundary corners as found or restored by cadastral surveyors using the Manual of Surveying Instructions.

The NILS process (called the GeoCommunicator) starts with the Survey Management component where cadastral surveyors perform a field survey locating the positions of these physical monuments (called “measured features” in NILS) by measuring angles, measuring distances, measuring locations by determining coordinates using GNSS, and measuring azimuths. Since all measurements have error, additional information about the measuring equipment is collected to help quantify the error for each mode of measurement.

The Measurement Management component of NILS is used next. A survey traverse is created from this field survey and an iterative parametric least squares adjustment of the traverse is performed so that each located physical monument will have a distinct set of coordinates with uncertainty or reliability of position being described by error ellipses. The end result of the Measurement Management component is the “feature fabric” showing coordinates and coordinate reliability that models the location of each physical monument (or “measured feature”) that controls the actual definitive location of a boundary corner.

The Parcel Management component is used next to either create or modify a parcel in NILS. After an initiating event occurs (such as a deed being recorded), the process of verifying the parcel begins:

1. If the deed includes a cadastral surveyor's plan of the parcel in digital form, then the parcel will be entered in NILS (subject to verification);
2. If the plan is not digital, then survey tools such as COGO will be used to enter the parcel into NILS (subject to verification);
3. If a deed is recorded with no plan, then survey tools such as COGO will be used to traverse the boundary of a metes and bounds description, or a pre-defined subdivision rule will be applied to the parent parcel (e.g. "quarter of a PLS section"). These tools will be used in an iterative way as needed until the proposed parcel "closes" and otherwise properly describes the land being described by words in the deed.

The end result of this verification process is the creation of a Legal Description of the stand-alone parcel described by deed or plan that "closes" and adequately shows the parcel called for in the deed or plan.

After the Legal Description is created for the stand-alone parcel, the next step of the Parcel Management component is to edit the Legal Description Fabric. This step resolves gaps and overlaps that might occur when the new Legal Description of the parcel is inserted into NILS. The procedure is to readjust the coordinates of the existing Feature Fabric to reflect data of the new Legal Description that is being added to NILS. As more accurate data is added to NILS by adding the new Legal Description for a new parcel,

then the seamless Legal Description Fabric of NILS will become more reliable and accurate.

The final step is to create the Parcel Fabric from the Legal Description Fabric, since a parcel of land ownership may consist of an association or aggregation of several Legal Descriptions in the Legal Description Fabric. Thus NILS is a parcel based cadastre that uses the concept of a “fabric” in which the collections of parcels share geometry at common corners and boundaries to create a seamless model of parcels.

2.5.1. National Geodetic Survey and NILS

The National Spatial Reference System (NSRS) is the official system of the Federal government, which allows a user to determine geodetic latitude, longitude, and height, plus orthometric height, geopotential, acceleration of gravity, and deflection of the vertical at any point within the United States or its territories. One mission of the NGS is to define, maintain, and provide access to NSRS. (NGS 10 year plan)

In 2007 NGS performed a new realization of NAD83, originally given the name “NAD 83 (NSRS2007)” but subsequently shortened to NAD83(2007), in which coordinates were determined for 70,000 nationwide passive geodetic control monuments. However, in the future, NGS will not actively pursue the installation of new passive monuments nor the maintenance of these passive marks for the definition of NSRS, and instead will regard these passive monuments as “tied to the NSRS” instead of “part of the NSRS”. Instead, NGS will be transitioning to a more virtual NSRS by having the Continuously Operating Reference Station (CORS) network serve as the sole means of defining points (Cartesian and ellipsoid coordinates) in the horizontal datum as well as defining the vertical datum using a geopotential datum based on CORS and a gravimetric

geoid rather than using passive benchmarks attached to the ground. CORS will become the primary method of maintaining and accessing the geometric (Cartesian and ellipsoidal) coordinates of the NSRS when using GNSS technology.

In the past NGS had added new, and maintained existing, passive geodetic control monuments through a rigorous process called “bluebooking”, after which the information about these passive monuments was entered into the NGS Integrated Database to become a part of NSRS. While the bluebooking procedure will cease to be used in a few years, NGS has created a new procedure called Online Positioning User Service Database (Opus-DB) in which information about passive control monuments can be entered into the NGS Integrated Database by using information gathered in the field by surveying professionals who are not necessarily in the employ of NGS. Monuments entered into the NGS Integrated Database through the Opus-DB procedure will not be part of the NSRS, but can be thought of as “tied to the NSRS”.

While NGS will not be collecting data in the field in the OPUS-DB procedure, it will be involved in the quality control of the final OPUS-DB submission that will go into the NGS Integrated Database. In order for NGS to accept and publish information about a passive monument into the Database, certain criteria must be met (National Geodetic Survey 2010):

- The passive monument must be stable, permanent, unique, recoverable, and safe;
- The GNSS data requirements are that they be “OPUSable” and consist of more than four hours of dual frequency GNSS data using an NGS calibrated antenna;

- GNSS data must be run through OPUS and the solution must have:
 - More than 70% of observations used;
 - More than 70% of ambiguities fixed;
 - Less than 0.04 m horizontal peak to peak;
 - Less than 0.08 m vertical peak to peak;
 - Less than 0.03 m RMS;
 - Used the IGS precise (or rapid) orbits (available the next day);
- Photos of the mark and the equipment as set up must be provided;
- Details of the mark such as name, type, and stability must be provided;
- A description must be provided to aid in the recovering of the mark;
- Information about the registered user submitting the data must be provided including name, address, agency, and amount of experience in using GNSS equipment and in using OPUS;
- Prior to publication in the Database, the OPUS results are emailed to the registered user who then must review the results and notify NGS that all the information is correct and that NGS may proceed to publication;
- NGS verifies that GNSS data meets requirements using the Opus statistics, and reviews photos and descriptions;
- The agency reviews that the final datasheet meets requirements.

Users of the published data in the NGS Integrated Database are warned of important databases notes:

- Positions are individually generated from non-redundant OPUS solutions;
- Errors may exist;

- Error checking is the responsibility of the data publisher;
- The datum for ellipsoidal coordinates may differ from that used for other marks in the NGS Integrated Database; and
- Orthometric heights are derived from GNSS and the geoid model used by OPUS.

One of the uses proposed by NGS for OPUS-DB is to archive the position of PLSS monuments. (National Geodetic Survey 2010) Thus OPUS-DB could be used by NILS to not only show the coordinate location of a PLSS monument, but also to show a photo of the monument and provide a description to aid in recovering the monument.

2.6. Title by Registration

Land location and ownership can also be adjudicated. Several states in the United States have some form of “Title by Registration”, whereby the legal system within the state decrees title to a parcel of land. The most familiar of one is the Massachusetts Land Court.

2.6.1. The Massachusetts Land Court

In 1898 the Great and General Court of Massachusetts created the Massachusetts Land Court (the Land Court), which was established to implement the Massachusetts version of the Torrens System of Land Registration (Buscher 1998) (The jurisdiction of the Massachusetts Land Court is found in Section 1 of Chapter 185 of the Massachusetts General Laws (M.G.L. c.185, §1).). Two of the functions of the Land Court are to adjudicate land title *in rem* (against the whole world) and to adjudicate boundaries. The judgment of registration contains a description of the land as finally determined by the Court (M.G.L. c. 185, §47). The Court may “require a further survey be made for the

purpose of determining boundaries and may order durable bounds to be set, and referred to in the complaint, by amendments.” (M.G.L. c. 185, §33). Every owner of registered land holds the land free from all encumbrances except for those noted in the Certificate of Title (M.G.L. c. 185, §46). No person may gain title or an easement or other right in another person’s registered land by prescription or adverse possession, nor shall a right of way by necessity be implied under a conveyance of registered land (M.G.L. c. 185, §53). For every registered parcel of land, the Massachusetts Land Court now and forevermore guarantees who the registered owner is, and where the boundaries of the parcel are located on the ground.

2.6.2. State of Minnesota

The Minnesota version of the Torrens System of Land Registration is described in Minnesota Statutes, Chapters 508 and 508A. The Minnesota Torrens System and the Massachusetts Torrens System are similar. Some Minnesota statutes are:

“...every decree of registration shall bind the land described in it, forever quiet the title to it, and be forever binding and conclusive upon all persons...” Minnesota Statutes, section 508.22;

“Every person receiving a certificate of title pursuant to a decree of registration and every subsequent purchaser of registered land who receives a certificate of title in good faith and for a valuable consideration shall hold it free from all encumbrances and adverse claims, excepting only the estates, mortgages, liens, charges, and interests as may be noted in the last certificate of title in the office of the registrar...” Minnesota Statutes, section 508.25;

“No title to registered land in derogation of that of the registered owner shall be acquired by prescription or by adverse possession...” Minnesota Statutes, section 508.02;

“An owner of registered land ... may apply...to the court to have all or some of the common boundary lines judicially determined. ... Before the issuance of any final order determining the location of the owner’s boundary lines, the court shall fix and establish the boundaries and direct the establishment of judicial landmarks in the manner provided by section 559.25. The final order shall make reference to the boundary lines that have been determined and to the location of the judicial landmarks that mark the boundary lines...” Minnesota Statutes, section 508.671.

However, unlike the Massachusetts Torrens System, the Minnesota Torrens System includes an alternative method to register land where there is an uncontested title in the land. This alternative method may be used by an owner of a fee simple estate who (1) has been found on examination by the examiner of titles to be the record owner of the land described; and (2) has satisfied the examiner of titles that the owner is in actual or constructive possession of the land described.

The purpose of this alternative is to provide a voluntary procedure for registration of certain possessory estates in land with certainty, at reasonable cost and speed, and without the necessity for the initial adjudication required by chapter 508. (Minnesota Statutes, section 508A.01) With this alternative, the owner does not immediately receive a certificate of title, but instead starts the registration process by receiving a certificate of possessory title (“CPT”). A CPT means that the land is registered subject to the rights of persons in possession, if any, and rights which would be disclosed by a survey but

protects the registered owner from losing title by prescription or adverse possession after the date of the first CPT (Minnesota Statutes, section 508A.02).

Any person subsequently claiming a right of possession or a right that would be disclosed by a survey in this land on which a CPT was issued, may file with the registrar of titles a verified claim of the unregistered interest. The person with the unregistered interest then has ten years to petition the court to adjudicate the matters alleged in the statement or claim. If the person with the unregistered interest fails to petition to adjudicate within ten years (or fails to record a new statement or claim, re-alleging the facts, which would start the ten year time frame again), then the adverse claim is terminated whereupon the court will cancel the CPT and issue a certificate of title to the land. (Minnesota Statutes, section 508.70).

Also, if no action is commenced by an opposing person within five years from the date of the first CPT, the registrar of titles shall cancel the CPT and issue a certificate of title. (Minnesota Statutes, section 508A.85, subdivisions 2 and 3).

This alternative method also has a five year time limit on determining the definitive location of boundary corners of the registered land (assuming that no person with an unregistered interest files a claim). The statute states that after five years, the boundaries of the parcel are set by the common law doctrine of practical location of boundaries. (Minnesota Statutes, section 508.02).

2.7. Singapore Co-Ordinated Cadastre

In August 2004, the Singapore Land Authority introduced the Singapore Co-ordinated Cadastre (Singapore Land Authority 2004)³. While this cadastre is considered by many to be the world's first complete legal coordinated cadastre, it fails because the registered coordinates marking the location of boundary corners of registered parcels are not guaranteed by the Singapore State (Andreasson 2006).

The Singapore Co-ordinated Cadastre is a "title by registration" system in which a "proprietor" is guaranteed title to an estate or interest as shown on the land-register.⁴

Boundary corner locations of all land parcels within the Singapore Co-ordinated Cadastre are described by coordinates approved by the Chief Surveyor.⁵

³ For statutes describing various aspects of the Singapore Co-ordinated Cadastre, see the Singapore Land Titles Act (SLTA), the Singapore Boundaries and Survey Maps Act (SBSMA) and the Singapore Land Surveyors Act (SLSA).

⁴ SLTA Chapter 157 Section 4(1): "Proprietor" means any person who appears from the land-register to be the person entitled to an estate or interest in any land which been brought under the provisions of this Act..."

SLTA Chapter 157 Section 154(1)(d): "No action of ejectment or other action for the recovery of registered land shall lie or may be sustained against the proprietor except in the case of ...a person deprived of land by fraud against the person who has become registered as proprietor of the land by fraud..."

SLTA Chapter 157 Section 151: "The [Singapore Land] Authority shall set apart...an assurance fund, from which shall be paid...any sum necessary to compensate claimants under [SLTA] Section 155..."

SLTA Chapter 157 Section 155(1): "...any person who is deprived of land or sustains loss or damage through any omission, mistake, or misfeasance of the Register...and who is barred by this Act from bringing any action for the recovery of land...may bring an action for the recovery of damages against the assurance fund."

SLTA Chapter 157 Section 159(1) & (5): "The Register may, upon such evidence as appears to him sufficient, correct errors and omissions in the land-register...any person who, having dealt on the faith of an erroneous registration, has suffered loss or damage by the exercise of the power conferred on the Registrar by this section shall...be entitled to be compensated from the assurance fund for the land of which he has been deprived and for any improvement made thereon by him or any predecessor in title, and may bring an action for the recovery of such compensation."

⁵ SBSMA Chapter 25 Section 7: The Chief Surveyor shall be responsible for establishing a co-ordinated cadastre and may, for that purpose ...

(b) declare, by notice in the Gazette, specified areas to be designated survey areas, being areas of land in respect of which cadastral surveys must be carried out by reference to survey control marks in accordance with survey instructions under this Act, and for which co-ordinates must be determined in accordance with those instructions;

Maps generated from the co-ordinated cadastre are conclusive evidence in all courts of the boundaries of the land shown therein, except for cases where:

- it is found that a map does not correctly represent the boundaries of any land;
- it appears that wrong boundary marks have been joined up in the survey resulting in incorrect boundary lines being shown on the map;
- it appears that there has been a change in position of a boundary from that which it held at the time of the survey.⁶

For cases involving these exceptions, the Chief Surveyor is empowered to hold an inquiry, hear the evidence of all interested parties, and make such an order as he thinks fit.⁷

(c) approve and record the co-ordinates of the boundaries of land within each designated area as determined by surveys carried out in the area (whether before or after the declaration of the area as a designated survey area), convert the co-ordinates recorded in relation to those parcels of land within the area and make any necessary adjustments to the recorded co-ordinates;

(d) where the co-ordinates for all parcels of land within a designated survey area have been so approved, recorded, converted and adjusted, declare, by notice in the *Gazette*, that area to be within the co-ordinated cadastre;

(e) generate, from the co-ordinated cadastre, maps for any area of land within the co-ordinated cadastre;

(f) where the co-ordinates for all parcels of land in Singapore have been declared to be within the co-ordinated cadastre under paragraph (d), declare, by notice in the *Gazette*, that the maps generated from the co-ordinated cadastre shall supersede all maps published under the repealed Act.

⁶ SBSMA Chapter 25 Section 13(2): “Every map generated from the co-ordinated cadastre shall be conclusive evidence in all courts of the boundaries of the land comprised in every land shown therein, subject only to any order made under section 12 for their modification, correction or alteration.”

SBSMA Chapter 25 Section 12(2)(a) & (b): “No map...generated from the co-ordinated cadastre shall be corrected, altered or added to in respect to any boundary of any land laid down, except in the following cases:

- (a) where it is found that a map does not correctly represent the boundaries of any land...due to inaccuracy of the survey caused by errors in measuring the angles or the sides of the land or in plotting the survey or in the process of conversion and adjustment [of the approved coordinates]...
- (b) where it appears that wrong boundary marks have been joined up in the survey and delineation of a boundary shown on a map, or where it appears that there has been a change in the position of a boundary from that which it held at the time of the survey...”

Ultimately, the High Court may decide the boundary position issues.⁸

If a person sustains loss or damage from the corrections made to boundary positions in these cases, the assurance fund is not used, nor is the government of Singapore held liable. Instead the registered land surveyor who performed the survey is held liable.⁹

All registered land surveyors (and survey companies) must have insurance against professional liability in amounts set forth by the Land Surveyors Board.¹⁰

⁷ SBSMA Chapter 25 Section 12(4) & (5): “(4) If any objection is lodged with the Chief Surveyor under subsection (2)(a), the Chief Surveyor shall hold an inquiry and make such order as he thinks fit. (5) If, after taking into consideration the evidence of the owners or their agents appearing at the inquiry under subsection (2) (b) and of such other persons who have knowledge of the subject, the Chief Surveyor is satisfied that the boundary as it appears from the then existing occupation of the land is the true boundary, the Chief Surveyor shall make an order for the correction of the map.”

⁸ SBSMA Chapter 25 Section 12(2)(e): “Where in any suit an order of the High Court has been made which affects the position of the boundaries of any land, the map may be altered upon an office copy of the order being served on the Chief Surveyor.”

⁹ SBSMA Chapter 25 Section 11D(5): “Notwithstanding that a survey plan has been approved by the Chief Surveyor, it shall be the duty of the registered surveyor who signed the survey plan to ensure that the survey plan and all information and matters set out in the survey plan are correct and accurate.”

SBSMA Chapter 25 Section 11E(2): “The Chief Surveyor may, at any time after the survey plan has been deposited with the Authority,...direct any registered surveyor...to correct at his...expense...any error in the cadastral survey made by that registered surveyor.”

¹⁰ SLSA Chapter 156 Section 15(3)(b)(i): “Any application by a registered surveyor [for a practicing certificate authorizing him to engage in survey work] shall be...accompanied by...evidence...that the applicant has complied with...the rules relating to insurance against professional liability.”

SLSA Chapter 156 Section 38(2)(g) & (h): “The [Land Surveyors] Board may...make rules...requiring all or any of the following to take out and maintain insurance against liability for breach of professional duty in the course of supplying survey services:

- (i) any partnership consisting wholly of registered surveyors applying for a license;
- (ii) any partnership or unlimited corporation applying for a license;
- (iii) any registered surveyor applying for a practicing certificate for the purpose of engaging in survey practice on his own account;
- (iv) any registered surveyor applying for a practicing certificate who is employed or about to be employed by any person or body referred to in sub-paragraphs (i), (ii) and (iii);
- (v) any other registered surveyor applying for a practicing certificate;
- (h) prescribing the terms and conditions of insurance against professional liability under this Act, including a minimum limit of indemnity.”

In summary, the Singapore Co-ordinated Cadastre is considered by many to be the world's first complete legal coordinated cadastre. This cadastre does have a "title by registration" system in which a proprietor is guaranteed title to an estate or interest as shown on the land-register. It also uses coordinates to define the location of all parcel boundaries. However, the locations of parcel boundaries as defined by the approved coordinates are not guaranteed by the state. If a boundary corner shown on the co-ordinated cadastre is found to be in error through an inquiry held by the Chief Surveyor, or by a suit before the High Court, the location of the boundary corner can change. If people have damages or loss because of such a change made to the co-ordinate cadastre, the registered surveyor is liable. Such damages are paid by professional liability insurance that is required to be taken out and maintained by all registered land surveyors.

2.8. Summary of Literature Search

1. A legal coordinated cadastre is not just a model showing where land parcels are located, but is in fact reality, actually showing and defining the definitive boundary corner locations.
2. There are no legal coordinate cadastres currently in existence that meet this criterion exactly.
3. The concept of land ownership is of a volume centered on the terrain surface and extending above and below the terrain surface to the extent necessary for the owner to enjoy and exploit the property.
4. A Torrens System of Land Registration such as that used by the Massachusetts Land Court can adjudicate land titles and land boundaries.

5. The current paradigm is that physical monuments set in the ground by the original surveyor or creator of a parcel of land and called for by the conveyance definitively locate boundary corners.
6. A monument set by the original surveyor and called for by the conveyance has no error of position.
7. The exact location of a corner not originally monumented by the original surveyor or creator of the parcel can never be known.
8. The exact distance and direction between two existing monuments set in the ground cannot be determined.
9. Multiple monuments can exist for a boundary corner for which the original surveyor did not set a monument (the pincushion effect).
10. De minimis encroachments over registered lands are allowed to exist in Hawaii by statute and may be allowed to exist in Massachusetts by case law.
11. Many US states allow a State Plane Coordinate to be used to definitively mark the location of a boundary corner.

3. THE MILLIMETER LEGAL COORDINATED CADASTRE

Research suggests that a “model of reality” may not in fact be the best approach to creating a cadastre. In order to evaluate the feasibility of my proposed cadastre, it is first necessary to discuss present accepted practice and its impact on future research and development.

3.1. Introduction

The legal coordinated cadastre would be a natural progression in the history of conveying land ownership in the United States. With the early system of livery of seisin, the parties (grantor, grantee, and all other interested parties) had to actually meet at the land parcel and walk the boundaries of the parcel in order to know what land was being conveyed and where it was located on the ground. Later, after enactment of the Statute of Uses by the English parliament in the 1600s, a written deed could be used to convey the ownership of the land without any party actually going to and viewing the parcel on the ground. However, even though called-for monuments that definitively marked boundary corners of the parcel could be described in the deed, a grantee wishing to know where the parcel was located on the ground would still have to visit the site in order to view the actual location of the called-for monuments. Thus, even though it was possible to convey property without the grantor or grantee ever stepping foot on the parcel, it still was necessary to visit the site to know definitively where the parcel was located on the ground. The next obvious step in the evolution of conveying land ownership is one in which a grantor could convey ownership to a parcel of land to the grantee and everyone would know the definitive location of the

parcel on the ground without ever going to the site. Such a new system is the legal coordinated cadastre.

Present day cadastres such as Cadastre 2014 and NILS are models of reality. They show a model of a land parcel on the map or computer screen, but one must go to the site to view where the parcel is actually located on the ground (by viewing the physical called-for monuments actually set in the ground).

A legal coordinated cadastre is not just a model of the reality of a parcel of land ownership; a legal coordinated cadastre becomes the reality of a parcel of land ownership. There would be nothing better than the legal coordinated cadastre to define who owns a parcel of land, what the rights are to that parcel, and where the parcel is located on the ground. A person need go no further than the legal coordinated cadastre to know who owns or has rights to the property, what those rights are, and where the parcel and the other rights are located on the ground.

In order to fully understand the concept and ramifications of a legal coordinated cadastre, one must compare the legal coordinated cadastre (where the definitive locations of land boundary corners are defined only by a geodetic coordinate) with the current cadastre paradigm (where the definitive location of land boundary corners are defined only by a physical monument set in the ground).

3.2. The Physically Monumented Cadastre

The physically monumented cadastre implies a degree of accuracy and precision that may not in fact be present in the final product. As will be shown, the very procedure of defining the monument location and then the physical act of setting

the monument incorporates unavoidable error. Relocation of those monuments may also include error.

3.2.1. Overview of The Physically Monumented Cadastre

The current paradigm of defining the location of registered land boundary corners is through the use of physical monuments set in the ground. A cadastre built using such a system will show parcels of land as surveyed by and shown on plans prepared by land surveyors. If boundary corners are defined by physical monuments set in the ground, then the measurements of distance and direction of the boundary lines that connect two of the said boundary corners will have unavoidable error, and plans created showing all the boundary lines of a parcel of land will also have error. To study this in more depth, the following will be discussed:

- measurement error when determining attributes of a boundary line that connects physical monuments set at two boundary corners;
- measurement error when setting a physical monument in the ground at a boundary corner location that is not originally defined with a physical monument set in the ground;
- measurement error when setting a monument along the line of an existing boundary line.

Next errors inherent in a plan prepared by a land surveyor that models all of the boundary lines of a given land parcel will be discussed.

3.2.2. Monuments Versus Deed Directions and Distances

Often, deeds not only describe monuments that mark corners of boundary lines, but also describe the direction and distance of these boundary lines themselves. These

boundary lines may have definitive monuments at both corners, at only one corner, or at neither corner. If a boundary line is described as having definitive monuments at both ends, and is also described with a direction and/or distance, there is a problem if the direction and distance conflicts with the location of the definitive monuments. Thus, sometimes the directions and distances must yield to the definitive location of the monument, and therefore the direction and distance are merely descriptive of the boundary line, while at other times the direction and distance are all important and must be held to determine where the boundary line is located on the ground. It depends on whether a boundary corner is described in a deed as having a monument set, a monument not set, or a monument to be set. These will be discussed in the following thought experiment.¹¹

Assume that a grantor, a grantee, and an original surveyor (Surveyor A) meet at a site to create a new parcel of land to be conveyed from the grantor to the grantee. Assume that the grantor and grantee agree on the parcel of land to be conveyed and agree on where to set (and have the original Surveyor A set) four physical monuments

¹¹ Sometimes researchers use a process called a *thought experiment* to explain, clarify or further identify key components of a concept. Thought experiments use the imagination to investigate the nature of things. Sometimes thought experiments help to illustrate and clarify and thereby aid in the understanding of abstract concepts. Thought experiments can sometimes overcome some of the disadvantages of performing a real experiment such as the financial cost to set up and perform the real experiment, the time needed to perform the experiment, and more importantly the difficulty in being able to control the experiment to properly illustrate the concept.

The concept being investigated in this thought experiment is that random error is present in all surveying observations. It is impossible to measure the exact distance between two physical monuments set in the Earth's surface because of random error. This thought experiment demonstrates how this inability to exactly measure the distance between two monuments affects the surveyor's plan.

Brown, J. R. and Y. Fehige (2010). Thought Experiments. The Stanford Encyclopedia of Philosophy (Winter 2010 Edition). E. N. Zalta. Stanford, CA, The Metaphysics Research Lab, Center for the Study of Language and Information, Stanford University.

in the ground that mark the four corners of the parcel without any initial regard to measurements between monuments or in area bounded by the four monuments. In other words, the bounds are set only to mark the location of the four boundary corners of the newly created parcel.

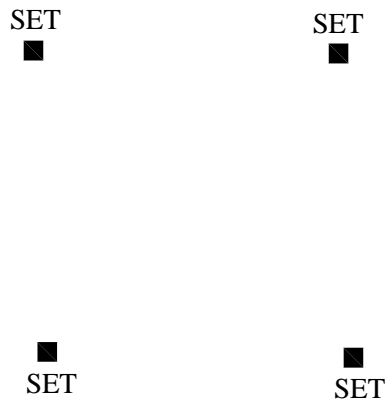


Figure 3.1 Four Physical Monuments Set Marking Definitive Boundary Corners

At this point, the surveyor's plan would look like Figure 3.1.

Since these monuments are not so massive and do not have such a unique description that their existence alone is sufficient to delineate a boundary corner location for all people for all time, other descriptors rather than just the monument themselves are required in the deed to help interested parties determine whether the monument still exists or whether that particular monument is the one that actually describes the boundary corner location. One such descriptor is the spatial relationship (such as the direction and distance) between two or more monuments that delineate boundary corners. While individual monuments delineate the absolute locations of boundary corners, these descriptors describe the relative spatial relationships between the definitive monuments. Surveyor A must measure the distance between the

definitive monuments. (All measurements have error. Assume, in this thought experiment, that surveyors can measure distances with a precision of 1 part in 15,000, which is the minimum precision for a closed field traverse required by the Massachusetts Land Court.)

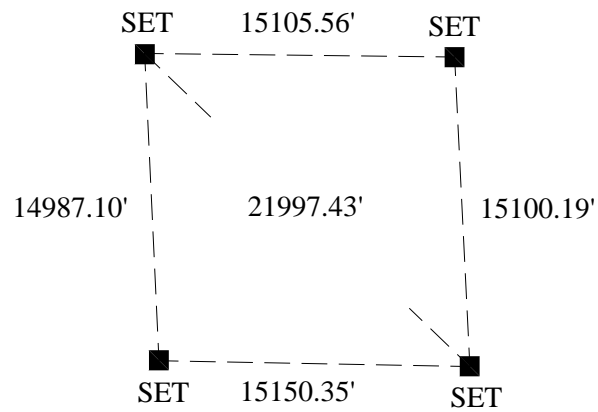


Figure 3.2 Measurement Distances Between Monuments

After measuring distances between the set monuments, the surveyor's plan might look like Figure 3.2.

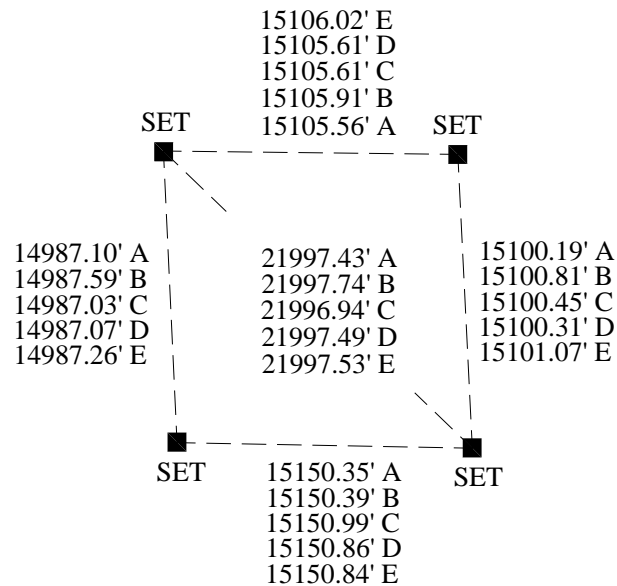


Figure 3.3 Multiple Surveyors-Measuring Distances Between Monuments

Next assume that the grantor and grantee, knowing that error is inherent in all measurements, are uncertain whether the measurements of Surveyor A are “correct”, and thus have four other equally competent surveyors (Surveyors B, C, D, and E) individually measure distances between the existing set monuments. The result of the measurements might be those as shown in Figure 3.3.

Thus five equally competent land surveyors independently measured distances between the set monuments to the best of their professional abilities, resulting in five different distances between each set of monuments. Because equally competent land surveyors measured them, it would be impossible to pick the measurement of any one particular land surveyor as being more correct than that of any other land surveyor. Thus the grantor and grantee realize that the exact measurement between monuments cannot be determined and instead, the most probable value of this measurement would

be the average of all measurements made by all land surveyors over all time (also known as the population mean). However, even this cannot be accomplished because the grantor and grantee only have 5 independent measurements rather than the full population of all measurements. Instead, a range (the standard deviation of the mean $S_{\bar{y}}$), may be determined within which this population mean should be located with some certainty by using the t (or student) distribution (Ghilani and Wolf 2010). For 5 observations and 95% certainty the t distribution value would equal 2.776. Thus the standard deviation of the mean can be calculated by: $S_{\bar{y}} = \pm \frac{2.776}{\sqrt{5}} S$.

Measurement Location	\bar{y}	S	$S_{\bar{y}}$
North Boundary	15105.74'	0.19'	0.24'
East Boundary	15100.57'	0.33'	0.41'
South Boundary	15150.69'	0.26'	0.32'
West Boundary	14987.21'	0.21'	0.26'
Diagonal line	21997.43'	0.26'	0.32'

Table 3.1 Summary of Measurements

Table 3.1 shows the mean (\bar{y}), the standard deviation (S) for one sigma, and the standard deviation of the mean ($S_{\bar{y}}$) for 95% certainty for the five measurements that were made.

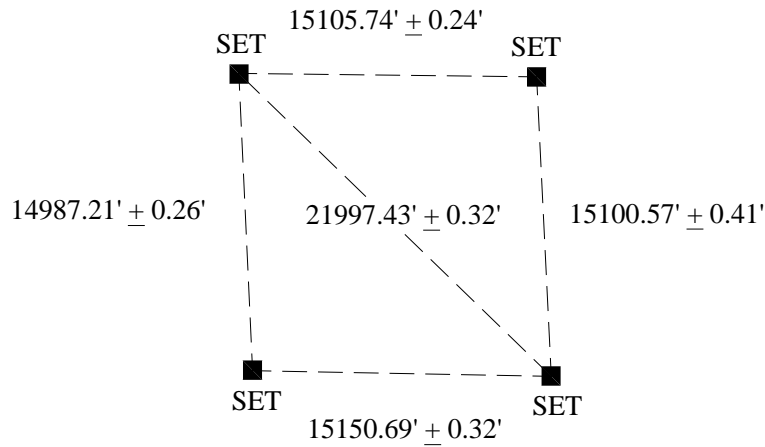


Figure 3.4 Precision Of Measurements Between Monuments

As shown in Figure 3.4, the plan thus shows the four monuments that were set, which have no error and definitively mark the locations of the four boundary corners, and also show the most probable value of measurements between monuments with the standard deviation of the mean for 95% certainty.

In our example, *positional tolerance* is defined as how close (accurate) a physical monument is located to the true location of one boundary corner (for this example, the positional tolerance between the physical monument and the definitive boundary corner is zero for 100% certainty). Statements about *precision of measurements* provide information about error in relative measurements between two physical monuments. For this example, the measurements between the monuments are imprecise as shown for 95% certainty.

Thus positional tolerance quantifies the absolute error between the location of one physical monument and the true boundary corner, while precision quantifies the error in measurement between two monuments. For this case, the definitive monuments have a positional tolerance of zero error for 100% certainty, while the

distances between the monuments have the error shown in Figure 3.4 for 95% certainty.

3.2.3. Boundary Corner Locations On The Original Plan As “Not Set”

Assume at this point that the grantor adds a triangular-shaped parcel of land to the right of the parcel created by the four “set” monuments, but decides not to monument the new boundary corner before selling the parcel to the grantee. Instead, a distance from the northeast “set” monument and a distance from the southeast “set” monument will define the said new boundary corner.

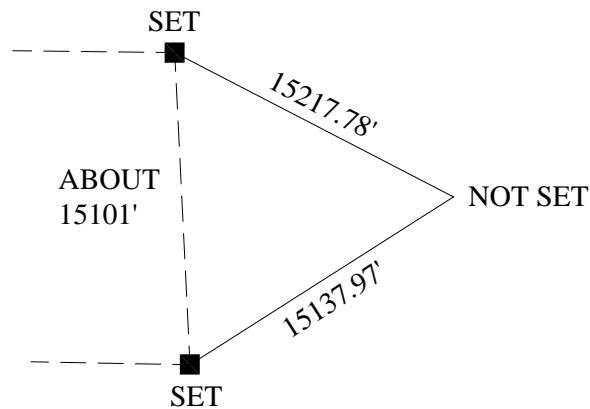


Figure 3.5 Boundary Corner Marked As Not Set

While that boundary corner will not be set by the original plan and original surveyor, and thus a monument will not be shown as being “set” on the plan and deed, in the future that boundary corner will probably be monumented many times by various land surveyors. Even though there is only one true location for that boundary corner (defined by distances from two existing “set” monuments), unavoidable random errors will be introduced when the land surveyors attempt to set the boundary corner by measuring from the existing “set” monuments. Each time the same or a different

land surveyor attempts to stake out this boundary corner, the unavoidable, random measurement errors will be different, resulting in the monuments being set at different locations. This will be examined with the help of Figure 3.5.

Assume that at the time of the conveyance of the parcel of land, no monument had been set and thus the boundary corner was marked on the plan as “not set”. Now assume that the same 5 land surveyors each independently monument this corner to the best of their professional abilities.

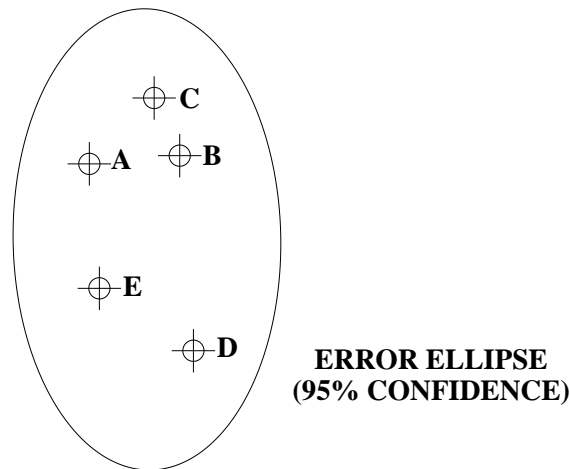


Figure 3.6 Location Of Boundary-Not Set By Original Surveyor

Each surveyor will use the two record distances, but because of measurement errors, it is probable that each surveyor will place their monument in a different location, for example as shown in Figure 3.6.

Since the land surveyors are experts in error theory they realize that each of them cannot state that their monument is more correct than any other, but only that the monument was set to the best of their professional ability. In fact, the land surveyors realize that because of random error in the measurements necessary to stake out this

corner, it is impossible to stake the definitive corner. While there can only be one definitive and “true” location of this boundary corner (the intersection of the two deed distances from two definitive monuments), because of random error it will be impossible for any surveyor to stake the exact corner. However, it is probable that all the monuments set by the various land surveyors will “cluster” together, and in fact an error ellipse for any given confidence level (for instance, the 95% confidence level) might be developed for this “pincushion” of monuments within which the “true” boundary will be located for the given certainty. See Figure 3.6.

Through this thought experiment, monuments marked on the plan and deed as “not set” are subject to the following:

- The “exact” location on the ground of a boundary corner marked “not set” on a plan and deed can never be known.
- Land surveyors can only certify that the monument he or she sets is the result of their best professional ability.
- A “pincushion” of monuments is an acceptable occurrence.
- The most probable location of the boundary corner is the average location of all monuments that can or will ever be set by all possible land surveyors.
- In the case of a boundary corner being shown on the original plan and deed as “not set”, the record distances from other definitive boundary monuments hold over any and all monuments set in the future by land surveyors at that “not set” point.

- As a corollary, if “set” monuments are disturbed or destroyed, (and cannot be replaced back in the original location from extrinsic evidence other than directions and distances from other “set” monuments as called for in the deed), and the only way to reset the monuments is to use directions and distances called for in the deed, then a new monument can never be placed back in exactly the same place as the original monument before it was disturbed for the same reason: in order to reset that monument, the land surveyor must use record distances from other existing “set” monuments as shown on the plan or deed. This is exactly the same scenario as having a plan showing the monument as “not set”.

3.2.4. Special Case: Setting Monuments - Existing Boundary Line

Setting new monuments along an existing boundary line (for instance, along a municipal boundary) is a special case that can best be described by another thought experiment. Assume that two municipalities have a common boundary marked by two physical monuments set in the ground that are about 15,000 ft. apart. Assume that they want to set two intermediate physical monuments on the ground that will be about 5,000 ft from each of the two existing monuments as shown in Figure 3.7. Assume also that once the physical monuments are set, the municipalities will petition the state government to legislate that the newly set physical monuments will legally mark the municipal boundary between the two towns. However, the municipalities want to make sure that the actual line between the municipalities will not change, and will still be a straight line between the two existing monuments #1 and #2. The municipalities hire Land Surveyor A to stake out for the new monuments #3 and #4. The land

surveyor creates a closed field traverse from which existing monuments #1 and #2 are located and from that traverse stakes out for the proposed monuments #3 and #4.

Assume that the municipalities want to check whether Land Surveyor A was “correct” in its stakeout, and thus also hires Land Surveyors B, C, D, and E to also stakeout the two proposed monuments.

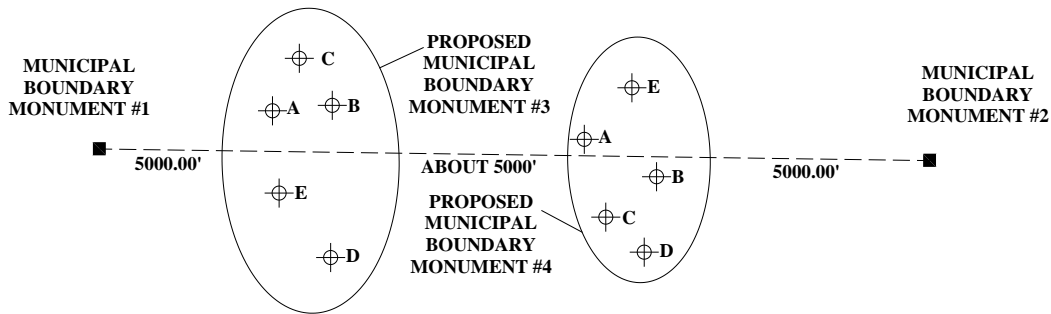


Figure 3.7 Staking Intermediate Monuments Along A Municipal Boundary

Because of random error, each of the five land surveyors will stakeout a different location for each of the monuments as shown in Figure 3.7. Since each of the land surveyors is equally competent, the municipalities cannot pick one of the 5 stakeout points as being better than any other. As mentioned above, from the positions of the 5 stakeout points, an error ellipse for any given confidence level (for instance, the 95% confidence level) can be developed for this “pincushion” of monuments within which the “true” boundary will be located for the given certainty.

Based on this information, it is impossible for the municipalities to determine the true location for proposed monuments #3 and #4, either from picking one of the 5 land surveyor's stakeout points, or even from performing a statistical analysis on those 5 locations to come up with a sixth possibility. Thus there are two possibilities:

- The municipalities will set a physical monument at #3 and #4, and will have the state government legislate that those monuments will be on the municipal line. In this scenario, the common municipal line will no longer be a straight line between monuments #1 and #2, but instead will now be 3 separate lines that will run from #1 to #3, from #3 to #4, from #4 to #1. Because of random error, monuments #3 and #4 will be angle points in the municipal line.

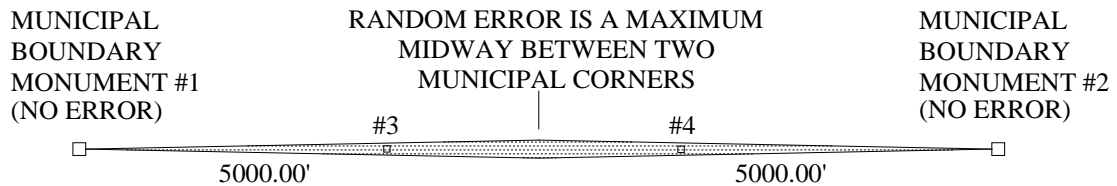


Figure 3.8 Fuzzy Boundary Line

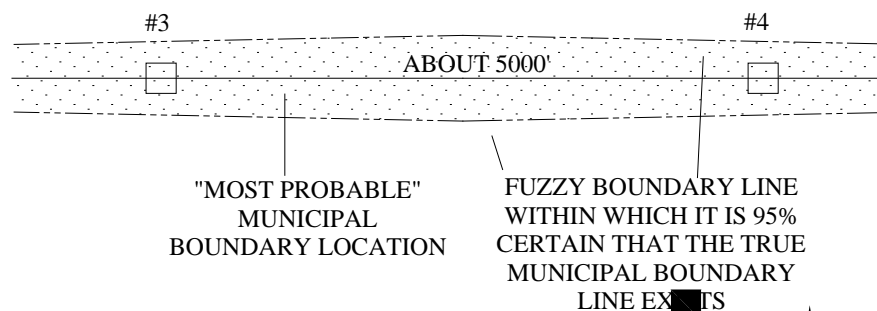


Figure 3.9 Detail of Fuzzy Boundary Line

- The municipalities will continue to keep the common boundary as a straight line between #1 and #2. Monuments #3 and #4 will not be on this common boundary because of random error in the measuring and stakeout process. However, #3 and #4 will be “close” to being on the common line, in a manner that can be quantified in the following usable way. It can be stated that the most probable location of the municipal line will be marked on the ground by #3 and #4, and that there is a given certainty (for instance, a 95% certainty) that the true municipal line will be located within the limits not of an error ellipse, but of a “fuzzy” boundary line. As shown in Figures 15 and 16, this fuzzy municipal boundary line will not be a one dimensional line connecting the two corners of the municipal line marked by monuments #1 and #2, but will instead be a two dimensional quadrilateral within which with 95% certainty, the “true” municipal boundary will lie. (Brown 1999)

3.2.5. Surveyor’s Plans Are Models of Reality

Surveyor’s plans detail the results of the survey for a parcel of land and typically show those physical monuments whose location on the Earth’s surface define the location of boundary corners, show information about boundary lines (such as measurements of direction and distance of boundary lines located between two boundary corners), and show the area of the parcel. In a system that uses the location of physical monuments set in the ground to definitively locate boundary corners, measurements between these physical monuments will have error (and this measurement error will be quantifiable if error of 1 mm or greater is defined to be

significant). Thus the surveyor's plan showing boundary line measurements and parcel area will only be a model of reality. This section will describe this in detail by using the procedure of land registration used in Massachusetts as described in the Massachusetts Land Court's Manual of Instruction.(Massachusetts Land Court 2006) Note that the sections shown in the next two paragraphs (e.g. 2.1.2.1.) refer to sections in the said Manual of Instruction.

The surveyor must search the public records and the record title of the property in question to obtain information concerning property descriptions and boundaries. The surveyor must also identify easements, restrictions, and other encumbrances that burden the parcel as well as appurtenant rights that benefit the parcel. (2.1.2.1.)

All plans showing boundary lines must be the result of an actual survey performed on the ground (2.1.3.1.2.). The survey must be predicated upon a closed field traverse of appropriate precision running around the property, either upon the boundary lines, or upon traverse lines from which the boundary lines are located, or upon a combination of both (2.1.3.1.3.). All observable features that may have a bearing on the determination of property boundary lines or title lines shall be directly located from the closed field traverse (2.1.3.1.4.)

In the survey analysis and computation, rectangular coordinates are necessary, and shall be used in all cases (2.1.4.1.1.). The closed field traverse is analyzed to ensure that it meets a minimum precision standard, and is then adjusted by an appropriate method (such as least squares method or compass rule) (2.1.4.1.3.). After the coordinates are determined for the stations of the closed field traverse, the coordinates of all physical monuments located from the said traverse are calculated.

Next the surveyor combines the record research with the field survey to come up with their best professional opinion of the parcel's shape and location. A plan is finally prepared showing the results of the survey.

The following thought process would show this process more clearly.

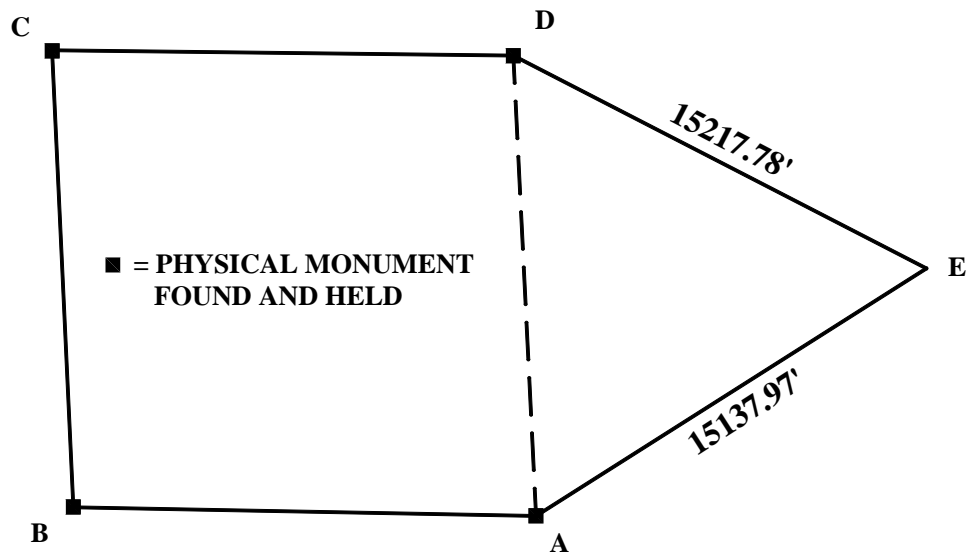


Figure 3.10 Definitive Land Parcel

Suppose a surveyor has determined that four boundary corners of a parcel are each defined by a physical monument that was found set in the ground (Points A, B, C, and D as shown on Figure 3.10) while a fifth boundary corner (Point E) is defined by record (deed) distances from two of the physical monuments (Points A and D). (See Figure 3.10)

The first thing the surveyor must do is create a closed field traverse from which will be located the physical monuments *A*, *B*, *C*, and *D*.

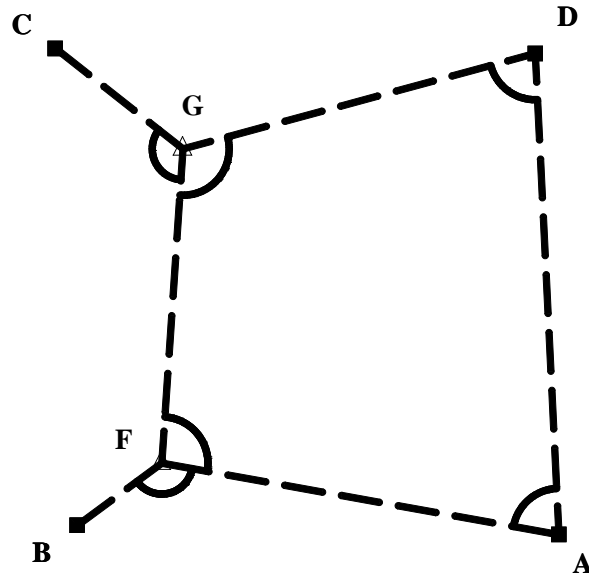


Figure 3.11 Field Traverse

Suppose the closed field traverse is made up of the existing physical monuments *A* and *D* and two other physical monuments (Points *G* and *F*) that are set in the ground, and that all lines will be measured, and angles will be turned as shown in Figure 3.11. (Notice that monuments *C* and *B* will be located from this closed field traverse.).

After finishing the field work, the surveyor must perform the calculations. Since a rectangular coordinate system must be used, it first must be defined. In defining a 2D coordinate system, a coordinate must be defined for one point on the Earth's surface, and an initial direction or orientation of the coordinate system must be defined. Suppose for this thought experiment that we define the initial coordinate of (N50,000, E50,000) as being located at the exact center point of the physical monument *A*, and the orientation of this coordinate system will be such that the

azimuth between points *A* and *D* will be defined as North (or North azimuth of 0 degrees).

Now that the coordinate system has been defined, the closed field traverse may be analyzed for closure error, and then the said error may be adjusted by an appropriate method. The end result will be that each of the physical traverse monuments that were set in the ground will be given a coordinate that will model the location of the traverse monument on the surveyor's plan. Since the coordinates are based on measurements that have unavoidable errors, these modeled coordinate locations will also have error as follows. Since we defined the coordinate system by giving a coordinate to traverse monument *A*, there is no error in the coordinate that models the location of monument *A*. Since we defined the azimuth of 0 degrees of our coordinate system by holding the line between traverse monuments *A* and *B*, there is not error in the easting coordinate that models the location of traverse monument *B*, but there will be an error in the northing coordinate. There will be an error in the northing and easting coordinates that model the location of traverse monuments *C* and *D*.

It is impossible to know the coordinate that gives the exact location (or location with no error) in our model plan of traverse monuments *D*, *G*, and *F*, however we can quantify the error by creating an error ellipse for each traverse monument.

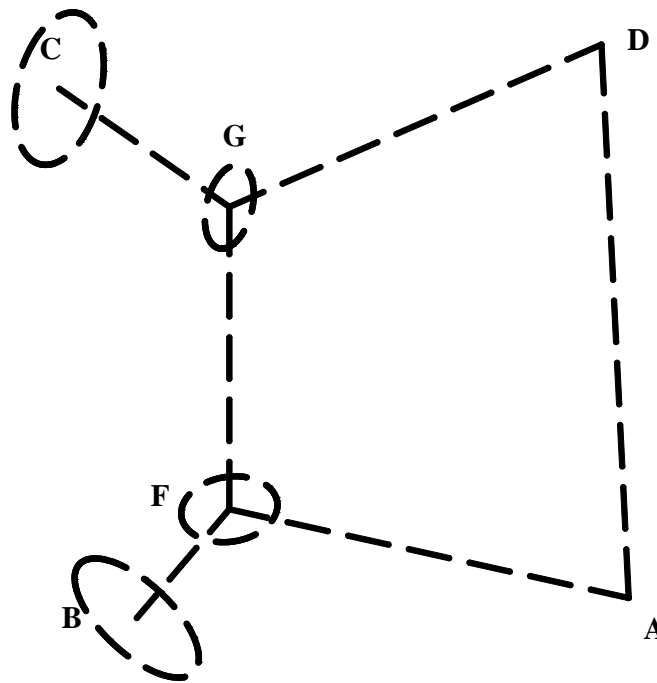


Figure 3.12 Coordinate Uncertainty Of Field Traverse

With such an error ellipse one can state that while it is impossible to know the coordinate in our model plan that gives the exact location of the traverse monument, we have a certain confidence (such as a 95% confidence) that the true coordinate will lie within the error ellipse. See Figure 3.12.

While it is impossible in the real world to know the exact coordinate of every traverse monument in our model plan, let us perform a thought experiment in which we are able to know the exact coordinates for the closed field traverse that has no error.

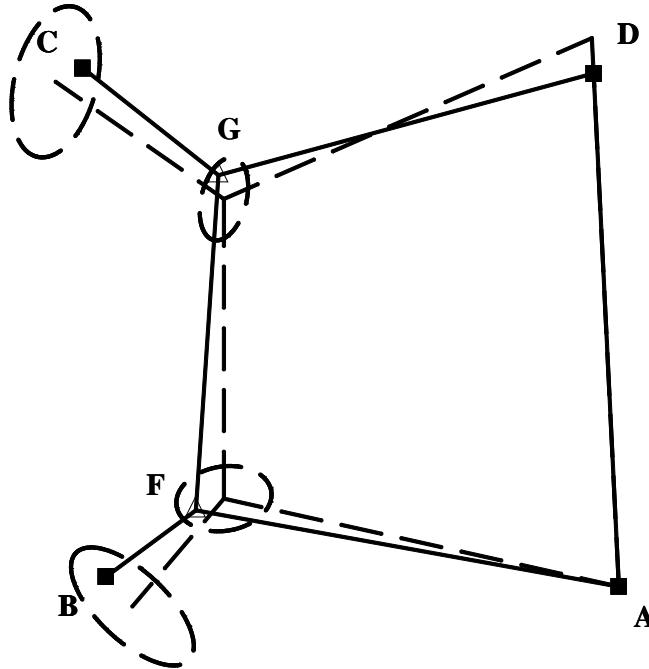


Figure 3.13 True Versus Measured Traverse

This exact closed field traverse is shown in the surveyor's model plan in Figure 3.13 as a continuous, solid line. The adjusted closed field traverse as computed by the surveyor is shown on the model plan in dashed lines. Note that the location of each traverse monument has been modeled by a coordinate that shows the most probable location of the monument on the model plan. Suppose that an error ellipse has been created for each monument at a 95% confidence level (as shown in Figure 3.13 in dashed lines). The surveyor is thus 95% confident that in the model plan, the true coordinate of each traverse monument will be located somewhere within its error ellipse. Next the model coordinates of the locations of the boundary monuments *B* and *C* are calculated (Note that lines shown as continuous or solid lines are "correct" locations shown on the model plan when we assume no error through our thought

experiment, and the lines shown as dashed lines are incorrect locations resulting from unavoidable measurement error). Note that the error ellipses are calculated for boundary monuments *B* and *C* (See Figure 3.13).

To summarize this thought experiment, we started with a surveyor determining that four boundary monuments that were found set in the ground defined the corners of a boundary parcel. If we were able to know the exact coordinates of these four corners (which is impossible in the real world, but possible in a thought experiment), then the true, exact boundary corners could be shown on the model plan that the surveyor creates.

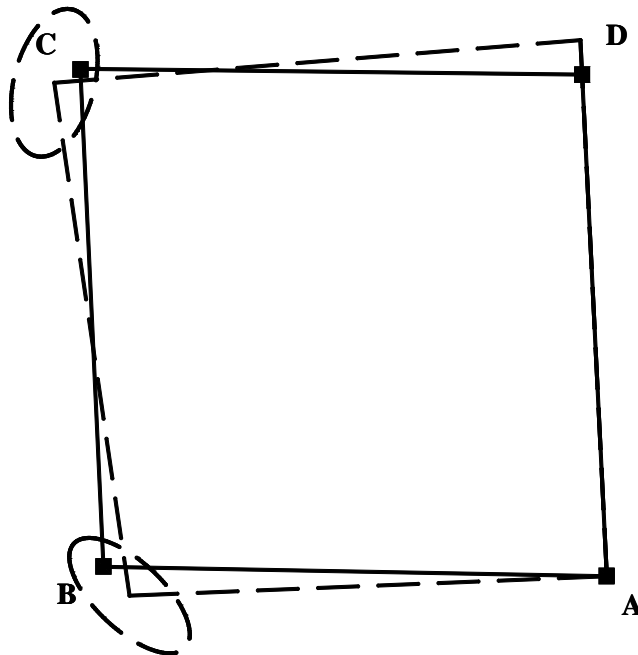


Figure 3.14 Surveyor's Plan Is Only A Model Of Reality

Exact distances and directions of the boundary lines that are created between two boundary corners could be calculated, resulting in exact parcel shape and location shown in continuous, solid lines in Figure 3.14. However, the parcel shape and

location that is actually created by the land surveyor and shown on the surveyor's plan (in the real world and thus has error) is shown on the model plan in dashed lines. Thus for parcels whose corners are defined by monuments set in the ground, the parcel as shown on the plan (and modeling the reality of what exists definitively on the ground) will be distorted and have error associated with it, and thus the surveyor's plan will only be a model of the actual parcel that exists on the ground.

To further illustrate that a surveyor's plan is only a model of reality, consider Massachusetts Land Court Case #38742 (See Appendix B for copies of plans). In 1972 Fred C. Pearson hired Raymond C. Pressey to survey his land on West Street in Newbury Massachusetts so that Pearson could register the land with the Massachusetts Land Court. In January 1973 Pressey prepared a surveyor's plan (Pressey's Plan) of the results of his survey. Pressey's Plan showed that physical monuments such as stone bounds and brass pins set in stone were set at boundary corners, and that measurements consisting of directions (bearings) and distances were given for boundary lines. The Massachusetts Land Court decreed that the parcel of land existed as shown on Pressey's Plan, registering the parcel as Land Court Case #38742A and issuing Certificate of Title #49169 to Fred C. Pearson. Thus by issuing Certificate of Title #49169 the Land Court guaranteed that Fred C. Pearson was the registered owner of the parcel. By decreeing Pressey's Plan as Land Court Case #38742A, the Land Court guaranteed the parcel geometry (bearings and distances of boundary lines) as shown on Pressey's Plan, and guaranteed that the registered parcel of land was located on the ground as referenced by the physical monuments shown on the plan.

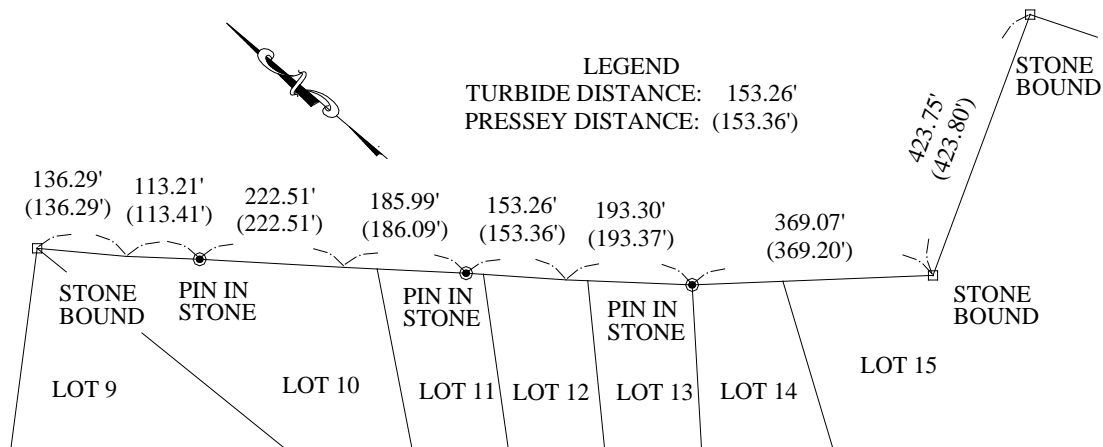


Figure 3.15 Comparison Of Pressey And Turbide - Land Court Surveyor's Plans

In 1986 the then current registered owner hired Paul D. Turbide (owner of Port Engineering Associates, Inc.) to prepare a subdivision plan of the land to submit to the Land Court. Turbide found most of the monuments shown on Pressey's Plan and prepared a surveyor's plan (Turbide's Plan) of the results of his survey. However, Turbide's measurements of boundary lines between the boundary corners located on the ground by the found physical monuments were significantly different. (See Figure 3.15) It appeared that Pressey's distance measurements were all larger than those determined by Turbide, and that this difference was proportional to the magnitude of the measured distance (i.e. the larger the measured distance, the larger the error). After consulting with the Land Court it was determined that Pressey probably had a systematic error in his distance measurements. While it was never conclusively proved, it appeared that Pressey had used a steel tape to measure distances and had not corrected the measured distances for temperature. (Steel tapes are created to be used at the "standard" temperature of 68° F. When the temperature is below 68° F the tape will contract with the result that the measured distances using that "short" tape will be

too long. When the temperature is above 68° F the tape will expand with the result that the measured distances using that “long” tape will be too short. The length of a 100 foot steel tape will change by 0.01 ft. for every 15° F of temperature change.) It was determined that during the Pressey survey field work, the distance between the “zero” end mark of the tape and the “100.00” end mark of the tape was probably actually between 99.955 and 99.965 ft rather than 100.00 ft. This could be explained by not correcting for temperature correction when the temperature at the time of the field survey was between 0° F and 12° F (In Massachusetts such temperatures are possible for the months of December and January, the time when the Pressey field survey was performed).

The Land Court accepted the Turbide measurements as “correct” (Turbide had used an electronic distance measuring instrument (EDMI) to measure distances and calibrated his EDM to the National Geodetic Survey EDM Calibration Base Line located in Georgetown, Massachusetts both before and after the Land Court field survey). The Land Court determined that the monuments set in 1973 by Pressey were the same monuments found by Turbide and that the monuments still definitively marked the locations of the parcel on the ground. However the Land Court also determined that the parcel geometry that had been decreed (and thus guaranteed) in 1973 were incorrect. The Land Court decreed a different parcel geometry when they decreed Land Court Case 28742B, which used Turbide’s Surveyor’s Plan.

Thus ultimately the Land Court determined that Pressey’s Plan did not show the actual, true measurements of boundary lines, but was merely a model of the reality of the registered parcel. The monuments must hold over the measurements when a

discrepancy becomes apparent. The Land Court has further clarified this in its “2006 Manual of Instructions for the Survey of Lands and Preparation of Plans”:

S-Petitions are covered in Section 3.1 of the Land Court Manual of Instruction. In cases where an existing registration plan or certificate must be altered to reflect inconsistencies between monuments and dimensions of record ... or where an insufficient number of undisturbed record monuments causes doubt concerning the proper location of the boundaries of an existing registered parcel, a so-called “S-Petition” should be filed with the Land Court pursuant to G.L. c. 185, §115. The surveyor should work with the attorney for the certificate holder to provide the information the attorney will need in order to file the petition. The petition should be filed with a ... Plan showing the corrected data ... and should name all parties having an interest. The Court will require a title examination to confirm the identity of interested parties. The Court will consider the S-Petition, and, if allowed, enter an order approving the new plan and amending the certificate, if necessary. The Order is filed with the ... Plan at the appropriate registry district.

S-Petition is a procedure where the Court will change an existing registered parcel of land by decreeing the parcel again using a new surveyor’s plan that contains information to correct inconsistencies between monuments and dimensions of boundary lines shown on the former surveyor’s plan. This procedure is much like that used when initially registering a parcel of land. Effectively the Court is decreeing the registered parcel anew.

Inconsistent Surveys (Section 3.2) If a new survey has a boundary line, which is common to a prior registration, and some discrepancy between the new field work and the old registration plan data or an insufficient number of undisturbed record monuments causes doubt concerning the proper location of the common line, the matter should be referred to the Survey Division for instructions.

Boundary Lines Must Be Maintained (Section 3.2.1) Boundary lines determined by the Court and fixed on the ground in relation to verified monumentation of record, existing or retraceable, must be maintained.

Slight Variations (Section 3.2.1.1). Record dimensions shall be used when the new measurements between undisturbed monuments previously recognized on Land Court Plans agree within the allowable errors applicable in prior surveys.

Some Errors (Section 3.2.1.2). Subject to review by the Court, changes may be made when the new measurements explain an already recognized or obvious error in the old work.

This section of the Land Court Manual of Instructions -*Section 3.2*, also talks about possible doubt as to whether the current land court case properly locates an existing registered land boundary line, and thus it is possible that an *S-Petition* might be required. *Section 3.2.1* states that physical monuments determined by the Court to fix registered boundary lines on the ground must be held. *Section 3.2.1.1* states that an *S-Petition* will not be required even though the boundary line measurements described on the original surveyor's plan are shown to be incorrect by new measurements, if the error is within the limits allowed at the time of the prior survey. Thus in this case the Court will realize that the boundary line measurements are not correct, but will allow them to be used anyway. *Section 3.2.1.2.* states that if new measurements explain an already recognized or obvious error in the old work, then a change can be made in the plan and the record measurement for the boundary line can be changed without filing an *S-Petition*.

Monuments Do Not Fit Record Math (Section 3.2.5) When a discrepancy exists between the record math and record monuments, a worksheet should be prepared showing the relationship of the monuments to the record location (Usually the monuments are shown offset perpendicularly from the property lines.). In determining whether to hold record monuments, the Court needs to review all pertinent data and its effect on abutting land. After consultation with the Survey and Legal Divisions, a judge decides what additional steps, if any, must be taken prior to the preparation of the final plan.

This section of the Land Court Manual of Instruction states that when a discrepancy exists between the record measurements shown on the surveyor's plan used to previously register a parcel of land, and the record monuments, the Court

wants to see all the information about measurements versus monuments. The judge will then decide if an S-Petition is required (or if there is some other remedy).

Plan Approval Request To Judge For Review (Section 3.2.7) When a plan is prepared that differs from record (holds monuments and changes dimensions or holds dimensions and references monuments), the plan is presented to a judge for review. The judge reviews the plan and determines whether the change requires an S-Petition. If an S-Petition is not required, the judge initials the plan approval request that has been signed by the owner or the owner's attorney allowing the plan to be filed and used without filing a petition

The Land Court Manual of Instruction. states in this section that if a new surveyor's plan is prepared (for a new registration of a parcel of land that adjoins an existing registered parcel, or when subdividing an existing registered parcel) that differs from a surveyor's plan previously used to register a parcel of land, a judge of the court will review the situation to determine whether an S-petition will be required. If an *S-Petition* is determined by the judge to not be necessary, then the judge will allow the plan to be filed using the new surveyor's plan without an *S-Petition*.

Thus it appears that that the Massachusetts Land Court understands the following:

- Undisturbed physical monuments that were decreed by the court to definitively locate boundary corners on the ground must be held.
- There is an unavoidable error when measuring between such physical monuments, and thus the surveyor's plan is only a model of reality (i.e. there is error in boundary line measurements shown on the plan).
- Even though the surveyor's plan is just a model of reality and has error, the Court will presume that the surveyor's plan is correct and without error (i.e. the

plan is reality) if the error is within limits allowed by the Court (Currently a closed field traverse is allowed to have a relative error of closure of 1:15000).

3.2.6. The Cadastre Creator’s Dilemma

If the same parcel is surveyed by many surveyors, each will come up with a different survey plan based on their own field traverse and analysis. For instance, assume that Figure 3.3 shows a lot whose four boundary corners are definitively located on the ground by physical monuments and that five surveyors (Surveyor A; Surveyor B; etc.) have each independently surveyed the lot, and the measurements shown are the final measurements determined by each surveyor that are then used to create their individual survey plan.

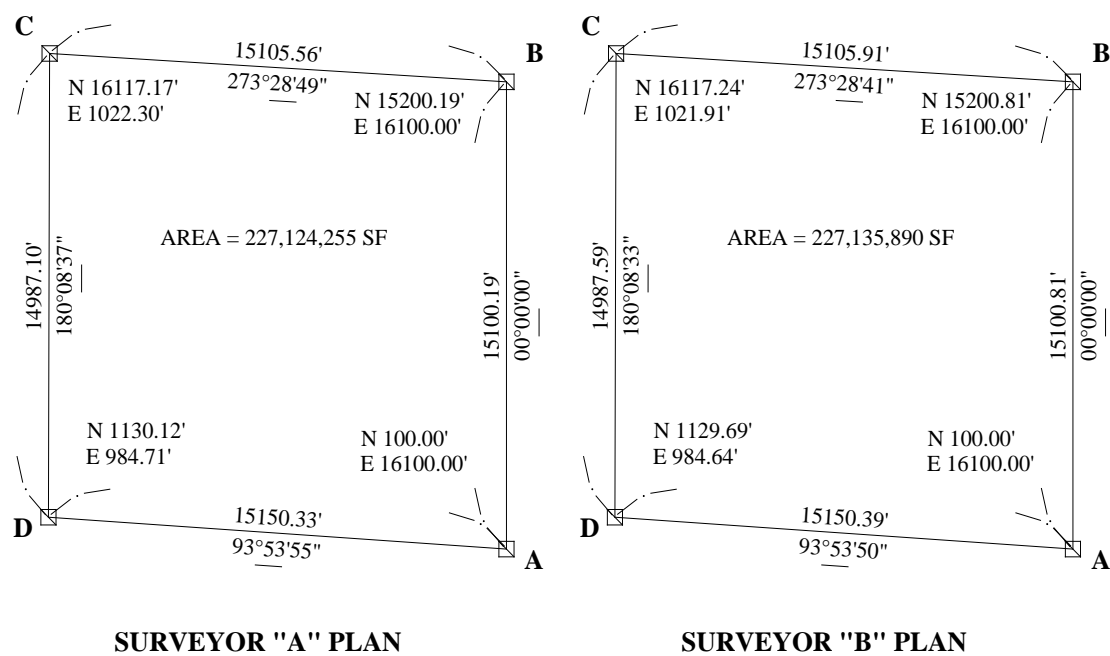


Figure 3.16 Plans Prepared By Two Surveyors For The Same Parcel

Examples of two such plans of the same parcel might be shown in Figure 3.16.

In this thought experiment (taken from Figure 3.3) there would be five different surveyor’s plans for the same parcel whose 4 corners are definitively located

by physical monuments set in the ground. (Assume that each surveyor holds the same coordinate for Bound A and the same azimuth (due North) for boundary line *AB*.)

Each of these plans would have different directions and distances for the boundary lines, a different parcel area, and different coordinates for each of the boundary corners as noted in the following table (Table 3.2):

Parameter	Surveyor <i>A</i>	Surveyor <i>B</i>	Surveyor <i>C</i>	Surveyor <i>D</i>	Surveyor <i>E</i>
Azimuth <i>AB</i>	00-00-00	00-00-00	00-00-00	00-00-00	00-00-00
Azimuth <i>BC</i>	273-28-49	273-28-41	273-28-35	273-28-48	273-28-32
Azimuth <i>CD</i>	180-08-37	180-08-33	180-08-45	180-08-44	180-08-37
Azimuth <i>DA</i>	93-53-55	93-53-50	93-53-45	93-53-56	93-53-48
Distance <i>AB</i>	15100.19	15100.81	15100.45	15100.31	15101.07
Distance <i>BC</i>	15105.56	15105.91	15105.61	15105.61	15106.02
Distance <i>CD</i>	14987.10	14987.59	14987.03	14987.07	14987.26
Distance <i>DA</i>	15150.35	15150.39	15150.99	15150.86	15150.84
Area (Sq Ft)	227,124,255	227,135,890	227,131,983	227,129,377	227,140,086
Northing <i>A</i>	100.00	100.00	100.00	100.00	100.00
Easting <i>A</i>	16100.00	16100.00	16100.00	16100.00	16100.00
Northing <i>B</i>	15200.19	15200.81	15200.45	15200.31	15201.07
Easting <i>B</i>	16100.00	16100.00	16100.00	16100.00	16100.00
Northing <i>C</i>	16117.17	16117.24	16116.39	16117.20	16116.81
Easting <i>C</i>	1022.30	1021.91	1022.19	1022.24	1021.76
Northing <i>D</i>	1130.12	1129.69	1129.41	1130.18	1129.59
Easting <i>D</i>	984.71	984.64	984.02	984.20	984.18

Table 3.2 Measurement Table

The cadastre creator will have a dilemma if this parcel is to be entered into the cadastre. Which plan should be used? Which coordinates should be used to model the boundary corners? Which directions and distances should be used to model the boundary lines? Instead of just passively compiling surveyor's plans into the cadastre, the creator will have an active role in determining which measurements and coordinates to use (The cadastre creator will have to pick one of the surveyor's plans to use, or will have to somehow average or otherwise come up with a new value to enter).

Realistically, it would be unusual for five surveyors to survey the same parcel before it goes into the cadastre. However, it is probable that a lot will be entered into the cadastre by using one surveyor's plan, while an abutting lot that shares common boundary corners and boundary lines will be entered into the cadastre by using a different surveyor's plan at a slightly later time.

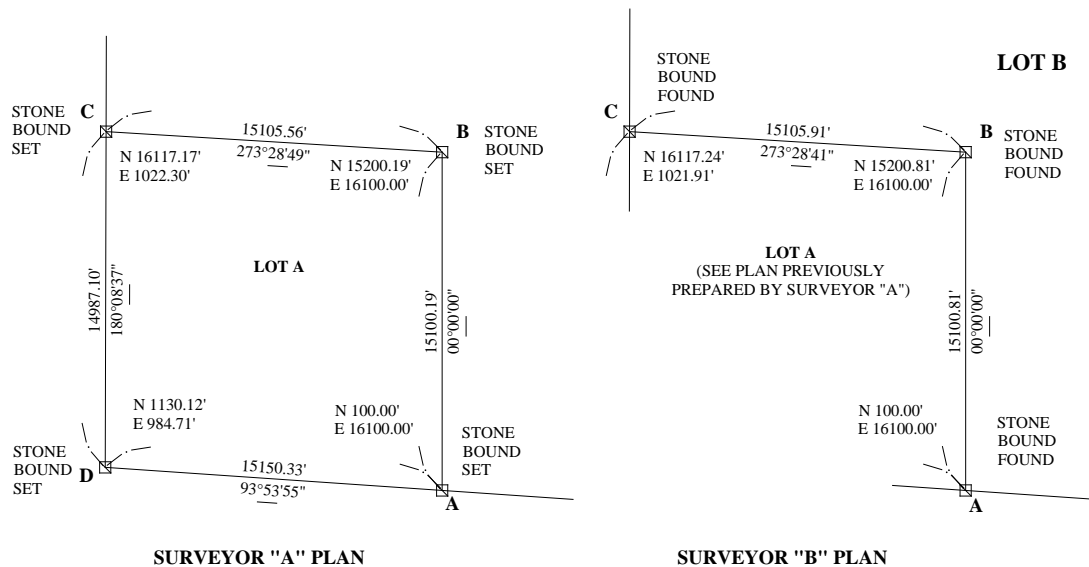


Figure 3.17 Surveyor's Plans Of Abutting Properties With 3 Common Corners

Assume that we change the previous thought experiment so that abutting lots (Lot A and Lot B) will be entered into the cadastre. Assume that bounds A, B, and C are common between the lots and that Surveyor A creates the survey plan for Lot A and then at a later date Surveyor B creates the survey plan for Lot B using the final measurements determined in Table 3.2. The two surveyor's plans might look like Figure 3.17.

Even though Lots A and B share the same three physical monuments definitively marking the same three boundary corners, the two plans will be different. The dilemma for the cadastre creator is what azimuth and distance to use for the two common boundary lines and/or what coordinates to use for the 3 common boundary corners. Even though the cadastre is only a model of parcel reality that is created by using the model of individual lots shown on surveyor's plans, the cadastre creator must be actively involved in analyzing and manipulating information from surveyor's plans to come up with the cadastre creator's professional opinion on what azimuth and

distance to show on each boundary line and what coordinate to show for each boundary corner.

One solution for this problem might be that the cadastre creator may hold individual surveyor's plans as they come into the cadastre. Subsequent surveyors creating surveyor's plans for new lots would be required to hold the measured distances and directions on boundary lines and to hold the coordinates of boundary corners previously entered into the cadastre. The problem would be that this might conflict with boundary line measurements and boundary corner coordinates determined by the subsequent surveyor as a result of a rigorous mathematical analysis of the survey field traverse performed by that surveyor. The subsequent surveyor, by holding these previously entered boundary line measurements and coordinates would most likely have to degrade the measurements and coordinates of the new boundary lines and corners that will go into the cadastre, resulting in more error going into the survey field traverse than just that caused by random error. This would result in the model of the land parcel shown on the surveyor's plan having even more error than the "true" land parcel that exists on the ground, which will also result in the cadastre having more error than that that exists on the ground.

3.2.7. Summary of a Physically Monumented Cadastre

A Physically Monumented Cadastre (PMC) is a cadastre using physical monuments set in the ground to define the location of boundary corners. A PMC is a model of reality. In summary, some characteristics of a PMC are:

- Surveyor's plans (on which a PMC is based) show parcel shapes that are distorted.

- Geodetic coordinates shown on a surveyor's plan (and describing the location of a boundary corner) have error.
- Measurements (directions and distances) shown on a surveyor's plan of boundary lines whose end points are definitively marked by physical monuments have error.
- Surveyor's plans that show boundary parcels have error and therefore are only models of reality (The reality being the definitive monuments in the ground that define a boundary corner.)
- Since a PMC is based on surveyor's plans, a PMC is also just a model of reality.

3.3. The Legal Coordinated Cadastre

As has been briefly discussed earlier, geodetic coordinates can be used to define the extent of property. The finite difference between this type of "monumentation" and other types discussed is that the property corners are defined using a mathematical construct and are thus not "visible" on the surface of the earth. They are in fact an application of the "physical monumentation" concept, which allows parcel delineation to be viewed in the virtual reality setting of the computer.

3.3.1. Overview Of Legal Coordinated Cadastre

A Legal Coordinated Cadastre (LCC) is a cadastre in which geodetic coordinates define the location of boundary corners of a registered parcel of land. Geodetic coordinates are a mathematical construct, a concept of the mind, not having a reality in the real physical world. Parcels of land that exist in an LCC may be viewed definitively on a computer monitor or a paper plan, and if the geodetic coordinates of

boundary corners are listed on the paper plan or may be determined on the computer monitor, then there is no better method of determining where the boundary corners are located than the computer monitor or paper plan. Thus an LCC is a system where the parcel exists in the virtual reality of the computer, and this virtual reality is in fact where the boundary corner locations of a parcel are defined (through the querying for a geodetic coordinate). To know where a boundary corner is located requires that the virtual reality of the LCC be queried for the associated geodetic coordinate by consulting the computer and the computer monitor. Thus the virtual reality of the computerized LCC becomes the actual reality of the parcel location. Since the location of every boundary corner of every registered parcel will be defined by a geodetic coordinate, then the LCC will show the definitive location of all registered parcels. Since the boundary corner locations of both ends of a boundary line are definitively known, the measurements of distance and direction of boundary lines can also be definitively determined. This also means that in an LCC, whether looking at a computer monitor of the LCC or a hard copy “snapshot” (a paper print) of the LCC, there is no distortion in the shape of parcels and thus no gaps or overlaps between parcels.

Thus, the LCC shows definitive locations and shapes of all registered parcels with no distortion and with no gaps or overlaps between parcels. There is nothing better than the LCC to show all the definitive parcels of land in a cadastre and where they are located. Suddenly, paper plans and images on a computer monitor no longer are showing a model of the reality of land parcel shape and location like they did in a PMC; instead in an LCC the plan and image are the reality of the land parcel. In a

PMC, the virtual reality of the computer and computer monitor were a model of reality, however in an LCC this virtual reality is no longer a model of reality but instead has become the actual reality of the definitive shape and location of parcels of land. (Note that Baudrillard in 1983 predicted that in certain situations virtual reality may become reality, a process that he called “hyperreality”. (Baudrillard 1983))

Even though a paper map or electronic image defines the definitive parcel of land, it is still necessary for parcel owners and others to know where the parcel is located on the ground. While the definitive coordinate of a boundary corner location can easily be determined in an LCC, the coordinate (and thus the boundary corner) cannot be automatically seen on the ground. A physical monument must be set in the ground to model the location of the definitive coordinate shown on the LCC. Land surveyors, professionals responsible for land boundary determinations, are the obvious choice for staking the location of such definitive boundary corner coordinates on the ground.

Geodetic coordinates define the location of boundary corners of parcels in an LCC, but owners and others still need to know where the parcel exists on the ground. A system must be instituted that allows geodetic coordinates to be staked on the ground. In the United States, NGS has created such a system. NAD83 is a terrestrial reference system, a virtual reality system in which geodetic coordinates may be defined (see Appendix A for a history of NAD83). When NGS created NAD83, they adopted all the fundamental and derived parameters that are associated with the Geodetic Reference System of 1980. These parameters included an ellipsoid whose semimajor axis was defined as having an exact distance of 6,378,137m and a flattening

number (to 12 significant figures) of 1/298.257222101. The center of the ellipsoid was defined as being at the geocenter of the Earth. The rotational axis of the ellipsoid was defined to have the direction of the Conventional International Origin for the Polar Motion (CIO) and the zero meridian was to be the same as that defined by Bureau International de l'Heure, (BHI). Geodetic coordinates may be measured on the surface of this ellipsoid. Such an ellipsoid and the geodetic coordinates measured on its surface are a mathematical construct, a concept of the mind, and if the ellipsoid is used to model the surface of the Earth, then the geodetic coordinates are virtual realities of locations on the Earth's surface. If geodetic coordinates alone define the location of boundary corners (as they do in an LCC), then the virtual reality of the geodetic coordinates becomes the reality of the definitive location of boundary corners of parcels included in the LCC. NGS has devised a method whereby virtual geodetic coordinates may be staked on the Earth's surface. NGS has taken the virtual reality of the terrestrial reference system known as NAD83 and tied it to the Earth's surface by creating a terrestrial reference frame such as NAD83 (CORS96). A reference system is "realized" into a reference frame by designating virtual geodetic coordinates based on the reference system to several identifiable points on the Earth's surface. For the reference frame NAD83 (CORS96), the locations of nine VLBI (very long base interferometry) stations in the United States were given geodetic coordinates, tying the reference system NAD83 to the Earth's surface. This tie was not an exact tie, since there is a certain amount (albeit a very small amount) of error involved. In other words, there is uncertainty and error in whether the geodetic coordinates that were designated for the location of the VLBI stations are correct. Thus there is some error

inherent in every reference frame, and thus when the reference frame NAD83 (CORS96) is used to designate a geodetic coordinate to a point on the Earth's surface there is some inherent error introduced.

Over the years, coordinates of a particular physical monument set by NGS have changed with each subsequent realization of the NAD 83 reference system. Over the years NGS has issued many different coordinates for the same point on the Earth's surface, and thus some may wonder whether a coordinate can in fact be used to define a boundary location. NGS has addressed this issue by creating NAD83 (CORS96), which is a realization not tied to specific physical monuments set by NGS, but is instead a "virtual" system using CORS stations that surveyors do not have to set upon. NGS monitors these CORS stations for movement to help maintain the high degree of accuracy of the CORS coordinates (See Appendix A for further discussion.)

A further explanation of the history of NGS and NAD83 is required to fully understand why NGS issued several coordinates over the years for the same point on the ground, and why the new realization NAD83 (CORS96) will solve this problem. (See Appendix A for a history of NGS and NAD83 and a discussion of the horizontal velocity of points in NAD83.)

3.3.2. Overview of Surveyors' Tasks In An LLC

The Surveyor will still have a defining role in the development and maintenance of a Legal Coordinated Cadastre (LLC). As either the original surveyor, or the retracement surveyor, their respective roles will involve using both physical monumentation and geodetic coordinates with respect to the registration process of the definitive location of a parcel of land.

3.3.2.1. Retracement Surveyors

Surveyors will perform two tasks for the LCC, and depending on which task is being performed will be classified as either an original surveyor or as a retracement surveyor. The task of the retracement surveyor is to stake on the ground with physical monuments the existing, decreed geodetic coordinates of parcel boundary corners (or to check that existing physical monuments previously set by other retracement surveyors still correctly mark the location of such geodetic coordinates). The task of the original surveyor is to aid the Court in the registration process whereby the Court first designates geodetic coordinates as the definitive location of boundary corners of new parcels of land being added for the first time into the LCC.

Retracement surveyors set physical monuments at the location of geodetic coordinates, but because of measurement error, it is theoretically impossible to definitively stake a geodetic coordinate on the ground. Thus, while the location of a boundary corner is definitively known on the computer monitor, it is impossible to definitively know where the boundary corner is located on the ground. Land surveyors are able to quantify the error inherent in staking such a physical monument in the ground that will model the location of the definitive coordinate.

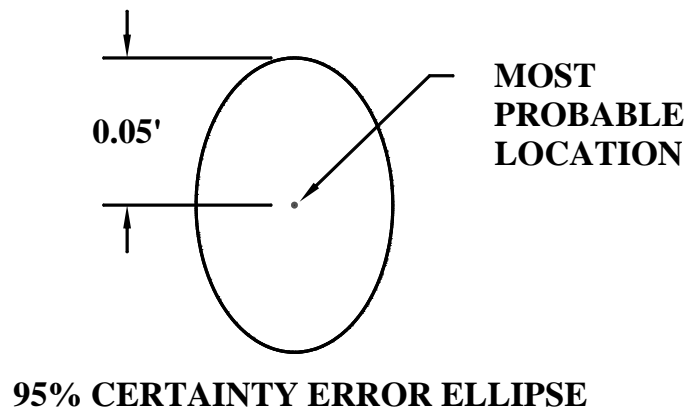


Figure 3.18 Uncertainty Of Staking A Geodetic Coordinate On The Ground

Thus, after setting such a physical monument in the ground, a land surveyor can certify to the best of their professional ability and opinion, that the center (or some other specified point) of the set monument is the most probable location of the definitive coordinate, but that the true location of the said coordinate is, for a given certainty (for instance, 95% certainty), within the confines of a given error ellipse that is centered on the most probable location. (See Figure 3.18 for an example).

Thus, for the situation shown in Figure 3.18, a parcel owner or others can rely on the fact that the true location of the boundary corner is located within ± 0.05 ft from the center (The center showing the most probable location of the boundary corner.) of the set monument with 95% certainty. The public will rely on the retracement surveyor who makes such a certification, and thus there will be liability issues involved for retracement surveyors. Certification and liability issues of the original surveyor are more involved and will be discussed in the next section.

As technology improves and geodetic coordinates can be staked on the ground with less and less error, there may be a time when this error (for the certainty required by law) will be less than 1mm. An assumption of this dissertation is that a measurement error of less than 1mm is insignificant and can be ignored and thus a measurement with such an error can be thought of as “exact”. Thus in the future a legal coordinated cadastre will not only show definitive boundary corner locations by a geodetic coordinate, but the physical monument set by the surveyor to mark where location of the boundary corner may also have no error.

3.3.2.2. Original Surveyors

When registering a new parcel into LCC, due process of law requires that all interested parties be able to see where the new boundary corners will be located on the ground. The courts will then adjudicate and decree geodetic coordinates as the definitive location of these boundary corners. The problem with this system is that physical monuments must first be set at the proposed boundary corners. Interested parties will then rely on those physical monuments as marking the proposed boundary corners and will respond to the adjudication process accordingly. After all interested parties are heard, the courts will decree geodetic coordinates as being the definitive location of the boundary corners. Thus interested parties will rely on physical monuments set before the adjudication process is complete, but the location of these relied-upon physical monuments will not be definitive, but will be subservient to the decreed geodetic coordinates.

Before an LCC is created, existing parcels are either non-registered parcels (created by deed in the registration of deeds process) or registered parcels (created through a Torrens type registration of title process), but in all cases the definitive location of boundary corners of such existing parcels is by the current paradigm of a physical monument set in the ground. Some of these physical monuments (such as a drill hole set in a massive piece of exposed bedrock) may have marked the definitive location of a boundary corner for hundreds of years. Yet when an LCC is created and a parcel of land is registered into the LCC, the physical monument that may have defined a boundary corner for hundreds of years will no longer serve that purpose. Such a physical monument can no longer be used; only a geodetic coordinate can definitively mark the location of a boundary corner. The procedure to register a parcel of land into the LCC is the legal process whereby the Court after due process will decree a new registered parcel of land whose location is defined by geodetic coordinates, and not by physical monuments set in the ground. This procedure can be developed to protect interested parties when they rely on the physical monuments prior to the court decreeing definitive geodetic coordinates.

The LCC registration process begins with a plan (the filed plan) submitted to the Court by the plaintiff, showing the proposed parcel of land with proposed geodetic coordinates that will define the location of the boundary corners. This filed plan is prepared by the plaintiff's surveyor (the original surveyor). (While the original surveyor is employed by the plaintiff, the original surveyor who prepares a filed plan with the Court owes his primary obligation to the Court, making certifications to the Court and following the Court's instructions.) The original surveyor serves as the eyes

of the Court, and thus the Court will be relying on the original surveyor to offer proposed geodetic coordinates marking the original surveyor's professional opinion of the location of the proposed parcel.

When a parcel is first registered into the LCC, the original surveyor will first have to determine his professional opinion of the size, shape, and location of the parcel. Prior to being registered into the LCC, every existing parcel of land presumably was defined by physical monuments set on the ground. Thus the original surveyor will follow the same procedure as that previously discussed for when surveyors prepare surveys and plans when physical monuments define location, which procedure is briefly described as follows.

After locating physical monuments and other pertinent information from a closed field traverse or GNSS survey, the original surveyor will create a plan in which rectangular coordinates will be created for the field-located physical monuments and other pertinent information. The original surveyor will then be able to use the said plan of existing conditions on the ground to determine his professional opinion of the size, shape, and location of the parcel. The original surveyor can then prepare a filed plan showing his professional opinion of the proposed parcel as well as the geodetic coordinates for the boundary corners for the parcel.

While a geodetic coordinate is used to define a boundary corner location in an LCC, it cannot be seen on the ground. However, the registration process requires that before the final judgment, all parties be able to see where the proposed parcel is located on the ground. Thus while only geodetic coordinates can legally define boundary corners, physical monuments are required to be set as part of the registration

process before the Court decrees the final location of the definitive boundary corner using geodetic coordinates.

The fundamental concept of the LCC is that boundary corners can only be defined by geodetic coordinates. Thus a fundamental problem that must be addressed is what to do if the location of the definitive geodetic coordinates as decreed by the Court is substantially different than the location of the physical monuments set before the final judgment and decree of the Court. In other words, what happens if the parties involved in the registration process (such as the parcel owner and abutting parcel owners) having relied on the physical monuments set by the original surveyor before the registration, are harmed because it is later found that the definitive geodetic coordinates decreed by the Court (after those physical monuments were set) are in a substantially different location.

The original surveyor is responsible for determining the proposed geodetic coordinates as shown on the filed plan for the parcel being registered, and is also responsible for setting physical monuments that model the location of where those coordinates exist on the ground. In fact, some of these physical monuments may already exist in the ground (such as the before-mentioned drill hole in a massive piece of exposed bedrock that for hundreds of years marked the definitive location of a boundary corner of a parcel of land that existed before the LCC was created). In such a case, the original surveyor will show on the filed plan the proposed geodetic coordinate for such a boundary corner, and will also show on the filed plan that the boundary corner is marked on the ground by a physical monument that existed before the registration process began to get the parcel into the LCC. It is possible that the

original surveyor could blunder so that one or more of the physical monuments are in a different location than that of the proposed geodetic coordinates. What happens when such a blunder occurs?

In an LCC only a geodetic coordinate can define a boundary corner. Thus if the location of a boundary corner is associated with both a decreed geodetic coordinate and a physical monument set in the ground, the geodetic coordinate will hold and the physical monument will fail to show the definitive boundary corner location. In the registration process where an existing non-registered parcel is being registered into the LCC, the procedure requires that the original surveyor set physical monuments at the location of proposed geodetic coordinates defining the proposed boundary corners of the parcel of land being registered into the LCC. In this case, the physical monument will exist before the Court decrees the geodetic coordinates as being the definitive location of the boundary corner, however the definitive location will be the geodetic coordinate and not the physical monument, even if there is a discrepancy between the two. Even in the case where the original surveyor uses an existing physical monument that previously marked the definitive boundary corners of a non-registered parcel of land that is now being registered into the LCC, if there is a discrepancy between the location of that existing physical monument and the decreed geodetic coordinate, the geodetic coordinate will hold, and the existing physical monument will fail.

The public will rely on the original and retracement surveyors' certification that the locations of physical monuments in the ground that mark the location of the definitive geodetic coordinates are within the required tolerance. This includes physical monuments newly set by a retracement surveyor, existing physical

monuments previously set by other original or retracement surveyors that are now being recertified by a retracement surveyor, or physical monuments set by the original surveyor as part of the registration process. If a party is harmed because the location of the physical monument was not at the location of the definitive geodetic coordinate within the specified tolerance, then the surveyor will be liable for damages. An LCC should therefore specify that all original and retracement surveyors must carry a specified amount of professional liability insurance for such situations.

A special case exists for those harmed because the location of physical monuments set by the original surveyor before the final judgment of the registration case do not mark the location of the final geodetic coordinates decreed by the Court after the physical monuments were set within the specified tolerance. In this case the LCC should follow the method that the Torrens system of registration uses for such a situation in that the owner of the land as registered and as located by the geodetic coordinates shall hold the land free from all encumbrances, while those that are harmed because they are deprived of the land as shown by the physical monuments will be able to make a claim against the Assurance Fund that will be a part of the LCC. Note that the original surveyor will still have liability issues with regard to the Court and other parties. For instance, the Massachusetts Land Court registration system states:

- *Every plaintiff receiving a certificate of title in pursuance of a judgment of registration, and every subsequent purchaser of registered land taking a certification of title for value and in good faith, shall hold the same free from all encumbrances except those noted on the certificate. (MGL c185 s46)*

- *... a person who, without negligence on his part, is deprived of land or of any estate or interest therein, by the registration of another person as owner of such land or of any estate or interest therein, through fraud or in consequence of any error, omission, mistake or miss-description in any certificate of title or in any entry or memorandum in a registration book may institute an action in contract in the superior court for compensation from the assurance fund for such loss, damage or deprivation; but a person so deprived of land or of any estate or interest therein, having a right of action or other remedy for the recovery of such land, estate or interest, shall exhaust such remedy before resorting to the action of contract herein provided. (MGL ch185 s101)*

Thus, when registering a new parcel into LCC, the original surveyor will set physical monuments on boundary corners before the adjudication process ends and the courts will decree geodetic coordinates for those same boundary corners after the adjudication process ends. The geodetic coordinates will be definitive, but interested parties can rely on the fact that the locations of the physical monuments set before the decree are located within a specified tolerance of the this definitive coordinate. If the location of the physical monument is located farther away than the specified tolerance, and if because of this the interested party is harmed, then the coordinate will hold and the interested party will be compensated by the Assurance Fund for such loss, damage or deprivation.

After a parcel is registered into LCC, retracement surveyors will either certify that existing physical monuments previously set by the original or other retracement surveyors are still located within the specified tolerance of the decreed geodetic coordinate; or will set new monuments to replace disturbed or destroyed physical monuments and will certify that these new physical monuments are located within the prescribed tolerance of the decreed geodetic coordinate. If an interested party is

harmful because the said monument is not within tolerance, then the retracement surveyor will be liable for damages.

3.3.3. Encroachments in an LCC

Besides knowing where boundary corners are located on the ground, parcel owners and others may want to know the distance that physical objects on the ground are located from a boundary line. This process will be illustrated through another thought experiment.

Suppose a parcel owner wants to know whether the corner of his garage encroaches over the boundary line. To know the definitive boundary line, one must look at the computer monitor of the LCC. The problem is that the corner of the garage is not automatically shown in the LCC. Someone must determine the coordinate of the garage corner and then enter the coordinate into the LCC so that it can be seen on the computer monitor. Because of measurement error, it is impossible to determine the true, exact coordinate of the location of the existing garage corner. However, a land surveyor can determine a coordinate that is his best professional opinion of the most probable value of the location of the garage corner, and can then certify that he is 95% certain that the true coordinate is located within a given error ellipse centered on the coordinate as so determined.

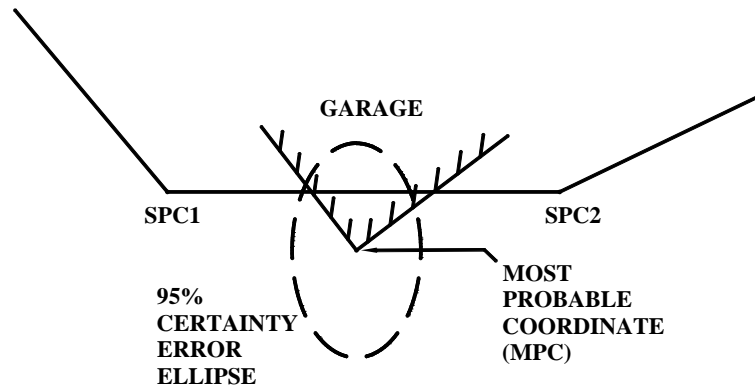


Figure 3.19 Most Probable Location Of A Physical Object Entered Into The LLC

For instance, assume that Figure 3.19 shows a possible situation in which a parcel owner wants to know if his garage encroaches over the boundary line.

Figure 3.19 shows an image of the computer monitor, or a copy of a paper plan of the LCC, and shows the definitive boundary lines as being between the definitive boundary corners whose locations are defined by coordinates SPC1 and SPC2. The most probable location of the corner board of the garage has been determined by a land surveyor to be coordinate MPC (named for “most probable coordinate”), and the 95% error ellipse associated with this coordinate is also shown (centered on MPC). The land surveyor knows that while the most probable location of the corner of the garage as shown in the computer monitor is at the center of the ellipse, the surveyor also knows that, with 95% certainty, the true coordinate of the garage corner lies somewhere inside the ellipse. While the surveyor might state that based on his professional opinion, the corner appears to encroach over the boundary line, he cannot say that it encroaches with 95% certainty. MPC is the coordinate showing the most probable location of the garage corner, in which case the garage corner does appear to encroach.

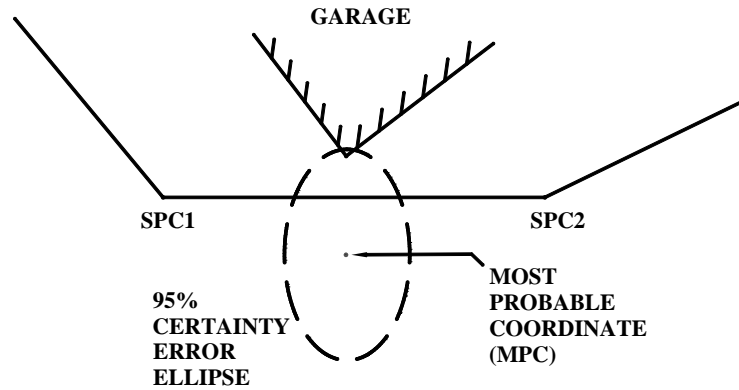


Figure 3.20 A Possible Location Of A Real World Object Entered Into The LLC

However, Figure 3.20 shows another possible location of the garage corner that is still within the 95% certainty ellipse, which would show no encroachment.

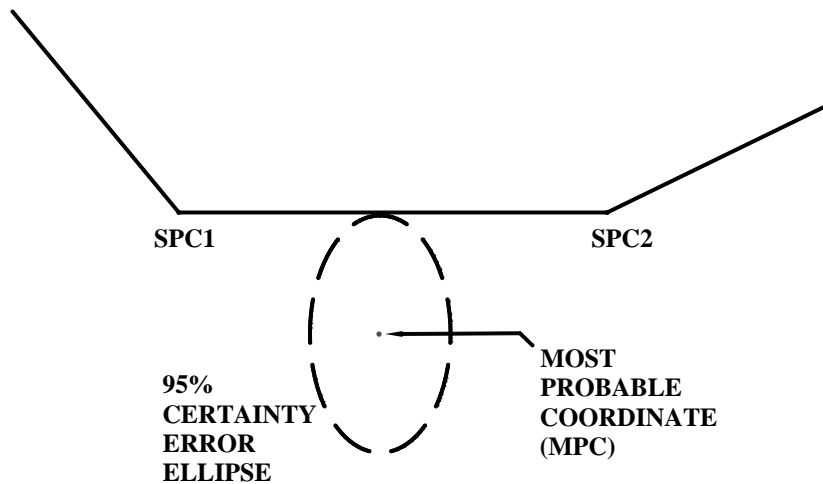


Figure 3.21 95% Certainty Of Encroachment

Thus, to be 95% certain that an encroachment has taken place, the entire 95% error ellipse must be located over the line, as shown in Figure 3.21.

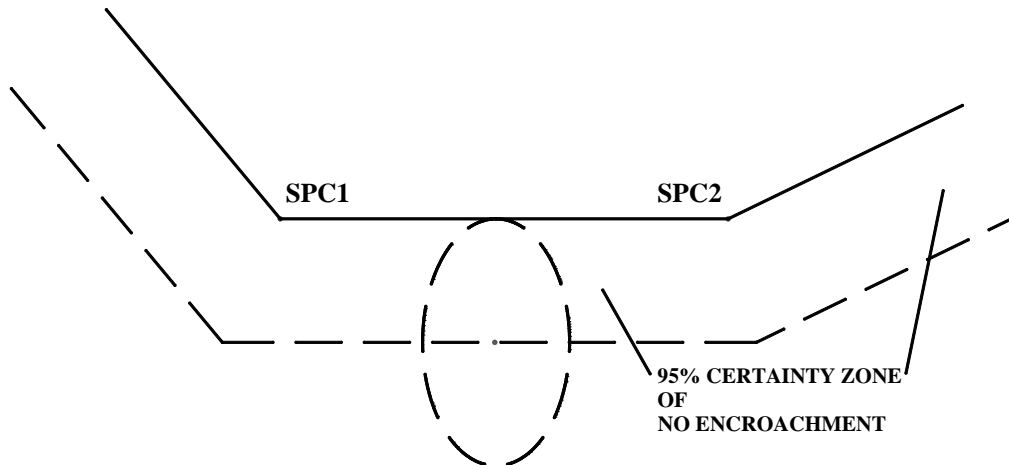


Figure 3.22 95% Certainty Of No Encroachment

To be 95% certain of an encroachment, the MPC must be encroaching by more than the semimajor axis distance of the error ellipse. Thus there is a zone along the boundary line within which the MPC may appear to encroach but for which there is less than a 95% certainty that there is in fact an encroachment. (See Figure 3.22).

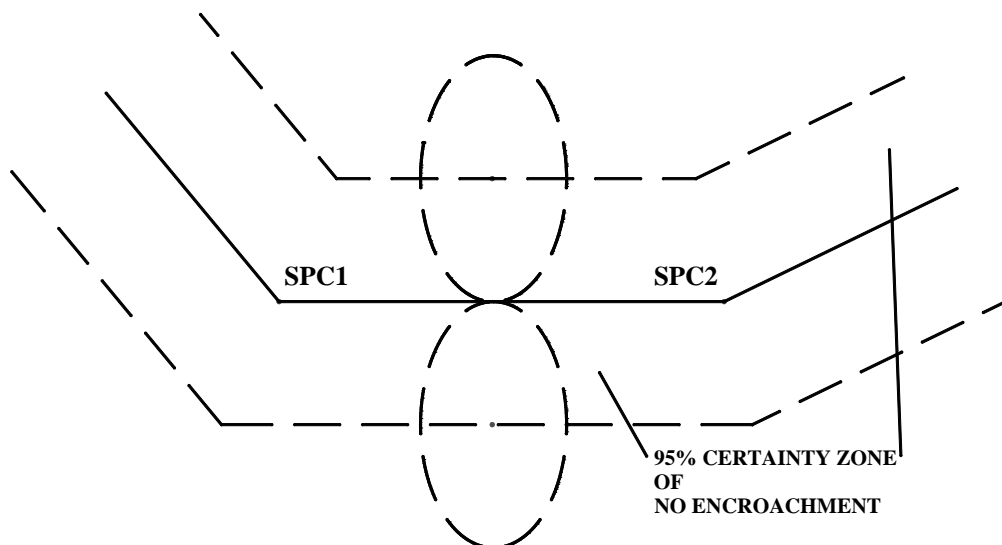


Figure 3.23 No Encroachment Zone For A Boundary Line

If we include this no-encroachment zone for the abutting parcel, the zone would look like Figure 3.23. Thus, if it can be shown that the MPC is located within this zone, then it can be said that it is not an encroachment with 95% certainty.

Therefore, with an LCC, two items need to be decided upon before the concept of encroachment can be dealt with: one is to decide upon the required certainty that an encroachment has in fact taken place; the other is to decide upon the required values of the parameters (the semimajor axis and semiminor axis lengths) of the error ellipse for the given certainty. Possible certainty values might be 95% or 99.7% (3 sigma). The parameters of the permitted error ellipse might be simplified by making an error circle out of the error ellipse by specifying that the semiminor axis be equal to the semimajor axis, in which case only one number (the radius) is needed to specify the error circle. This error circle might be determined based on how precisely land surveyors can determine the coordinate of an existing object.

As a final note, historically plans and images on a computer monitor that have modeled boundary lines have shown the boundary lines as having the same line width no matter what scale the boundary lines are shown at. For instance, a paper plan might show a line width of 0.35mm, and the computer monitor image might show a line width of one pixel, no matter if the scale shown is 1=10 or 1=10,000. Thus, if we zoom in or zoom out, the boundary line is always the same width on the plan or image. (For instance, a 0.35mm line on the paper plan will correspond to a 3.5mm line on the ground at a scale of 1=10, but will correspond to a 3500mm (3.5 m) line on the ground at a scale of 1=10,000). For an LCC, if the widths of boundary lines are fixed by using

an absolute width equal to the diameter of the said error circle, then the no-encroachment area of a boundary line will be shown no matter how much one may zoom in.

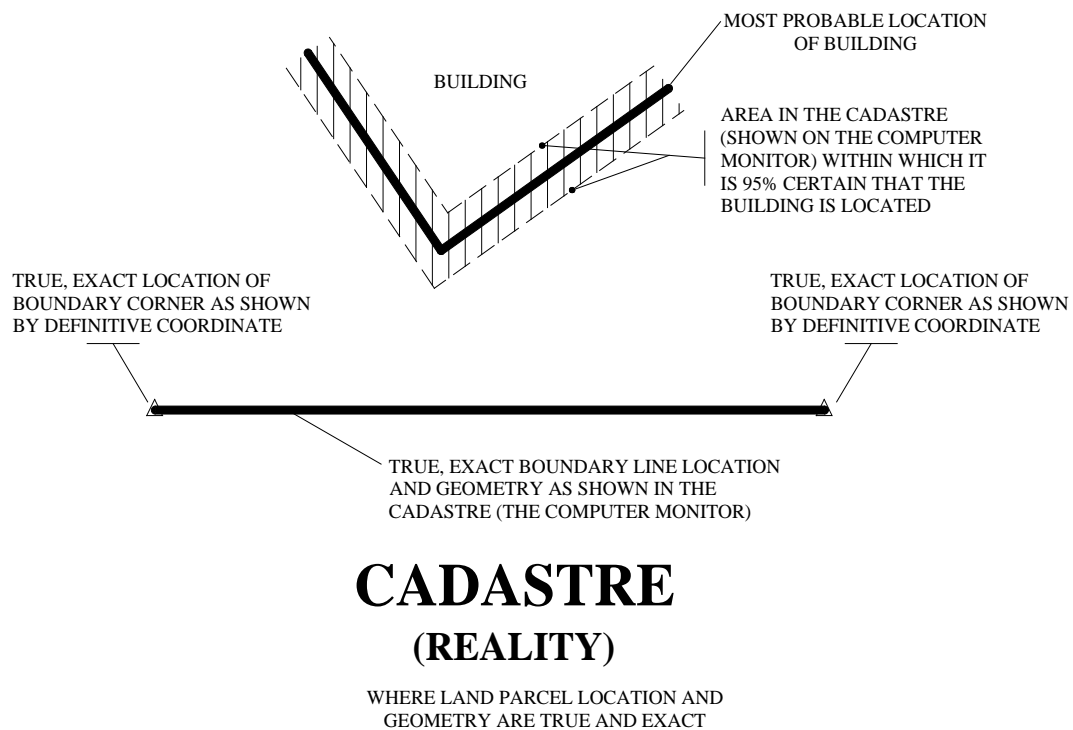
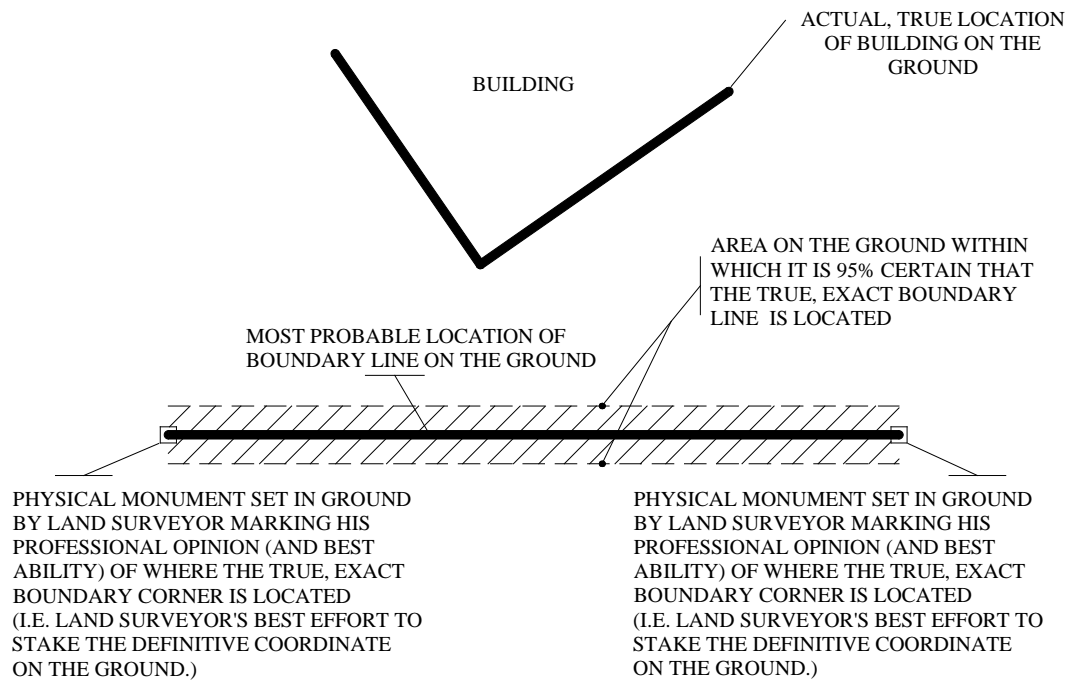


Figure 3.24 The Cadastre Reality Is Shown On A Computer Monitor

In an LCC, reality is shown on the cadastre as it appears on the computer screen (as shown in Figure 3.24). True and exact locations of boundary corners are shown by definitive coordinates. Boundary line locations and geometries are also true and exact. However, the location in the cadastre and on the computer screen of any object that exists in the real world on the surface of the Earth is only approximately known.



ON THE GROUND (MODEL)

WHERE LAND PARCEL LOCATION AND
GEOMETRY ARE MODELED

Figure 3.25 The Cadastre Can only Be Modeled On The Earth's Surface

As shown in Figure 3.25, the cadastre can only be modeled approximately on the surface of the Earth. Thus the location of a boundary corner can only be approximated by a physical monument set in the ground, and the location of boundary lines can only be approximated. However, (obviously) the locations of real objects (such as buildings) on the ground are true and exact.

3.3.4. Surfaces in an LCC

One of the challenges of the Legal Coordinated Cadastre has to do with surfaces-specifically two-dimensional and three-dimensional surfaces as they relate to parcel location and its depiction in a seamless, multipurpose cadastre. To adequately understand the ramifications of these types of surfaces and their respective impacts to accurate parcel depiction, we need to discuss how they relate to parcel definition both on the surface of the earth and in a model such as a plan or on a computer screen.

3.3.4.1. Overview of Surfaces in an LLC

Cadastrals should be seamless. (For instance, the goal of the National Integrated Land System is to create a seamless national multipurpose cadastre (Bureau of Land Management 2006)). “Seamless” means that there will be no gaps or overlaps in the fabric of land ownership (In other words, every point on the terrain surface in the nation will be included in one and only one parcel of land.) As described above, the two-dimensional horizontal plane is normally used when describing a parcel’s dimensions and area. However, for large parcels of land it is necessary to take into account the curvature of the Earth.

A two-dimensional coordinate system that is draped over the two-dimensional terrain surface itself would be ideal because a cadastre using such a coordinate system to model a point on the terrain surface would only need two coordinates. One reason why such a coordinate system would be difficult to model is the tremendous range of elevations that exist on the terrain surface (For instance, while Mount Everest has an

elevation that is higher than 8000 m above the mean level of the oceans, the Mariana Trench has an elevation that is lower than 10,000 m below the mean level of the oceans.)

A simplification of the above system would be to reduce the location of all points on the terrain surface to a two-dimensional curved surface that has a common datum (or “elevation”). Thus all points on the terrain surface might be described by the two-dimensional coordinate on the curved surface, as well as a third value of the elevation difference between the datum “elevation” and the elevation of the point on the terrain surface. Since gravity is important in determining the horizontal plane, so gravity would be important to this simplified surface. One such surface, the geoid, has a datum that is an equipotential surface that approximately coincides with the mean ocean surface. Thus every point on the terrain surface can be described by a unique two-dimensional coordinate on the geoid surface and a third value of the difference in height between the geoid and the point on the terrain surface (This height is defined as the orthometric or vertical height.) However, because of gravity anomalies and other factors, the geoid surface cannot be easily defined mathematically. A better system might use a reference ellipsoid instead of the geoid.

A reference ellipsoid, whose surface is mathematically defined, may be created to approximate the geoid surface. One reference ellipsoid used in the United States is the Geodetic Reference System of 1980 (GRS 80). Every point on the terrain surface can be described by a two-dimensional geodetic coordinate (longitude $\{\lambda\}$ and latitude $\{\varphi\}$) on the surface of GRS 80, and a third quantity of the difference in height between the ellipsoid and the point on the terrain surface (the ellipsoidal height).

Performing ellipsoidal computations on the reference ellipsoid to determine dimensions of boundary lines and area are complex, and flat maps are more convenient and useful than globes when modeling large parcels of land. A map projection might be used to reduce the two-dimensional curved surface of a parcel of land on the ellipsoid to a flat surface that can be shown on a flat map. One such map projection used in the United States is the State Plane Coordinate System of 1983 (SPC 1983) (Stem 1983). To describe a point on the terrain surface, map projection systems must first be reduced to the ellipsoid. Conversely, field measurements and observations on the terrain surface must be reduced to the ellipsoidal surface before being further reduced from the ellipsoidal surface to the map projection surface. While this dissertation will use geodetic coordinates to describe locations on the terrain surface, these locations could also be described by SPC.

3.3.4.2. Use of the Ellipsoidal Normal to Model the Plumb Line

When describing the volume of ownership of a parcel of land, physical monuments are typically placed on the terrain surface to establish the location of the parcel boundary corners. The volume of land ownership that exists above and below the terrain surface runs along the direction of gravity (or in the direction of the plumb line). The plumb line is the space curve that is always tangent to the direction of gravity and connects a point on the surface of the Earth to a point on the geoid (Smith 2001). However, when using geodetic coordinates (or SPC) to model this volume of Earth, the ellipsoidal normal (rather than the plumb line) is used to connect a point on the surface of the Earth with a point on the ellipsoid. The problem is that the direction

of the ellipsoidal normal is different than the direction of the plumb line. Thus while the plumb line does run along the boundary of the volume of land ownership, the ellipsoidal normal does not.

The direction of gravity depends on the gravity potential field of the Earth, which changes for the following periodic and secular reasons (Smith 2001):

- Lunar and solar tides on the oceans, atmosphere, and lithosphere
- Seasonal shifts in the water table
- The falling of leaves, and growing of new leaves in fall and spring (small, probably barely measurable, but an unquestionable seasonal shift in the mass distribution of the Earth)
- Plate tectonics
- Post-glacial rebound

While the plumb line is a space curve, it is typically considered as a straight line (and thus describes the “average” direction of gravity at a particular point on the surface of the Earth). The difference between the direction of the plumb line and the direction of the ellipsoidal normal is quantified by the Deflection of the Vertical (DOV). (The National Geodetic Survey (NGS) has developed a database and software program called DEFLEC09 that can calculate the DOV for a point with known (ϕ, λ, h) . The DOV is made up of a component ξ (ξ) along the meridian, and a component η (η) along the prime vertical. (National Geodetic Survey 2006))

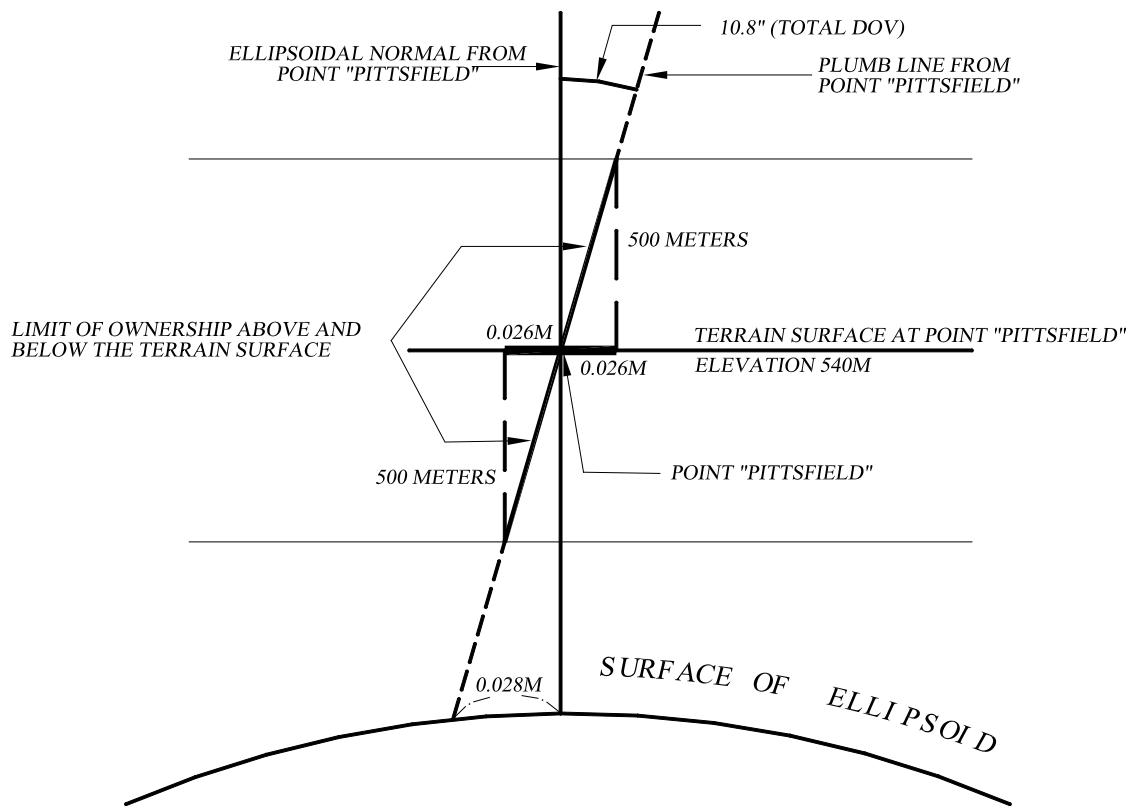


Figure 3.26 Ellipsoid Normal Modeling The Plumb Line

In order to describe the error introduced by using the ellipsoidal normal to model the plumb line, please refer to Figure 3.26

Figure 3.26 will be used to analyze the error introduced by using the ellipsoidal normal to model the plumb line (See also (Brown 2002) Figure 1). This figure describes a hypothetical boundary corner (Point Pittsfield) located on the terrain surface in western Massachusetts. This point was scaled off of the Pittsfield West Quadrangle 7.5 minute series topographic map that was prepared by the United States Geological Survey. The scaled coordinates of Point Pittsfield on the terrain surface on the said map have a latitude of North 42 degrees, 25 minutes, 00.00000 seconds, a longitude of West 73 degrees, 22 minutes, 30.00000 seconds and an ellipsoidal height

of 540 m (The USGS map uses orthometric heights, which can be converted to ellipsoidal heights by applying the geoid height N . For this point an orthometric height of 570 m was scaled off the map. The NGS software program GEOID09 (National Geodetic Survey 2006) calculated an approximate $N = -30$ m and thus the ellipsoidal height is about 540 m.) Based on these geodetic coordinates, the DEFLEC09 program (National Geodetic Survey 2006) gives DOV with components $\xi = +1.10$ seconds and $\eta = -10.76$ seconds. Using these components, the maximum DOV for this point is about 10.8 seconds.

Two problems are evident in Figure 3.26. The first problem has to do with describing three points on the vertical boundary line (of the volume of land ownership) that goes through Point Pittsfield. Assuming the limits of ownership to be 500 m above and below the Earth's surface, then the three points would be the upper limit of the vertical boundary line, the lower limit of the vertical boundary line, and the vertical boundary line as it intersects the terrain surface (at Point Pittsfield) half way between the upper and lower limits of the vertical boundary line. As described above, the volume of ownership follows the plumb line. If instead we drop an ellipsoidal normal from the upper limit of the vertical boundary line, it will intersect the terrain surface about 26 mm (0.026 m) from Point Pittsfield. Extending an ellipsoidal normal up from the lower limit of the vertical boundary line will intersect the terrain surface about 26 mm (0.026 m) from Point Pittsfield, but in the opposite direction of the first. The result is that these two ellipsoidal normals will intersect the terrain surface 52 mm apart (0.052 m). Thus using the ellipsoidal normal to model the direction of the volume of land ownership will introduce an error of ± 26 mm.

The second problem has to do with describing the location of Point Pittsfield by where it intersects the ellipsoidal surface (which is the surface on which ellipsoidal coordinates are located). In order to determine what the ellipsoidal coordinates are for Point Pittsfield (which exists on the terrain surface), the ellipsoidal normal must be dropped from Point Pittsfield until it intersects the ellipsoidal surface. The coordinates of this intersection point on the ellipsoidal surface will be the coordinates of Point Pittsfield. However, if we next extend a plumb line from Point Pittsfield, the intersection point with the ellipsoidal surface will be 28 mm (0.028 m) away from the intersection of the ellipsoidal normal dropped from Point Pittsfield.

One way to deal with these two problems would be to model the location of Point Pittsfield on the terrain surface by using the ellipsoidal coordinates created by dropping an ellipsoidal normal from Point Pittsfield (at the terrain surface) to the ellipsoidal surface, but then realize that modeling the vertical boundary line of the parcel volume by the ellipsoidal normal will introduce a total error of ± 26 mm when describing the upper and lower limits of ownership.

While Point Pittsfield was picked to show the error created by using the ellipsoidal normal to model the plumb line because of the extreme values of ellipsoidal height (540 m) and DOV (10.8”), there will be error at all points where the DOV is not equal to zero.

A	B	C	D	E	F	G	H	I
ashleyfalls	42.0340	-73.2900	645	-30.307	615	2.39	-11.52	11.8
cohasset	42.1445	-70.4800	15	-27.684	-13	-4.93	-2.19	5.4
greenfield	42.3730	-72.3720	60	-28.162	32	-3.63	1.72	4.0
newburyport	42.5000	-70.5500	15	-26.941	-12	-0.68	-3.26	3.3
methuene	42.1920	-72.3420	64	-28.574	35	-2.74	-1.54	3.1
pittsfieldwest	42.2500	-73.2230	570	-30.260	540	0.98	-10.47	10.5
pocasset	41.4000	-70.3230	40	-28.367	12	-1.30	-6.33	6.5
springfieldsouth	42.0230	-72.3230	60	-28.962	31	-2.96	-0.13	3.0
townsend	42.4000	-71.3730	123	-27.779	95	-2.83	-1.30	3.1
webster	42.0500	-71.5000	222	-29.055	193	-4.70	1.77	5.0
williamstown	42.4000	-73.1230	290	-29.610	260	2.34	-12.12	12.3

Column A: Name of USGS Quad Sheet from which point was scaled

Column B: Latitude of scaled point (Degrees.Minutes.Seconds)

Column C: Longitude of scaled point (Degrees.Minutes.Seconds)

Column D: Orthometric height of scaled point (Meters)

Column E: Geoid undulation N for scaled point (Meters)

Column F: Geodetic height for scaled point (Meters)

Column G: DOV along the meridian ξ (Seconds)

Column H: DOV along the prime vertical η (Seconds)

Column I: Total DOV (Seconds)

Table 3.3 Representative Sample of DOV in Massachusetts

Table 3.3 (taken from (Brown 2002)) is a representative sample of DOV for various points in Massachusetts, created by scaling geodetic coordinates and orthometric heights from USGS topo maps and inputting these values into the NGS DEFLEC09 program to come up with the DOV. Column F describes the ellipsoidal

height and Column I describes the DOV for each point. (See also Figure 1 (Brown 2002) for a more extreme example located in Colorado.)

For example, assuming a 500-meter limit of ownership above and below the Earth's surface, the use of the ellipsoidal normal to model the plumb line will result in an error of 69 mm for Williamstown, and 30 mm for Pocasset.

3.3.4.3. Equipotential Surface

In the United States, the surface on which legal distances, directions and areas of parcels of land are measured is the horizontal plane. Thus the LCC should also use the horizontal plane for such legal measurements

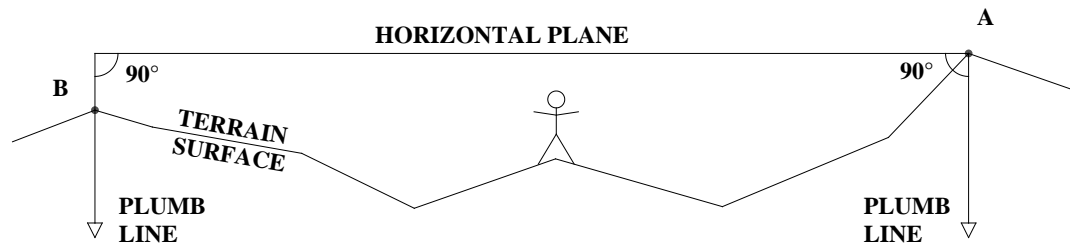


Figure 3.27 Horizontal Distances Measured On Horizontal Plane

Horizontal distances must be measured between boundary corners, even if the Earth's surface (the terrain surface) between the boundary corners is not a horizontal plane. Figure 3.27 shows an example where it is desired to know the distance of the boundary line between boundary corners A and B. Such a boundary line distance must be a horizontal distance, which is measured on a horizontal plane. Such a horizontal plane may be created by picking a common point on the terrain surface that will also be a point on the horizontal plane (Point A in Figure 3.27), and orienting the plane so

that it is perpendicular in all directions to the plumb line at that point. Since the horizontal plane is only fixed to one point (Point *A*) on the terrain surface, it is probable that the other point (Point *B*) will not be exactly located on the horizontal plane. It is therefore necessary to project Point *B* onto the horizontal plane by using a plumb line at Point *B*.

When measuring a horizontal distance between Points *A* and *B*, it is assumed that the plumb lines at both *A* and *B* are perpendicular to the horizontal plane (an acceptable assumption for relatively small parcels of land) as shown on Figure 3.27 (More generally, the assumption is that plumb lines at every point on the horizontal plane will be parallel to each other.). However, this is not the case because plumb lines are oriented toward the center of the Earth's mass and are affected by local and regional gravity anomalies, and thus plumb lines of points within the horizontal plane are not parallel to each other, nor perpendicular to the horizontal plane (except for Point *A* used to define the horizontal plane).

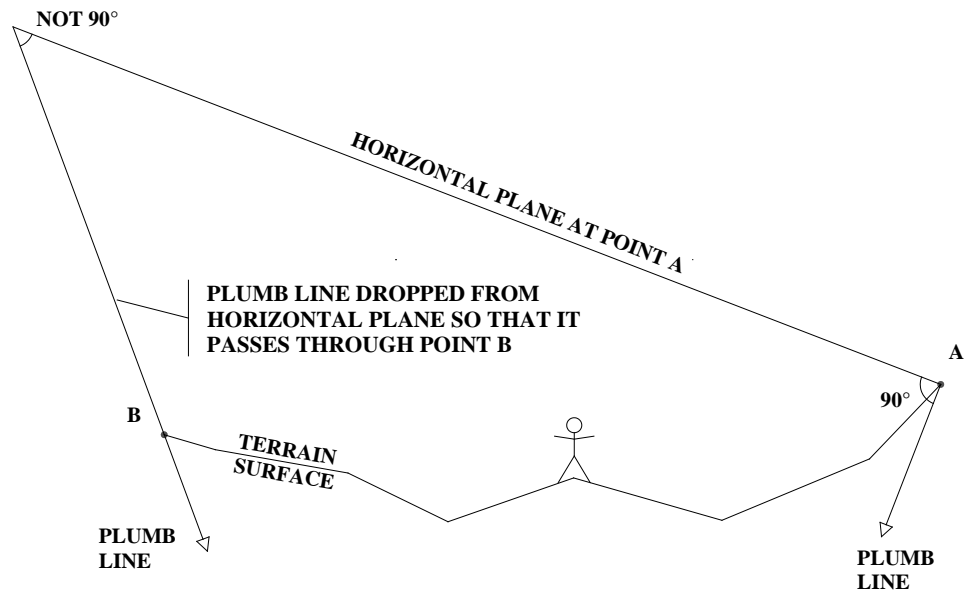


Figure 3.28 One Horizontal Plane On The Terrain Surface

For example, Figure 3.28 shows such a situation where the plumb line at Point *B* is not perpendicular to the horizontal plane. The horizontal distance between boundary corners *A* and *B* as measured on the horizontal plane will have error because the plumb line at *B* is not perpendicular to the horizontal plane.

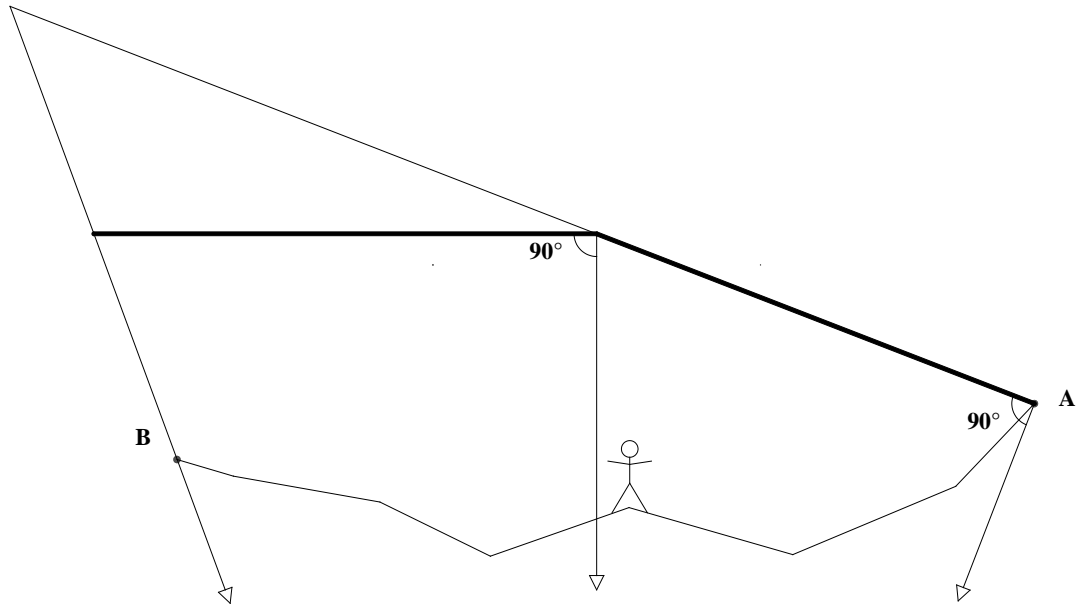


Figure 3.29 Two Horizontal Planes On The Terrain Surface

Figure 3.29 shows an example where two horizontal planes are used to measure the distance between Points *A* and *B*. In the figure, the horizontal plane to the right is perpendicular to the plumb line at Point *A*, while the horizontal plane to the left is perpendicular to the plumb line at a point about halfway between Points *A* and *B*. Note that the plumb line at Point *B* is still not perpendicular to this second horizontal plane, but is closer to perpendicular than the single horizontal plane in Figure 3.28.

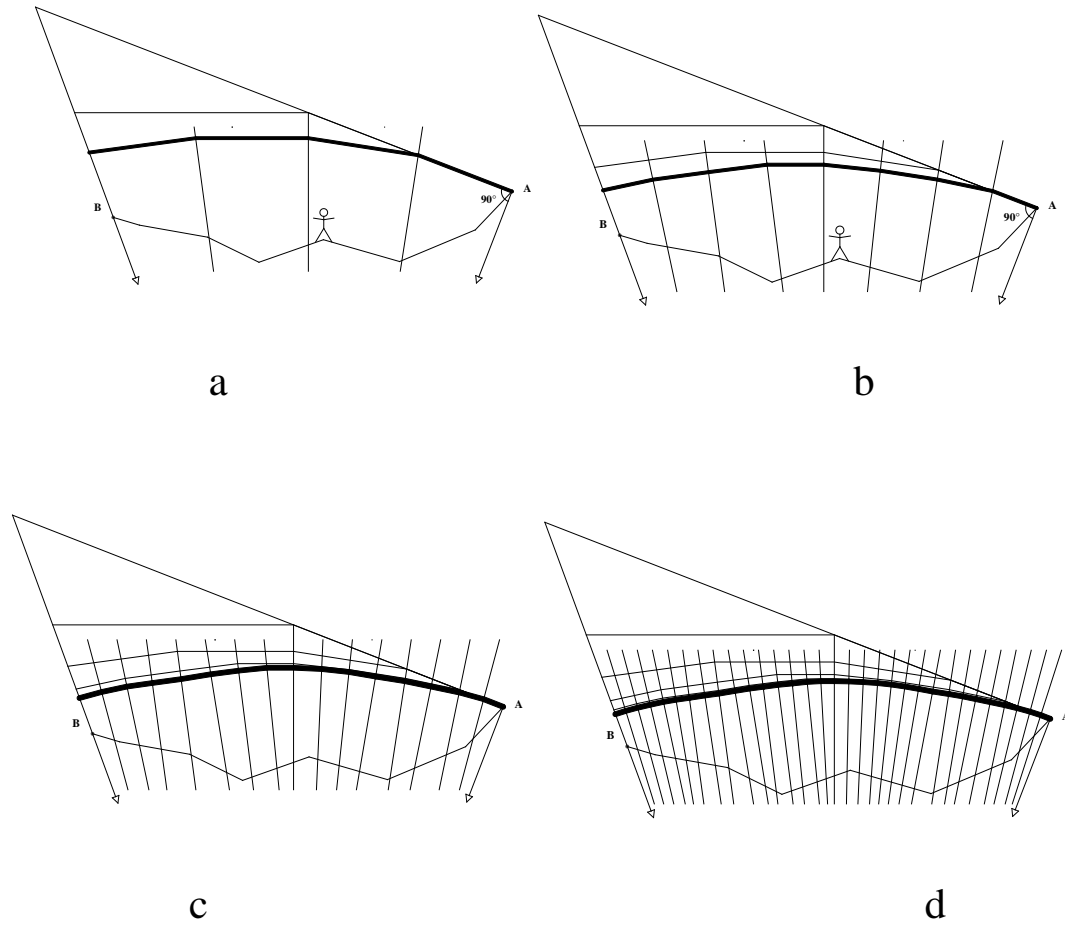


Figure 3.30 Multiple Horizontal Planes Added On The Terrain Surface

Figure 3.30a shows four horizontal planes, each of which is perpendicular to the plumb line located at its right corner. The horizontal distance between Points A and B is the total distance measured along each of the 4 horizontal planes. (Note that while the left most horizontal plane is not exactly perpendicular to the plumb line at Point B, it is getting closer). Figures 3.30b, 3.30c, and 3.30d show 8 horizontal planes, 16 horizontal planes, and 32 horizontal planes, respectively. (Note that the left most horizontal plane in Figure 3.30d is very close to being perpendicular to the plumb line at

Point *B*, and thus the total distance of all the distances measured on each of the 32 horizontal planes will be very close to the legal distance of the boundary line between Points *A* and *B*).

This procedure can be continued, and as more and more horizontal planes are created between Points *A* and *B*, the distance measured along each of the planes will be smaller and smaller. As the number of horizontal planes approaches infinity, the distance along each plane will approach zero, at which time there will be an infinite number of points on the “horizontal” line between Points *A* and *B*, all of which are perpendicular to the plumb line located at each of the points.

If this procedure is further expanded to include all points located within the parcel (and not just along one boundary line), then a three-dimensional surface will be created with the characteristic that the surface will be perpendicular to the plumb line at every point on the surface. Such a surface is defined as an equipotential surface, and in this example an equipotential surface at Point *A* will have been created.

Thus the surface upon which “horizontal” measurements should be determined for a parcel of land should more precisely be the equipotential surface created at one point located in the parcel, rather than the horizontal plane created at the said point.

3.3.4.4. Stratified Lots

The concept of “stratified lots” introduces another dimension to the association of property rights included and depicted in a modern cadastre. This concept examines the three-dimensional or vertical aspect of property ownership and how that concept might need to be addressed in an LLC.

3.3.4.4.1. Overview Of Stratified Lots

Parcels of land have been described as having more of a 3D aspect (have a volume of ownership associated with it) than a 2D aspect (only associated with the terrain surface). However, it has been implied that even though the parcel is 3D, that there is only one owner for the parcel who has a fee-simple estate. It is in fact possible to have two or more owners who have a different fee-simple estate over the same parcel of land if we use what Stoter calls “stratified properties” (Stoter 2004 p. 5).

With stratified properties it is possible to have two or more owners of a parcel of land in which each owns a different volume of the entire parcel, and where those volumes are positioned on top of each other. For example, one owner could have a fee-simple estate to that volume of a parcel that is located 50 ft above the terrain surface, with the second owner having a fee-simple estate to that volume of land that is located below the first owner. While it does not appear that such stratified lots are prohibited from being created in Massachusetts, there are two situations where stratified lots could be created that are dealt with differently: air rights and condominiums.

3.3.4.4.2. Air Rights

By statute, air rights can be created over state highways by the Massachusetts Department of Public Works (“The DPW”) (MGL Chapter 81 §7L) and air rights can be created over the Massachusetts Turnpike and over the Boston extension portion of the Metropolitan Highway System by the Massachusetts Turnpike Authority (“The MTA”) (MGL Chapter 81A §15). These air rights are not conveyed in fee-simple, instead the air rights are created as leaseholds with terms not to exceed 99 years.

These leaseholds, with the consent of the DPW or the MTA, can be assigned, pledged,

or mortgaged, and the lien of such pledge or mortgage may be foreclosed by appropriate action. Any building or other thing erected under such a lease shall be taxed to the lessee or his assigns in the same manner and to the same extent as if the lessee or his assigns were owners of the land in fee. Any such leasehold estate may be sold or taken by the collector of taxes of the city or town in which the leasehold estate is situated for nonpayment of any taxes in the same way that real estate may be sold or taken for nonpayment of taxes (The statute for the MTA further clarifies that only the leasehold, but not the land itself, may be taken or sold for nonpayment of taxes).

While there are no specific sections that deal with air rights created over private lands, MGL Chapter 167E §1 (Mortgages and Loans: Definitions) defines “real estate” to also include “...leasehold interests created in air rights over land”. Thus it appears that air rights over private lands may be created as a leasehold.

3.3.4.4.3. Condominiums

Condominiums are used to create exclusive ownership and possession of individual units in a building, and thus these units may be thought of as a 3D “cube-in-space” of fee ownership, which would fit the definition of a stratified property. In a coordinated cadastre, boundary corners will be defined only by coordinates and not by physical monuments, and thus if a condominium unit is to be created as a stratified property, then the “boundary corners” of the cube-in-space must be defined by (xyz) coordinates. In Massachusetts, it appears that the existing concept of owning a condominium unit will not allow for the creation of such stratified properties, and instead will be more of a contract-based system that defines the legal relationship between all owners of units of the condominium.

The relationship between unit owners of a condominium is described in the master deed of the condominium. MGL Chapter 183A §8 states:

CHAPTER 183A. CONDOMINIUMS

Chapter 183A: Section 8. Master deed; recording; contents

Section 8. The master deed shall be recorded in the registry of deeds or the land registration office where the real estate is located and shall contain the following particulars:—

- a) ...*
- b) A description of the land on which the building or buildings and improvements are located.*
- c) A description of each building stating the number of stories, the number of units if there is more than one and the principal materials of which it is constructed.*
- d) The unit designation of each unit, and a statement of its location, approximate area, number of rooms, and immediate common area to which it has access, and any other data necessary for its proper identification.*
- e) A description of the common areas and facilities and the proportionate interest of each unit therein*
- f) A set of the floor plans of the building or buildings, showing the layout, location, unit numbers and dimensions of the units, stating the name of the building or that it has not a name, and bearing the verified statement of a registered architect, registered professional engineer, or registered land surveyor, certifying that the plans fully and accurately depict the layout, location, unit number and dimensions of the units as built.*
- g) A statement of the purposes for which the building and each of the units are intended and the restrictions, if any, as to their use.*
- h) The method by which the master deed may be amended.*
- i) The name and mailing address of the corporation, trust, or association, which has been formed and through which the unit owners will manage and regulate the condominium, together with a statement that such corporation, trust or association has enacted by-laws pursuant to this chapter. ...*

Thus the master deed must give a description of the land on which the building is located. This would be the parcel of land owned by the condominium association.

The master deed describes the contractual obligation of and legal relationship between unit owners. The floor plans must show the location and dimensions of each unit ASBUILT, and thus locations of the individual units are determined by the actual

physical location of the asbuilt building. Thus the unit is not a stratified property in which the location of the cube-in-space is by coordinates, but instead is located by the actual physical location of the asbuilt building. If the building settles, deforms or sags, the unit will move with the physical location of the building.

4. DESIGN OF A LEGAL COORDINATED CADASTRE

So far, we have discussed the theory behind developing a legal coordinate cadastre. Now it is necessary to apply some of the principals previously reviewed as we look at how to design a cadastre that will be dynamic, technologically feasible, and still adhere to the legal constraints necessary to show parcel ownership and location.

4.1. Legal Coordinated Cadastres In Massachusetts

The design of a legal coordinated cadastre in Massachusetts will not be a 3D cadastre in which stratified properties will be created. Instead the cadastre will be what Stoter calls a “hybrid approach” (Stoter 2004 p. 217) in which parcel registration is based on a 2D surface but for which the concept of 3D ownership exists.

4.2. The First Legal Coordinated Cadastre

LLC1 is the first cadastre that is being proposed based on the use of geodetic coordinates.

4.2.1. Overview of LLC1

The first legal coordinated cadastre (LCC1) to be designed will be modeled after the current Torrens system of land registration used by the Massachusetts Land Court modified by using some aspects of the Minnesota Torrens System. The main difference between LCC1 and the current Massachusetts and Minnesota Torrens Systems will be on how to define the location of boundary corners of registered parcels. While the current Torrens Systems uses physical monuments set in the ground to definitively locate boundary corners, LCC1 will only use geodetic coordinates (and not physical monuments set in the ground) in determining definitive boundary corner location.

4.2.2. Description

LCC1 will be a Torrens system of registration of land modeled on the Massachusetts system. Many aspects of LCC1 will be the same as the current system (References given are for Massachusetts General Laws with Chapter and Section):

- Judgments of confirmation and registration will be used to create the cadastre. (Confirmation is to decree who the owner is, where the parcel is located, and what the shape and dimensions of the parcel are. Registration is to keep the parcel in the system forever, so that owner, location, and dimension of the parcel are definitively known.) (MGL c185 s45)
- Judgment confirming title is against all the world. (MGL c185 s42)
- Once registered, the land shall be and forever remain registered land. (MGL c185 s52)
- The registration process will be only for parcels of land in which the owner or owners have a fee-simple estate. All interests less than a fee-simple estate will not be part of the registration process, but a brief memorandum of the lesser estate will be entered upon the certification of title of the registered parcel. (MGL c185 s59). (Note that this means that a separate registry of deeds system (apart from the LCC1 registration of title system) will still be necessary to store deeds and other evidence of these lesser interests.)
- No title to registered land, or easement or other right therein, in derogation of the title of the registered owner, shall be acquired by prescription or

adverse possession. Nor shall a right of way by necessity be implied under a conveyance of registered land. (MGL c185 s53)

- Owners of registered land shall hold the land free and clear of all encumbrances except those noted on the certificate of title. (Registered land also may be subject to several encumbrances that are not specified on the certificate, such as liens, claims or rights arising or existing under the laws or constitution of the United States or the statutes of the Commonwealth of Massachusetts, which are not by law required to appear of record in the registry of deeds in order to be valid against subsequent purchasers or encumbrances of record. Typically these consist of liens and taxes to which the land is subject.) (MGL c185 s46)
- Once a parcel of land is registered, who the owner is and what are the shape and location of the parcel are definitive and cannot be changed. (For instance, suppose a plaintiff fraudulently represents himself as owner of a non-registered parcel of land, and then registers the parcel into LCC1, subsequently conveying the parcel to a party who is innocent of the fraud. The innocent party would thus have a certificate of title for the registered parcel and thus would be the definitive owner. The party who owned the parcel before it was registered would not be able to recover the land, even though they lost the parcel through fraud. (However, such a party who is harmed by the fraud would be able to act against the Assurance Fund for LCC1 for the value of the land.) (MGL c185 s62 and s101)

- An alternative system (modeled on the Minnesota Torrens System) will be introduced when the Land Court determines that the title in land is uncontested. In this alternative, the initial adjudication of land will not be used, which will speed up the process and lessen the cost. Instead, a “certificate of possessory title” (CPT) will be issued, which will mean that the land will be registered subject to the rights of persons in possession, if any, and rights which would be disclosed by a survey. Issuance of a CPT would protect the registered owner from losing title by prescription or adverse possession after the date of the first CPT. Any person subsequently claiming a right of possession or a right that would be disclosed by a survey in this land on which a CPT was issued, would be able to file with the Land Court a claim of the unregistered interest. The person with the unregistered interest then would have ten years to petition the court to adjudicate the matters alleged in the statement or claim. If the person with the unregistered interest fails to petition to adjudicate within ten years (or fails to record a new statement or claim re-alleging the facts, which would start the ten year time frame again), then the adverse claim would be terminated whereupon the court would cancel the CPT and issue a certificate of title to the land. Also, if no action was commenced by an opposing person within five years from the date of the first CPT, the registrar of titles would cancel the CPT and issue a certificate of title.

Registration into LCC1 will be voluntary, and thus there will be registered parcels in LCC1 (in which geodetic coordinates mark definitive boundary corner locations),

registered parcels in the old Land Court registration system in which physical monuments marked definitive boundary corners, and non-registered parcels using the registry of deeds system in which physical monuments mark definitive boundary corners. (Note that existing registered parcels in the old Land Court registration system must go through the registration process again to become registered into LCC1).

LCC1 will require new statutes, laws, and regulations in order to convert a Torrens-type land registration system from one in which physical monuments define boundary corner locations to one in which geodetic coordinates define boundary corner locations. Some of these new laws are outlined as follows.

- In LCC1, definitive boundary corner locations shall be specified by geodetic coordinates and not by physical monuments set on the ground. When a boundary corner location is defined by a geodetic coordinate and a physical monument exists at that corner, the geodetic coordinate shall be definitive, and such definitive location defined by such a geodetic coordinate never will be contingent, inferior to, or subordinate to the location described by any physical monument set in the ground. Even if a physical monument is set by or designated as marking the location of a boundary corner before the registration process is completed, the location of the said physical monument will be contingent, inferior to, and subordinate to the location described by the geodetic coordinates as decreed by the Court at the conclusion of the registration process.
- All boundary lines of parcels registered into LCC1 will have a zone of no encroachment associated with it (the width of this zone to be specified by

the Court before LCC1 is instituted). To determine if an encroachment has taken place, a land surveyor must determine the geodetic coordinate of the object (certifying to its accuracy as an original surveyor would), and then this geodetic coordinate of the object will be entered into the LCC1 database and cadastre. If the said geodetic coordinate is within the zone of no encroachment, then the object will not be considered as encroaching, nor will it be considered a basis for a zoning violation.

- Land surveyors will be authorized to set physical monuments at boundary corners of registered parcels. The land surveyor will certify that the physical monuments have been set within the tolerance and certainty as specified by the Court. Each land surveyor shall be required to be covered by professional liability insurance in the amounts and based on the procedure as specified by statute. In setting such a physical monument, the land surveyor will be designated as either an original surveyor or as a retracement surveyor. A retracement surveyor will be responsible for setting a physical monument at boundary corners whose locations have been previously been decreed by the Court using geodetic coordinates or for recertifying existing physical monuments previously set by other retracement or original surveyors. An original surveyor will be responsible for marking proposed boundary corners on the ground as part of and before the end of the registration process. Such markings may be either new physical monuments set by the original surveyor, or existing physical

monuments that the original surveyor designates as marking the proposed boundary corners.

- If the retracement surveyor harms a party because the location of the decreed geodetic coordinates marking a boundary corner is different than the location of the physical monuments set by the retracement surveyor by a distance more than the tolerance specified by the statute, then an action against the professional liability insurance of the retracement surveyor may take place.
- If the original surveyor harms a party because the location of the final decreed geodetic coordinate marking a boundary corner is different than the location of a physical monument set or designated as marking the proposed boundary corner of a parcel, two things may happen. First, the owner of the land as registered and as located by the geodetic coordinates shall hold the land free from all encumbrances, while those that are harmed because they are deprived of land because the physical monuments do not reflect, within the mandated tolerance, the location of the geodetic coordinates, will be able to make a claim against the Assurance Fund of LCC1. Second, all parties as well as the Court may act against the Professional Liability Insurance of the original surveyor.
- The Court will establish LCC1, and will be responsible for its upkeep, accuracy, maintenance, and administration. LCC1 will be a computerized cadastre showing on a computer screen all registered parcels as well as geodetic coordinates of all boundary corners. Since each parcel of land

must be registered into LCC1 by a court proceeding, and since it is not mandatory that a parcel be registered, such a cadastre will show a patchwork of registered parcels, and other areas of non-registered parcels will be blank in the cadastre.

4.3. The Second Legal Coordinated Cadastre

LLC2, the second cadastre being proposed, is also reliant on geodetic coordinates. However, instead of just relying on previous systems, examination of current research and application of findings will be used to define a new “ideal” cadastre.

4.3.1. Overview of LLC2

LCC1 is a cadastre built upon an older system. Cadastres presently exist that use a Torrens system of land registration in which boundary corners are defined by physical monuments set in the ground, and LCC1 takes such a cadastre one step further by defining boundary corners only by geodetic coordinates. However, a better cadastre may be created by first determining what the needs are of the users, and how best to meet those needs.

4.3.2. Description

In 1995 the International Federation of Surveyors (FIG) described the cadastre:

A Cadastre is normally a parcel based, and up-to-date land information system containing a record of interests in land (e.g. rights, restrictions, and responsibilities). It usually includes a geometric description of land parcels linked to other records describing the nature of the interests, the ownership or control of those interests, and often the value of the parcel and its improvements. The Cadastre is the primary means of providing information about property rights. More specifically,

the Cadastre provides the private and public sector with:

- *information identifying those people who have interests in parcels of land;*
- *information about those interests (e.g. nature and duration of rights, restrictions, and responsibilities);*
- *information about the parcels (e.g. their location, size, improvements, value). (FIG 1995)*

FIG states that a cadastre specifically gives information on people who have interests in parcels of land, and information about the interests, giving examples of interests as rights, restrictions, and responsibilities. (Note that FIG does not say that a cadastre should be involved only with fee-simple estates. If they did, then they might have said: “More specifically, the Cadastre provides the private and public sector with information identifying those people who have interests in a parcel of land...”_ instead of “...who have interests in parcels of land...”).

The current paradigm is that cadastres are parcel based, with the smallest unit of a cadastre being a parcel of land for which a person or persons have a fee-simple estate.¹² Parcels of land are registered, and a certificate of title is issued to the people who have a fee-simple estate in the parcel. Typically all other interests other than a fee-simple estate cannot be registered. In the case of the Massachusetts Torrens System, all lesser interests are dealt with in the registry of deeds, and a brief memorandum of the lesser interest is written on the back of the certificate of title.

¹² A fee-simple estate includes all rights that are possible to possess over a parcel of land. One might think of a fee-simple estate as the sum of all possible interests and rights that are possible to own, control or possess over a parcel of land. Some think of each individual right as a stick, with the fee-simple estate being the entire bundle of sticks.

A cadastre should show all interests that all people have to a specific parcel of land. A person should have to go no further than the computer screen of the cadastre to know all the people that own, control or hold an interest over a piece of land. A better cadastre would be one where all interests are registered, not just the fee-simple estates. Note that the current paradigm is that a parcel of land is registered that includes all the land for which a person possesses a fee-simple estate. A better system would be one where a parcel of land is registered over which a person has a specific interest. This concept has been defined as a “cadastron”. (Brown 1999)

The characteristics of a cadastron are that there is one person who owns or has control of one specific interest over one parcel of land. An interest is any legal right that may exist over a parcel of land. An interest could be a possessory estate such as a fee-simple estate, an estate for life, or a leasehold. An interest might be a non-possessory estate such as an easement or profit. An interest could also be one created by government powers.

Individual ownership rights in land are limited because of powers or rights held by federal, state and local governments for the general welfare of the community. These government powers are police power, eminent domain, taxation, and escheat. (Galaty, Allaway et al. 2002 p. 103) While all these government powers will affect a cadastre, the police power needs special attention.

Police power is the authority possessed by individual states of the United States to enact legislation to preserve order, protect the public health and safety, and promote the general welfare of its citizens. This state authority is passed on to the municipalities and counties through legislation called “enabling acts”. Environmental protection laws and

zoning ordinances are examples of regulations that restrict what a land owner may do with a parcel of land. (Galaty, Allaway et al. 2002) Every such restriction can be thought of as an interest that has been taken by the government. If a cadastre includes information on all interests that exist over a parcel of land, then these restrictions imposed by police power must be included.

Thus a cadastre should include information on all interests that people have over a parcel of land. This could be done by registering cadastrons instead of fee-simple estates. The cadastre could be queried to find all interests that exist for either one specific point (one geodetic coordinate) or for a parcel of land the extents of which are specified by the user (by a series of geodetic coordinates that define the boundary corners of the desired land).

Many demands are made of those responsible for a cadastre. The cadastre must be maintained and updated as items change, such as change of ownership of estates or interests, or the creation of new interests with new boundaries. This must be done methodically and in a timely manner so that the cadastre is correct and up to date.

The cadastre must be flexible so that users get the desired output for their specific needs. However, it is difficult to create one cadastre that meets the needs of all users. (In fact, it is impossible to anticipate what the needs will be, as users continually think of new ways to use the cadastre.) Historically, there has typically been a limit as to what information is shown and how it is shown, forcing the user to use information that may not be in the ideal format, or the format that the user would like.

The cadastre must be able to show the spatial location of all interests and the spatial relationships between various interests. Thus one of the outputs of the cadastre should be a map or plan showing the spatial locations of interests.

A cadastre must also give information about the location of boundary corners, dimensions of boundary lines, and areas of boundary parcels. Boundary corner locations will be defined by geodetic coordinates. Dimensions of boundary lines (and areas) must be measured on the horizontal plane. As was previously discussed, there can be a problem when measuring on the horizontal plane because of curvature of the Earth. In the past, when measurements were taken with a steel tape or an electronic distance measuring device (EDM) as part of a closed field traverse that ran around the parcel, this was not a problem because a different horizontal plane was used for each individual measurement (see figures 3.29 and 3.30). However, with GNSS technology replacing steel tapes and EDM, and the possibility that GNSS surveys will replace the old system of using closed field traverses, the problem of measuring on the horizontal plane may become a problem. Instead of directly measuring on the horizontal plane, geodetic coordinates will be used from which boundary line dimensions may be calculated (either on the ellipsoid or on a state plane projection) that then would have to be converted to the local horizontal plane for the parcel. A cadastre must be able to provide dimensions of boundary lines (and horizontal areas) of parcels on a horizontal plane that is unique for each parcel (i.e. parcels on a horizontal plane must tie to at least one point in the parcel that is on the Earth's surface).

In summary, an ideal cadastre should:

- provide information on all interests that exist over and within an area of land whose extents are specified by the user;
- be maintained and updated so that information is current;
- provide a flexible output format so that users can create a plan or map to their full requirements and expectations;
- provide spatial information (such as a map) showing all interests and the spatial relationship between interests for a specified area;
- provide horizontal measurements for all boundary lines and areas.

4.4. Discussion Of Cadastron Parameters

An ideal cadastre should definitively show all cadastrons that affect a given land area. Thus an interested party should have all the information needed to determine exactly:

- what uses can or cannot be exercised and the exact limits of where those uses are located;
- who has rights within the land area, what are the exact nature of the rights, and the exact location of those rights;
- what encroachments exist over the land area.

In an ideal cadastre, a party should not have to go beyond the cadastre for any of this information.

However, such an ideal cadastre is nearly impossible to create. The location of every cadastron will have some uncertainty to it. In some instances there can even be

doubt as to whether the interests in a particular cadastron actually exist. Encroachments are typically not shown on the cadastre. In many instances an interested party will have to go outside the cadastre to determine whether a cadastron interest actually exists, where that cadastron is located on the ground, and whether an encroachment exists.

Every boundary line of a cadastron will be associated with some uncertainty as to its exact location on the ground. As previously described (for instance, see Figure 3.23) every boundary line has a zone of no encroachment associated with it, which can be shown on a cadastre as a boundary line that has an absolute width associated to it. (For instance, for a fee-simple estate the width of a boundary line might be 4 cm, which describes the zone of no encroachment.)

Because of uncertainty involved in putting the locations of such cadastrons on the ground, there are three zones that are associated with every cadastron. Zone 1 is the zone over which it is certain that a point located within this zone is located within the cadastron. Zone 3 is the zone over which it is certain that a point located within this zone is not located within the cadastron. Zone 2 is the zone within which it is not certain whether a point located within this zone is located inside the cadastron or is located outside the cadastron. (Note that in LCC2, the legal definition of “certainty” will be where we are more confident than the certainty specified by law, such as being more than 95% confident, or being more than 99.5% confident where 95% or 99.5% are certainty values specified by the law.)

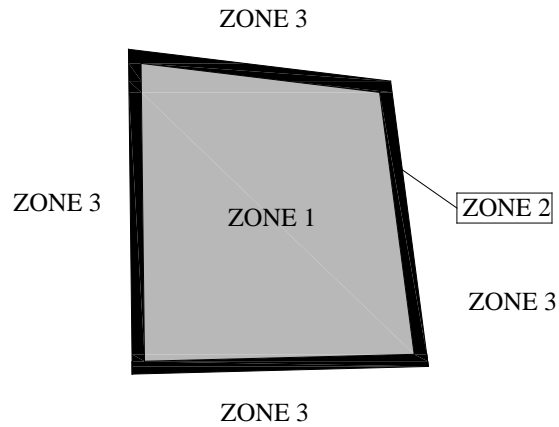


Figure 4.1 Cadastron Showing A Fee-Simple Estate

Thus for a cadastron showing a fee-simple estate, the “no encroachment “ zone shown on Figure 3.23 can be changed to Zone 2 as shown on Figure 4.1. As mentioned before, a typical width for Zone 2 might be 4 cm centered on the boundary line drawn between the decreed geodetic coordinates definitively marking the boundary corners of the boundary line.

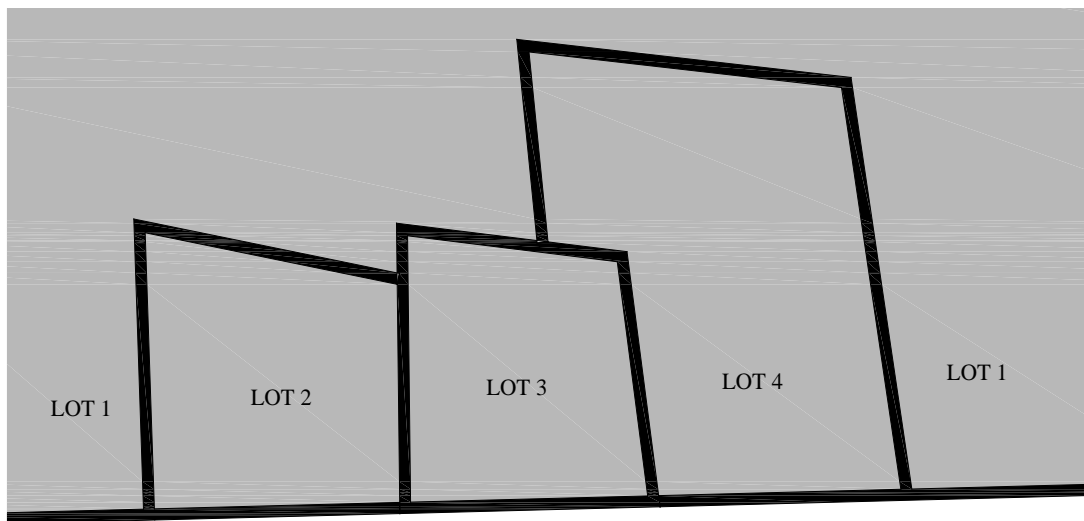


Figure 4.2 A Cadastre Showing Multiple Cadastrons Of Fee-Simple Estates

A portion of a cadastre might include cadastrons in which the interests are fee-simple estates. Figure 4.2 shows Zone 1 in grey and Zone 2 in black. For each individual cadastron, the area outside of Zone 2 would be its Zone 3.

Certain cadastrons might have a boundary line that changes with time, such as a cadastron showing a fee-simple estate where a boundary line is defined as the “mean high water” of a tidal river or “high water” of a stream. Because these boundary lines can change with time by such actions as reliction, accretion, erosion or avulsion, the Zone 2 width for these boundary lines must take this temporal change into account. One solution might be to have a mechanism where these boundary lines could be observed at a certain time interval, or after certain storm events so that the Zone 2 of these boundaries shown in the cadastre can more closely reflect conditions on the ground.

The zones for a cadastron describing a regulation or restriction held by police power can be of three types: Restriction Type 1; Restriction Type 2; and Restriction Type 3. Restriction Type 1 is where the boundaries of the restriction or regulation are definitely known and described by geodetic coordinates. Restriction Type 1 will therefore have Zone 1, Zone 2, and Zone 3, exactly as those described above. Examples of Restriction Type 1 might be a zoning district for which the boundary corners are located by definitive geodetic coordinates.

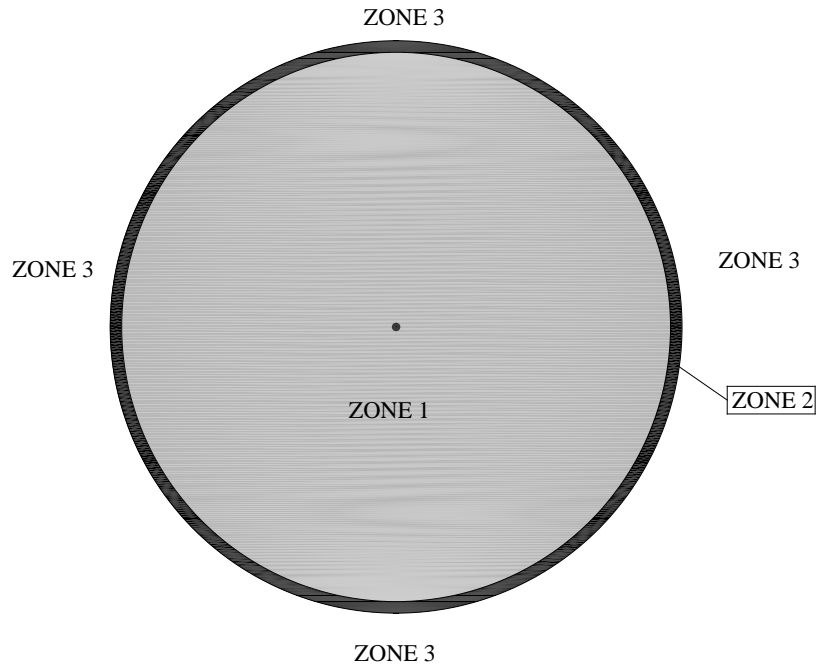


Figure 4.3 Cadastron Showing A Well-Head Protection Zone

Another example (Figure 4.3) might be a well-head protection zone defined by a circle with a radius of one mile centered on the center of an existing municipal well casing for which the municipal water department has defined a geodetic coordinate. In this last case, Zone 2 would have a width of 4 cm centered on the perimeter or circumference of a circle with a radius of exactly 5280 ft. whose radius point is located by the specified geodetic coordinate.

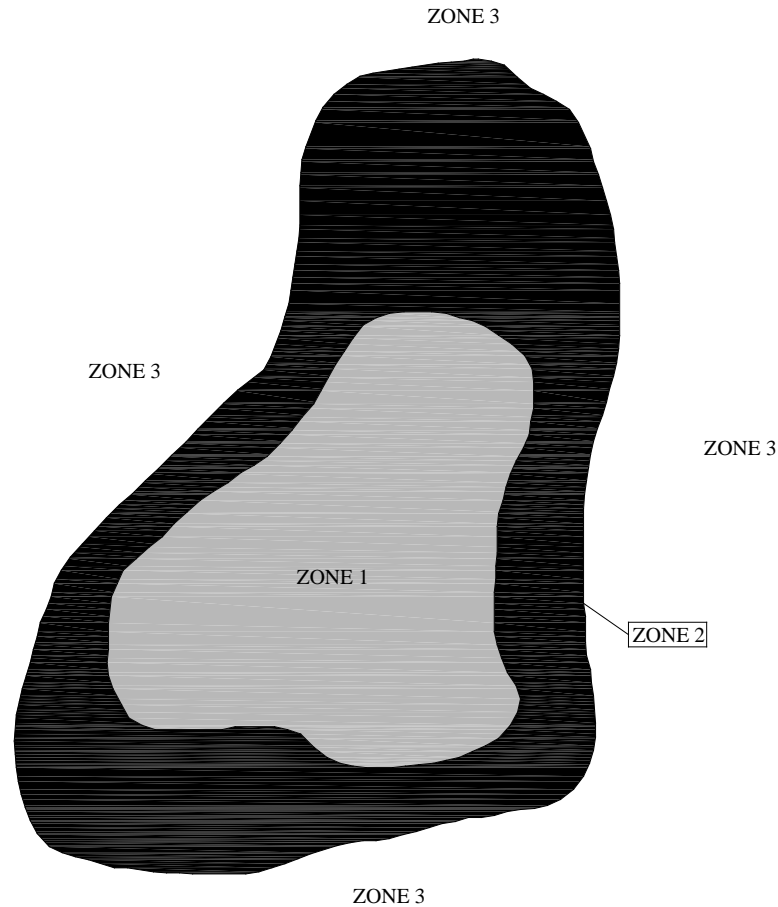


Figure 4.4 Cadastron Showing Wetland Restrictions

Restriction Type 2 is one for which Zone 1 and Zone 3 definitely exist, but for which Zone 2 may not be definitively known or may change with time. An example might be a cadastral that exists around a wetland (see Figure 4.4). A regulation might say that there be no filling or altering of the surface of the ground within 75 ft of a wetland. Another part of the regulation may define how to determine whether a wetland exists (for example the regulation may state a regulated wetland must have some quantity or quality of hydric soils, hydrology, and vegetation) while a third regulation may state who is qualified and authorized to make a professional opinion of

where such wetlands are located on the ground. The location of regulated wetlands may change with time depending on whether it is an abnormally wet year or abnormally dry year. Thus for a specific wetlands, Zone 2 may change with time, but no matter how dry or wet the season there will be an area (Zone 1) that will always be considered a regulated wetlands, and an area (Zone 3) that will always be considered to not be within a regulated wetlands. For Restriction Type 2 cadastrons, the landowner can rely on the cadastron to show areas that definitely are within Zone 1 or Zone 3. However, Zone 2 shows an area for which it is uncertain whether it is either within the cadastron or outside the cadastron. If the owner wants to know more certainly where the wetlands boundary is located for an instant in time (and thus make Zone 2 have a much smaller width of uncertainty) then the owner can go outside the cadastre to employ a professional to determine more precisely where the regulated wetland's boundaries are located on the ground.

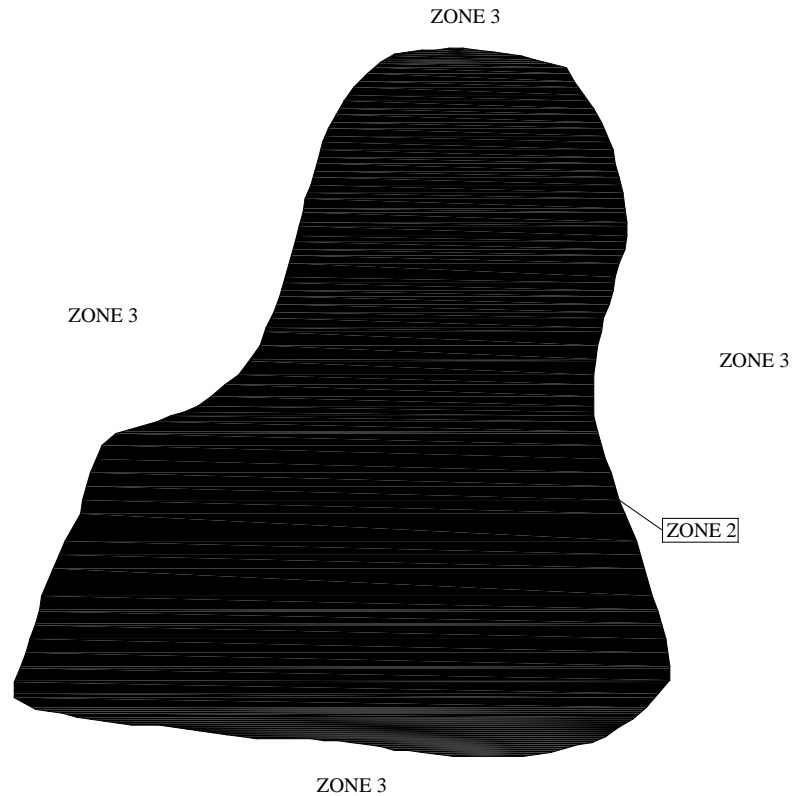


Figure 4.5 Cadastron Showing Rare Wetlands Wildlife Habitat

Restriction Type 3 describes a regulation or restriction for which it is uncertain whether Zone 1 exists. For this special case the cadastre will show a cadastron that only has a Zone 2 (a zone of uncertainty), and a Zone 3 (a zone where it is definitely known not to be within the cadastron). To determine whether this cadastron actually exists for a particular point or for a particular area, the user will have to go outside the cadastre to get more information. An example of this type of cadastron is a regulation of the Massachusetts Department of Environmental Protection (MDEP) as described in the Code of Massachusetts Regulations as 310 CMR 10.37, Estimated Habitats of Rare Wildlife (see Figure 4.5). In this regulation, any proposed project shall not be permitted to have any short or long term adverse effects (as determined by MDEP) on the local

habitat of a State-Listed Rare Wetlands Wildlife. MDEP does not make such a determination until a Notice of Intent of all the details of the proposed project is submitted to MDEP from the developer proposing the project, and until it is determined by the developer that some or all of the proposed project is located within the most recent Estimated Habitat Map of State-Listed Rare Wetlands Wildlife as published by the National Heritage and Endangered Species Program (The Program). The Estimated Habitat Maps are based on the estimated geographical extent of the habitats of all State-Listed Rare Wetlands Wildlife vertebrate and invertebrate animal species for which a reported occurrence within the past 25 years has been accepted by the Program and incorporated into its official database. Once the developer has determined that all or part of the proposed project is located within an estimated habitat area, then the Program has 30 days to report back to MDEP with a determination of whether any State-Listed species identified on the estimated habitat map are likely to continue to be located on or near the site of the original reported occurrence and, if so, whether the area to be altered by the proposed project is in fact part of the species' habitat (and if so, then MDEP will have to make a determination as to whether the proposed project will have any short or long term adverse effects on the said habitat). There is also a provision in the regulation that states that any proposed project that would alter a resource area that is not located on the most recent estimated habitat map shall be presumed not to be within a rare species' habitat (thus defining Zone 3, in which a point or area is not located within a cadastron, and for this particular case, the point is not located within a rare species' habitat for which there are regulations). Note that it is uncertain whether an area located within the estimated habitat region as shown on the estimated habitat maps is actually within a protected State-

Listed Rare Wetlands Wildlife habitat. Thus the estimated habitat regions shown on the estimated habitat maps will be shown on the cadastre as Zone 2 regions, areas of uncertainty as to whether the regulation applies. In order to determine whether Zone 2 is subject to the regulation detailed in the cadastron, the user will have to go outside the cadastre, prepare detailed plans of the proposed project, and submit them to MDEP. However, any proposed projects in Zone 3 (located outside the confines of the cadastron) are presumed to be outside of the cadastron and thus not subject to the regulation.

An interested party will have to go outside the cadastre to determine what encroachments (and other observable evidence that might affect the use of the land) exist over a specified area. The method of determining whether encroachments actually exist is best described in the “2005 MINIMUM STANDARD DETAIL REQUIREMENTS FOR ALTA/ACSM LAND TITLE SURVEYS” (American Congress on Surveying & Mapping 2005). When surveyors prepare such a land title survey, they use Section 5 and Table A of the above mentioned detail requirements to determine if any encroachments may exist.

4.5. Three Components Of LLC2

In designing LLC2, it is evident that one needs to further define the cadastron before one can discuss how to create the new cadastre.

4.5.1. Three Parts of Cadastrons

LCC2 will split the function of creating a cadastre into three parts: registration of cadastrons, determination of cadastron boundary line, and area measurements, and creation of the cadastral map.

4.5.2. Registration of Cadastrons

Characteristics of cadastrons in LCC2 are:

- Boundary lines consist of an infinite number of points, the most important of which are the two endpoints of the boundary line.
- Ownership of land is over a volume, the vertical boundaries of which follow the plumb line that exists at every point on a boundary line.
- Boundary corners decreed by the Court will consist of a coordinate (xyz) located somewhere on the plumb line that exists for a particular boundary corner.
- Land surveyors are responsible for staking on the surface of the ground physical monuments that represent the land surveyors' professional determination of where the plumb line for the decreed (xyz) boundary corner intersects the actual terrain surface.
- Parcels must not have any gaps or overlaps with abutting parcels (either along a common boundary line or a common vertical boundary surface of the parcel volume).

Consequently, the decreed coordinate (xyz) does not have to be located on the actual terrain surface, it just has to be located somewhere on the plumb line that defines the vertical extent of the parcel volume for that particular boundary corner. (Note that it will be the responsibility of the land surveyor to stake with a physical monument the intersection of the plumb line associated with the decreed coordinate (xyz) with the actual

terrain surface.) However, there should be no gaps or overlaps between adjacent parcels, which implies that a boundary corner that is common to two or more parcels should have the same (xyz) coordinate.

Thus LCC2 will consist of a data base of decreed coordinates (xyz) for all boundary corners of all registered cadastrons. A grid made up of all of the (xyz) coordinates for all the cadastrons will be a 2D continuous (though nonmathematical) surface showing all of the registered cadastrons. Thus LCC2 will be what Stoter calls a ‘hybrid approach’ (Stoter 2004 p. 217) in which parcel registration is based on a 2D surface but for which the concept of 3D ownership exists.

While it is not required that this 2D surface of decreed (xyz) boundary corners be coincident with the actual terrain surface, it would be convenient to do so. The USGS has created a seamless digital elevation model (DEM) for the entire country, which is a grid of points that closely matches the terrain surface. Original land surveyors and the Court could use this seamless DEM to help create (xyz) boundary corners that are located close to the actual terrain surface. This would help land surveyors who will be staking out their professional opinion of where the boundary corner is located because the (xyz) coordinate will be located relatively closely to the actual terrain surface. It will also help the Court to create common (xyz) coordinates for common boundary corners of new cadastrons to help ensure that there will not be any gaps or overlaps when new boundary corners are created. Thus, the original land surveyor creating a plan of a new cadastron to be created could use the USGS DEM to aid in the creation of (xyz) coordinates for new boundary corners.

When creating LCC2, the first part will be the registration of cadastrons. For each cadastron registered into LCC2, the Court will decree the owner of the cadastron, the specific interest that the cadastron covers, and the geodetic coordinates of boundary corners of the cadastron. This information will be put into a database as described in my prior research (Brown 1999). The Court will not be responsible for officially determining boundary line and area measurements nor will it create an official all-encompassing cadastral map that all users would be required to use as the sole means of determining definitive cadastron information. The Court would be responsible for maintaining the cadastron database.

The Court will only be decreeing boundary corner locations and will not officially decree boundary line and area measurements. Boundary corner locations will be at the Earth's surface using 3D geodetic coordinates. Since measurements are not part of the official decree, these geodetic coordinates could be based on the Cartesian coordinate system (x,y,z) of the terrestrial reference system, or on the reference ellipsoidal coordinates (λ,ϕ,h) .¹³

The cadastron database maintained by the Court will have a temporal component of the time interval for which the cadastron is (or was) effective. This time interval will consist of two components, the date that the cadastron is first created and becomes

¹³ Measurements are made on the horizontal plane (or perhaps more appropriately on an equipotential surface). The horizontal plane must be tied to the earth's surface at one point, which is the reason why boundary corner locations must be 3D coordinates describing the boundary corner location at the earth's surface. Note that the location of this 3D coordinate does not have to be exactly (to the millimeter) on the earth's surface, it may be "above" or "below" the earth's surface by a small distance (perhaps plus or minus one meter). Surveyors would not be required to set a monument so that top center of the monument is exactly at the location of the 3D coordinate, they would just be required to have the top center of the monument located somewhere on the plumb line that passes through the said coordinate.

effective, and the date when the cadastron is officially decreed by the Court to have ended.¹⁴ The database will consist of all cadastrons that ever existed in the cadastre.

4.5.3. Cadastron Boundary Line and Area Measurements

A cadastre (and the concept of land ownership in general) is associated with two surfaces, the terrain surface on which physical monuments are set and a surface on which boundary line measurements may be determined. Boundary line measurements shown on a PMC (physically monumented cadastre) are typically taken from plans prepared by land surveyors showing the results of their professional survey for one or more lots in a particular region of the cadastre. If the land surveyor performed a closed field traverse, measuring distances by steel tape and/or EDM, then the horizontal plane (or as previously explained, the local equipotential surface) was used to determine boundary line measurements. If a GNSS survey was used instead of a closed field traverse, then it is likely that a steel tape and/or EDM was not used, with the data collected in the field being GNSS coordinates on the reference ellipsoid surface (or perhaps on a state plane coordinate system or some other projection system of the reference ellipsoid). If a GNSS survey is used, then the land surveyor will most likely calculate grid distances on a SPC

¹⁴ A cadastron consists of an interest, the owner of the interest, and the boundary corner locations of the parcel of land for which the interest is effective. The cadastron ceases to exist if one of these three components changes. Thus if the owner of an interest changes, such as when an owner (grantor) conveys his fee-simple estate to another (the grantee) the former cadastron ends and a new cadastron begins with the new owner (the grantee) now being listed as the owner of the estate. Also, if an owner subdivides one larger parcel into two smaller parcels, the original cadastron for the larger parcel will cease to exist and two new cadastrons will be created, one for each of the new lots. For cadastrons that are still effective, there will be no termination date, and the data entry for the termination date might be “current”. Brown, C. A. (1999). Investigation of the Necessary Components of a 500-year Cadastre. Department of Geo-Information Science. Salem, Massachusetts, Salem State College: 52.

(or a like projection) grid and then make scale factor corrections and elevation corrections to these grid distances to approximate a horizontal distance at the ground surface.

In an LCC, geodetic coordinates are probably a SPC or other projection system of the terrestrial reference frame. In this case grid distances are calculated and may held as approximate horizontal distances or a scale correction and elevation correction can be made for each boundary line measurement. (Andreasson reports that the Singapore LCC shows parcel area dimensions that existed before the cadastre was created, rather than use areas calculated from the cadastre coordinates. (Andreasson 2006))

For LCC2, a new method of determining boundary line and area measurements is proposed. LCC2 will use two surfaces, the terrain surface and a local equipotential surface for each parcel. LCC2 definitive boundary corners will be 3D geodetic coordinates that typically will be located on or close to the terrain surface. Boundary line measurements will be on local equipotential planes that will be determined separately for each parcel by using a new gravity interpolation tool to be introduced by NGS by the year 2018. (National Geodetic Survey 2008)

NGS defines an equipotential surface as a closed smooth surface of Earth's gravity field formed by a locus of points all having the same gravity potential, and which has the property that the direction of local gravity at every point on the equipotential surface is perpendicular to the surface (National Geodetic Survey 2008). While the surface may in reality be a closed smooth surface, it is not necessarily an easily determined mathematical surface. NGS is proposing to introduce an interpolation tool to be used to determine equipotential surfaces at any point in the United States. In fact,

NGS is proposing to redefine the vertical datum (for orthometric heights) for the United States by 2018 based on a new geopotential datum realized through the combination of GNSS technology and gravity field monitoring. Rather than perform traditional geodetic leveling to determine orthometric heights, GNSS units with its 3D coordinate positioning will be used. (There is a very strong correlation ($>99\%$) that all points on an equipotential surface will have the same orthometric height. (National Geodetic Survey 2007)) NGS is planning that by 2018 orthometric heights for any point in the United States may be determined by GNSS to an accuracy of 1 cm (National Geodetic Survey 2008). This means that by 2018, points on a particular equipotential surface will be able to be defined with an accuracy of 1 cm. (It is anticipated that the NGS interpolation tool will convert (λ, ϕ, H) (where H is orthometric height) to (xyz) , and convert (xyz) to (λ, ϕ, H) .) The following example will demonstrate the general procedure that would be used to create a mathematical model that could be used to calculate a horizontal distance between two boundary corners.

Given that a boundary line is defined by two boundary corners A and B whose locations are defined by coordinates $(xyz)_A$ and $(xyz)_B$. Find the horizontal distance of the boundary line.

Step 1. Determine the orthometric height (H_A and H_B) for both points by using the NGS interpolation tool.

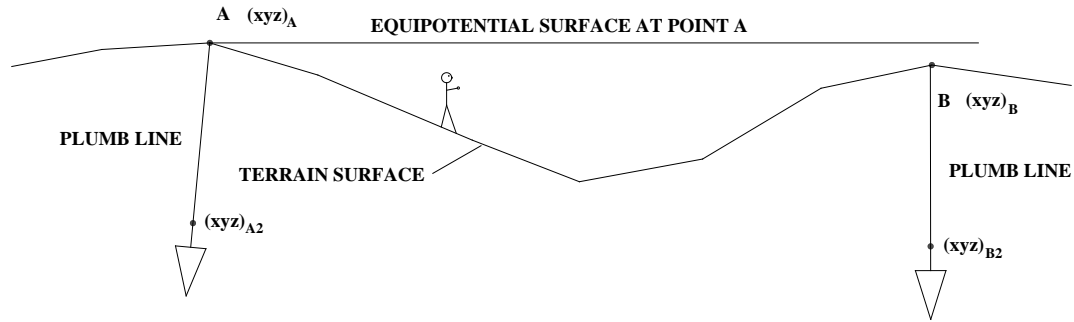


Figure 4.6 Equipotential Surface Created At Point A

Step 2. Create an approximate equipotential surface for orthometric height H_A at point A (See Figure 4.6) by creating a grid of points for the equipotential surface associated with an orthometric height of H_A

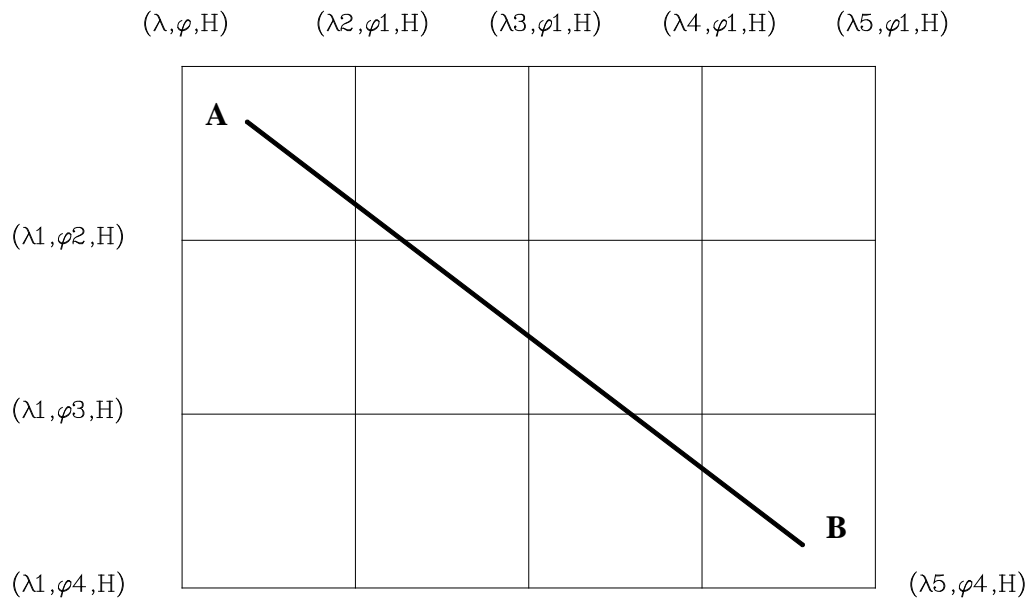


Figure 4.7 Equipotential Surface Associated With Orthometric Height H_A

Note that these points will have coordinates such as $(\lambda_m, \varphi_n, H_A)$ where λ_m is the longitude of column “m”, φ_n is the latitude of row “n” and H_A is a constant. (See Figure 4.7)

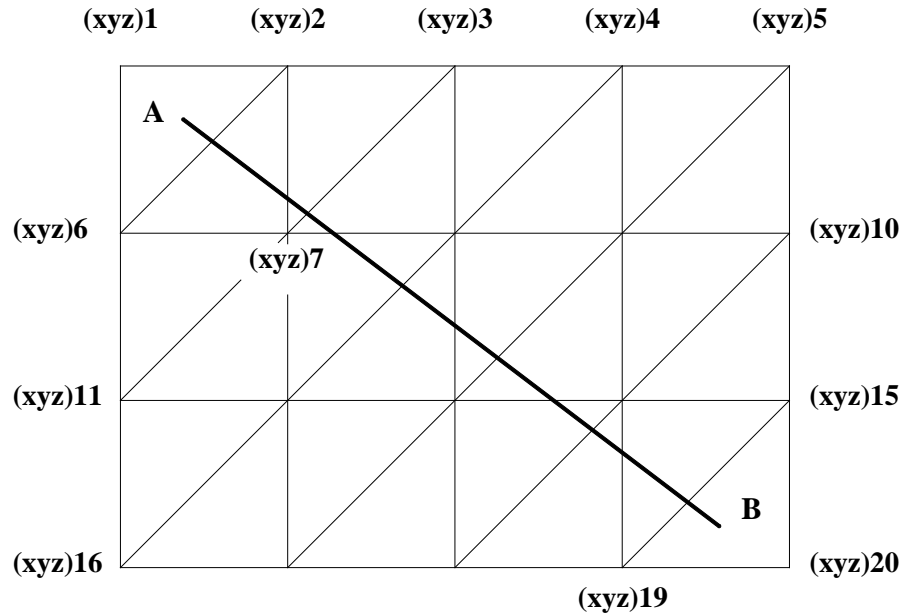


Figure 4.8 Convert From (λ, ϕ, H) To (xyz)

Step 3. Use the NGS interpolation tool to convert the grid from (λ, ϕ, H) to (xyz) .

(Note that the equipotential grid will be made up of a series of triangular planes, each being defined by 3 (xyz) coordinates). (See Figure 4.8)

Step 4. Using the NGS interpolation tool, determine the direction of the plumb line from Point A and the direction of the plumb line at Point B. (See prior discussion about the difference between the ellipsoidal normal and the plumb line.) Note that the direction of the plumb line could be defined by the two coordinates, the first coordinate being the initial coordinate $(xyz)A$, and the second coordinate $(xyz)A2$ being a second coordinate calculated by using the NGS interpolation tool (See Figure 4.6).

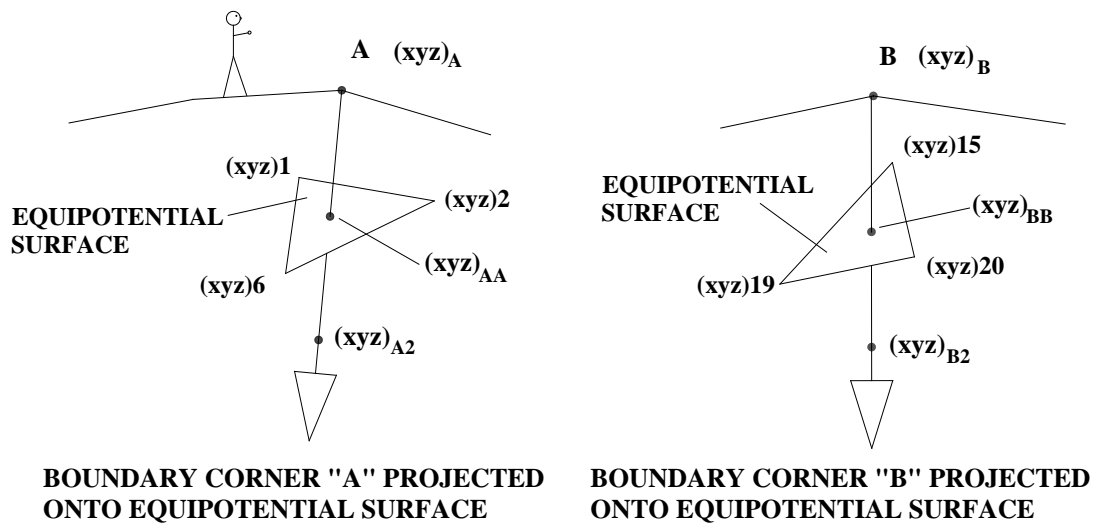


Figure 4.9 Projected Boundary Corners On To Equipotential Surface

Step 5. Project the boundary corner coordinate $(xyz)_A$ to the equipotential surface along the plumb line to create $(xyz)_{AA}$. (This would involve intersecting a line defined by points $(xyz)_A$ and $(xyz)_{A2}$ with a plane defined by the triangular plane $(xyz)1$, $(xyz)2$, and $(xyz)6$.) Do the same for boundary corner at B. (See Figure 4.9).

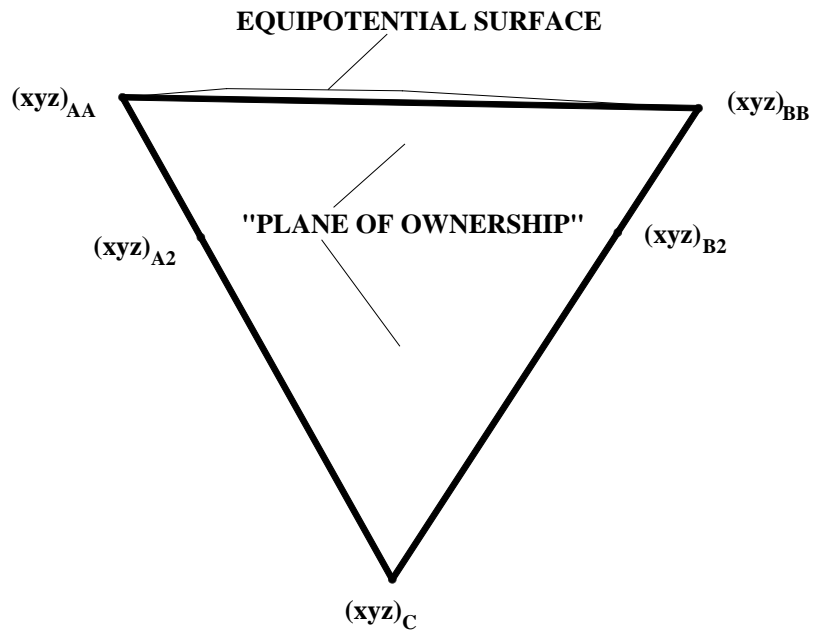


Figure 4.10 "Plane Of Ownership"

Step 6. Create the "plane of ownership" by intersecting the two plumb lines to create $(xyz)_C$. (See Figure 4.10)

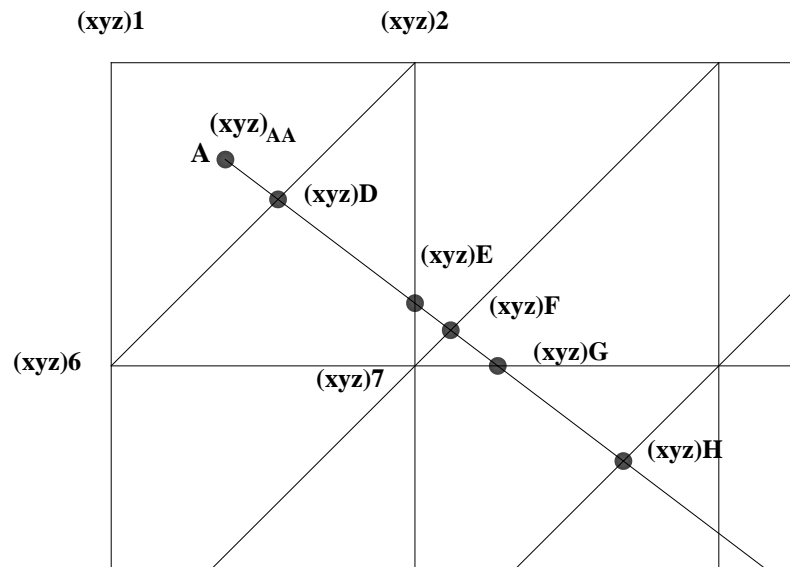


Figure 4.11 Coordinates Of intersection Of Line AB With Equipotential Surface

Step 7. Intersect the “plane of ownership” $(xyz)AA$ -(xyz)BB-(xyz)C with the equipotential triangle side $(xyz)6$ -(xyz)2 to create the point of intersection $(xyz)D$.

Continue this process to create intersection points $(xyz)E$, $(xyz)F$, etc. (See Figure 4.11)

Step 8. Calculate the horizontal distances: $(xyz)AA$ -(xyz)D; $(xyz)D$ -(xyz)E; etc.

Step 9. Calculate the total horizontal distance from A to B by adding up all the intermediate horizontal distances.

The above discussion is for a situation where all points along the line being measured have values of deflection of the vertical and orthometric heights that are about the same. For other areas (such as mountain ranges) additional calculations must be performed.

An elevation correction factor must be applied when measuring a horizontal distance to an accuracy of 1 mm on hilly terrain. (Note that this is the same elevation correction factor used to convert observed distances at some terrain elevation to distances on the ellipsoid or to mean sea level).

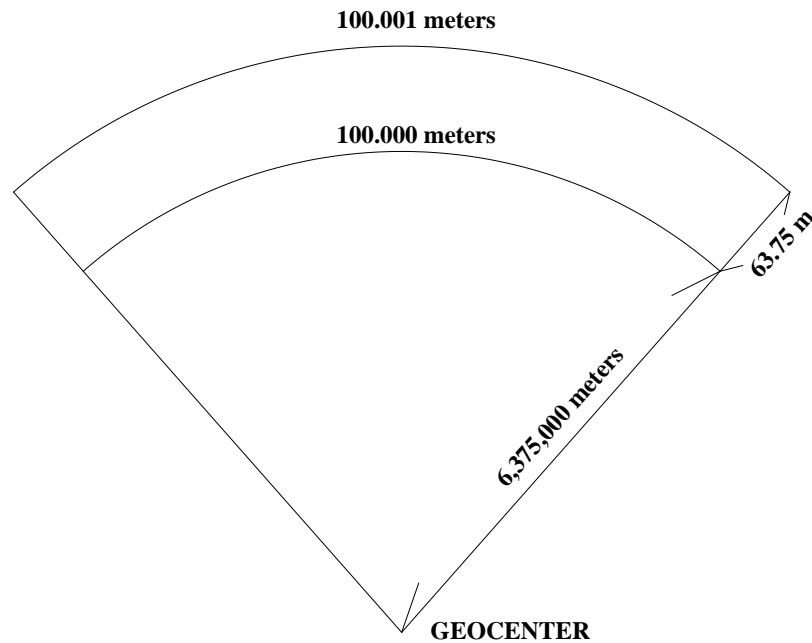


Figure 4.12 Height Difference To Create 1 mm Error In 100 m Length

Assume that a sphere with radius of 6,371,000 m models the Earth, and that a 100 meter line is measured on the Earth's surface. If instead we measure this distance on a sphere that has a radius of 6,371,063.71 m (63.71 m “higher”) then the observed distance would be 100.001 m ($100.001 = 100.000(6371063.71/6371000)$). Thus a 63.71 meter (about 210 ft) increase in elevation will increase a horizontal 100.000 meter measurement to 100.001 m, an increase of 1 mm (Figure 4.12).

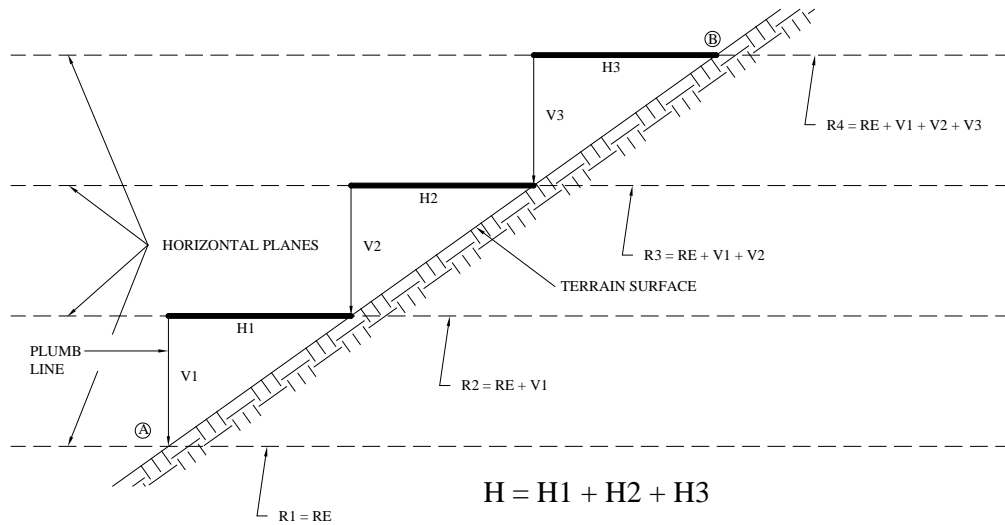


Figure 4.13 Measuring Slope with Steel Tape and Plumb Bob

This was not a problem when surveyors used a steel tape and plumb bobs to measure on a slope. In Figure 4.13 the horizontal distance H is the sum of 3 observed measurements ($H1$, $H2$, and $H3$). Note that each of these observed measurements was measured on a surface that had a different radius ($R1$, $R2$, $R3$, $R4$). For this case there is no need for an elevation correction because the elevation difference between the terrain surface and the horizontal planes on which the measurements were made is usually less than 10 ft when using plumb bob and steel tape.

Thus in LCC2, when calculating boundary line measurements between 2 boundary corner points on the equipotential surface, an additional procedure is required if there is an elevation difference of more than 100 ft between the adjacent intermediate points on the boundary line. The additional procedure is to calculate a new equipotential surface for an orthometric height that has been raised 100 ft, by projecting along the plumb line.

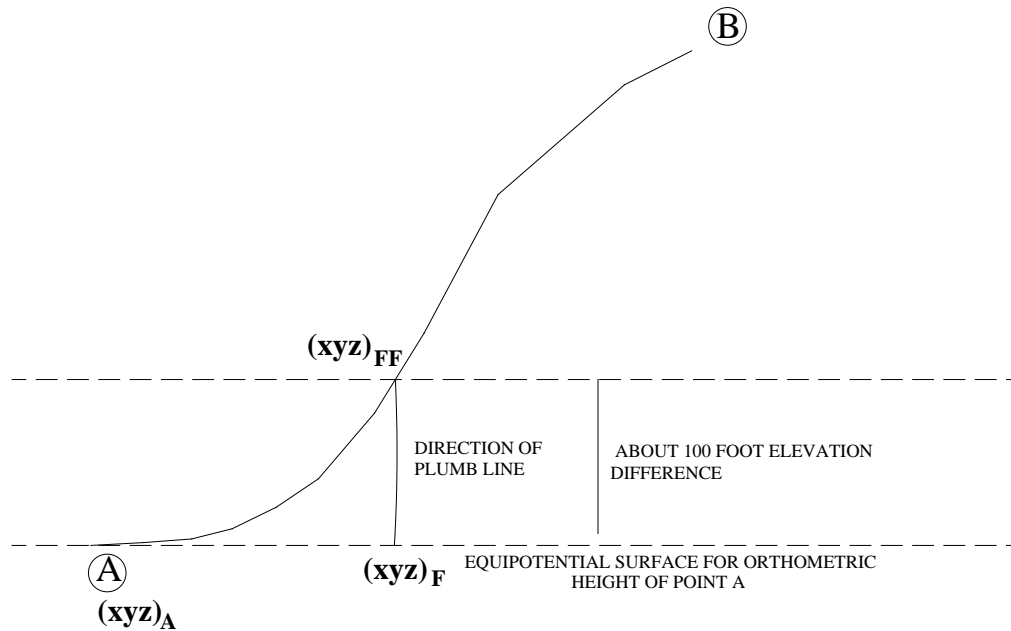


Figure 4.14 New Equipotential Surface For 100-Foot Elevation Difference

For instance, assume in Figure 4.14 that $(xyz)_F$ is found to be 100 ft below the terrain surface. The procedure would be to create a new equipotential surface for an orthometric height that is 100 ft higher. Next the plumb line at $(xyz)_F$ would be intersected with the closest triangular plane of the new equipotential surface (much like in Figure 4.9) to create $(xyz)_{FF}$ as shown in Figure 4.14. Then the intersection of the “plane of ownership” (Figure 4.10) with each leg of the equipotential surface triangle would continue, with the calculation of more horizontal intervals.

The above procedure is used if the values of the deflection of the vertical of all the points located on the boundary line are about the same. If the values of the said deflections of the vertical are substantially different, then a new procedure must be used.

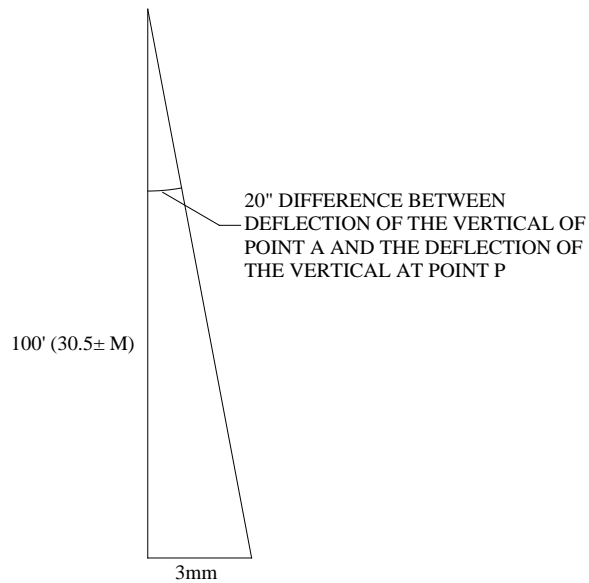


Figure 4.15 Deflection Of The Vertical Difference

For instance, assume that boundary line AB is being measured and the deflection of the vertical of point A had $XI = 0''$ and $ETA = 0''$. Suppose that as the horizontal distance is being calculated, one of the intermediate points (Point P) is found to have a deflection of the vertical of $XI = 0''$ and $ETA = 20''$, and also has an elevation difference of 100 ft compared to Point A. In the above procedure we would create a new equipotential surface that is 100 ft higher, and would intersect the plumb line at Point P with one of the triangular planes of the new higher equipotential surface. However, the deflection of the vertical will create an error of 3mm as shown in Figure 4.15.

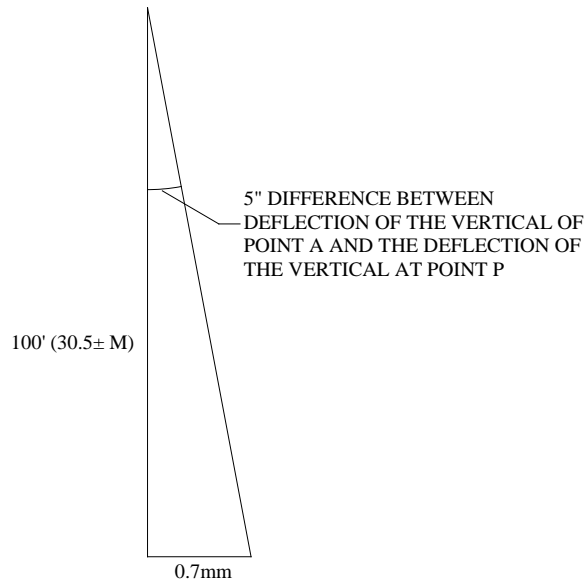


Figure 4.16 5-Second Deflection Of The Vertical Difference

Note that if the difference of deflection of the vertical is limited to 5", then the error would be less than 1mm (0.7mm) in a difference of 100 foot of elevation. See Figure 4.16)

Therefore, to minimize introduced error in determining horizontal distances between 2 boundary corners, a new equipotential surface must be created when there is either a 100 foot elevation difference, or if the deflection of the vertical changes by 5" (in which case the new equipotential surface would be for the elevation of the terrain surface at that intermediate point).

4.5.4. Creation of the Cadastre

LCC2 will split the function of creating a cadastre into three parts. We have discussed the first two parts (registration of cadastrons and determination of cadastron boundary line and area measurements). The third part is the actual creation of the cadastre.

In LCC2 the Court will not be responsible for creating a computer image of a plan showing the relative and absolute spatial orientation of cadastrons (the cadastral map). The Court will only be responsible for maintaining and updating the cadastron database. The cadastral map will be created by inputting the official cadastron database into software written by the user or purchased from private vendors. Some of these proposed cadastral maps might be the following:

- A cadastral map that shows all parcels that existed at a specific instant of time. This cadastral map would show the definitive shape, location, and fee-simple ownership of each parcel. To create this map the database would be queried for all cadastrons whose interest is a fee-simple estate and for which the specified instant of time is between the effective beginning date and the effective ending date of the cadastron (i.e. the cadastron was “effective” or existed at that specified instant of time). Probably the most used specified “instant of time” would be the “current” time (that instant of time when the cadastral map that the user specifies is actually created). Note, however, that once such a “current” cadastral map is created, either as a hardcopy print on paper or a static image on a computer monitor, that it is in fact a cadastral map that shows conditions that existed at a specified instant of time in the past (albeit the “near” past). The software would create a cadastral map on the ellipsoid surface (converting (x,y,z) to longitude $\{\lambda\}$, latitude $\{\varphi\}$, and ellipsoidal height $\{h\}$) or on a state plane grid.

- A cadastral map that shows all cadastrons that existed at a specific instant of time. This cadastral map would show all the registered rights and owners of those rights that exist over a specified point or area defined by a specified coordinate or coordinates at a specific instant of time. (Again, probably the most used specified “instant of time” would be the “current” time.)
- A cadastral map for an ALTA/ACSM Land Title Survey (“Title Insurance Survey”). The purpose of the Title Insurance Survey is so that a Title Insurance Company can insure title to the property free and clear of survey matters. The cadastron database would be queried for all cadastrons that are “current”, which will show all the registered rights that people have to the property as well as all registered regulations and restrictions to which the land is subject. The resulting cadastral map could be used as a base map for the land surveyor preparing the survey. The land surveyor would still be required to go outside the cadastre and visit the site to observe certain conditions that may not show up or be covered by the cadastre, such as recent encroachments.

5. SUMMARY AND DISCUSSION

Within this summary, discussion is focused on comparing the various cadastres already in use that were previously examined, along with the two proposed cadastres- LLC1 and LLC2. Also introduced are the recent advances in technology that suggest other opportunities to create cadastres using both physical monuments and geodetic coordinates. We have multiple opportunities to apply forward thinking toward creating “virtual models” of land ownership/use that can be accessed not only at a municipal, state, and national level, but world-wide in an ever-increasing global economy.

5.1. Comparison Of Cadastres

Criteria must be created to compare Cadastre 2014, NILS, the Singapore Co-ordinated Cadastre, LLC1, and LLC2. These criteria will be based on the hypothesis of the dissertation (Note that “true” and “exact” have been defined in this dissertation as having an error of 1 mm or less.):

“The hypothesis is that a cadastre can be designed for the United States of America in which an interested party looking for information about a parcel of land would only have to go to the cadastre to know “everything” there is to know about the lot that exists at that time (the “current” time, or “right now”) such as:

- *the exact, true location (including the location on the ground) of all boundary corners of the parcel;*
- *the exact, true measurements (such as direction and distances) of all boundary lines of the parcel (and thus the exact geometry of the parcel as it exists on the ground);*
- *the exact, true area of the parcel;*
- *the exact, true information on every interest (and all interests) that exists over the parcel, including the person who owns the interest and the exact nature and extent of the interest.”*

Criterion #1: The exact, true location (including the location on the ground) or all boundary corners of the parcel can be known.

As discussed previously, physically monumented cadastres such as Cadastre 2014 and NILS do not meet this criterion:

- Physical monuments set at boundary corners by the original surveyor who first created the parcel, or by decree of the court in a Torrens System of land registration, mark the true, exact location of those boundary corners. Conversely, all boundary corners not so set can never be exactly known.
- The half-life of definitive physical monuments can reasonably be assumed to be twenty years. Thus, half of the physical monuments that exist at a particular moment can be expected to be disturbed or destroyed in the following twenty years. If an original, definitive physical monument is disturbed or destroyed then thereafter the definitive exact location of that boundary corner can never be determined. Thus, as time passes, fewer boundary corners will have locations that are definitively known.
- The lack of stability of a definitive physical monument can create uncertainty as to whether the monument may have moved and been disturbed. In the current paradigm of physically monumented cadastres, the only way to check for disturbance would be to check courses and distances of boundary lines shown on the definitive plan that connect three or more definitive physical monuments.

Since there is error in all measurements shown on such cadastral plans, this procedure could only determine disturbances in the location of the monuments that would be greater than the error in the measurements.

The Singapore Co-ordinated Cadastre does meet this criterion with conditions. Geodetic coordinates define the exact location of boundary corners only if they can be relied upon forever. However, in the Singapore Co-ordinated Cadastre, such coordinates may not be relied upon for certain conditions where:

- it is found that coordinates shown on the cadastre do not correctly represent the boundaries of any land;
- it appears that wrong coordinates have been joined up in the survey resulting in incorrect boundary lines being shown on the cadastre;
- it appears that there has been a change in position of a boundary from that which it held at the time of the survey.

LLC1 and LLC2 do meet this criterion. The legal, definitive location of all boundary corners will be shown on the cadastre (computer monitor) by coordinates that will not change with time.

One issue to consider is that since interested parties cannot see a coordinate on the ground, surveyors must set physical monuments on the ground to model the definitive location of the boundary corner. In the near future, the location of these physical monuments will have error but the certainty about the magnitude of this error will be guaranteed, and the public will be able to rely on the fact that these physical monuments do represent the definitive boundary corners within the mandated tolerance. However, in the more distant future it may be possible for surveyors to stake the definitive geodetic coordinate with a physical monument with an error of less than 1mm. An assumption of this dissertation is that a measurement error of less than 1mm is insignificant and can be ignored and thus a measurement with such an error can be thought of as “exact”. Thus

in the more distant future a legal coordinated cadastre will not only show definitive boundary corner locations by a geodetic coordinate, but the physical monument set by the surveyor to mark where location of the boundary corner may also have no error.

Criterion #2: The exact, true measurements (such as direction and distances) of all boundary lines of the parcel (and thus the exact geometry and area of the parcel as it exists on the ground) can be known.

As discussed previously, physically monumented cadastres such as Cadastre 2014 and NILS do not meet this criterion because measurements describing boundary lines, the end points of which have been definitively located by physical monuments, can never be exactly known.

The Singapore Co-ordinated Cadastre also does not meet this criterion. Horizontal distances are typically used to describe boundary lines. Distances of boundary lines in Singapore are grid distances based on the Singapore Coordinate System called SVY-21, a Transverse Mercator projection.

LCC1 and LCC2 do meet this criterion. Boundary corners will be defined by a 3D coordinate (either (x,y,z) or (λ,ϕ,H) where H is orthometric height). Distances will be measured on equipotential planes based on elevation and Deflection of the Vertical in a process described above.

Criterion #3: All information should be available and correct when querying the cadastre for a specified point in time.

(This specified point in time will probably be “right now” or the “current” moment although it might also be a moment in the past.)

For a cadastre to be “current” and “up-to-date”, “right now” means that as soon as a parcel or interest is decreed or approved, then the cadastre should be immediately updated. It also means that there should be a temporal component to the database of parcels and coordinates so that the cadastre can be viewed for its configuration at any time in the past. NILS will not comply with this criterion because ownership of land is transferred first by deed and then after the land has been transferred the database is compiled using the new deed and thus there be a time lag between the two happenings. Cadastre 2014, the Singapore Co-ordinated Cadastre, LCC1, and LCC2 all create a database of coordinates and information on property rights and thus it is possible that they might be able to comply with this criterion.

Criterion #4: The exact, true information on every interest (and all interests) that exists over the parcel, including the person who owns the interest and the exact nature and extent of the interest can be known.

Cadastre 2014, the Singapore Co-ordinated Cadastre and LCC1 use the Torrens Systems of land registration and are based on parcels of land ownership, with the extent of land ownership being the fee simple estate. Any interest less than fee simple ownership is typically not shown as a parcel on these cadastres. Certain interests less than fee simple may be shown on a cadastre in a separate layer than the parcels. Torrens systems usually register only fee-simple parcels, with lesser interests not being specifically registered, but instead being added as a memorandum of encumbrance on the certificate of title. Certain interests are not shown on cadastres, such as restrictions or regulations created by the police power of the state. Finally, even if these lesser interests

are included in some fashion in the cadastre, the definitive location over which these interests are valid is not shown.

NILS does not use a Torrens System of land registration, instead using a registry of deeds system. Thus information on interests that may exist over a parcel require that the appropriate professional give a professional opinion.

LCC2 will use the concept of registration of cadastrons, rather than registration of parcels of fee-simple ownership. Registration of cadastrons will guarantee the nature and legal extent of the interest, the owner of the interest, and the location on the ground over which the interest is effective. The concept of cadastrons will allow most of the lesser interests than fee-simple estates such as easements, regulations, and restrictions to be registered.

However, there are certain interests over land that cannot be included in LCC2, in which case an interested party will have to go outside the cadastre to determine if they exist. In these cases, a land surveyor must go on the ground to investigate and observe whether, in their professional opinion, these unregistered interests exist or do not exist. Examples of unregistered interests that may not be in LCC2 are:

- Encroachments over a boundary line and other evidence of unregistered possession over land such as: buildings; fences; paved ways; underground utilities; signs; observable evidence of site use as a solid waste dump, sump, or sanitary landfill.
- Evidence of use of driveways, alleys, and other ways of access that cross the property by those who do not have a registered right to do so.

- Evidence of access to a public way on land such as curb cuts and driveways, or the lack of access by the erection of fences, guardrails, and buildings, or the installation of utilities such as utility poles or other required structures.

While geodetic coordinates will legally define the location of a boundary or cadastron corner, it is impossible to see such a coordinate location on the ground. The location of physical monuments set in the ground by land surveyors to model such legal coordinate locations will have error. Thus LCC2 will have boundary and cadastron lines that are not one-dimensional lines, but rather will have a certain width (called a “no encroachment” zone, also called Zone 2 in this dissertation) within which it will not be certain whether certain interests exist or are valid.

Certain boundary lines locations have a temporal component, in that they may change with time. Examples might be:

- A cadastron showing a fee-simple estate where the boundary line is defined as the “mean high water” of a tidal river or “high water” of a stream. Because these boundary lines can change with time by such actions as reliction, accretion, erosion or avulsion, the Zone 2 width for these boundary lines must take this temporal change into account. One solution might be to have a mechanism where these boundary lines could be observed at certain prescribed time intervals, or after certain storm events so that the Zone 2 of these boundaries shown in the cadastre can more closely reflect conditions on the ground.
- A cadastron over land whose location has shifted by seismic activity or some other deformation, such as land through which a transform fault

boundary (where tectonic plates slide past one another) exists. Existing legal precedents for these situations must be included into LCC2.

5.2. Comparison Summary

The following table summarizes the comparisons of the various cadastres for the various criterion.

	Cad. 2014	NILS	Singapore	LCC1	LCC2
Criterion 1 Exact boundary corner location is known	NO	NO	YES with conditions	YES	YES
Criterion 2 Exact measurement of boundary line is known	NO	NO	NO	YES	YES
Criterion 3 All information is up-to-date	NOT POSSIBLE	POSSIBLE	POSSIBLE	POSSIBLE	POSSIBLE
Criterion 4 Exact information on all interests is known	NO	NO	NO	NO	YES with conditions

Table 5.1 Comparison Summary of Cadastres

5.3. Conclusion

The hypothesis is that a cadastre can be designed for the United States of America in which an interested party looking for information about a parcel of land would only have to go to the cadastre to know “everything” there is to know about the lot that exists at that time (the “current” time, or “right now”) such as:

- the exact, true location (including the location on the ground) of all boundary corners of the parcel;
- the exact, true measurements (such as direction and distances) of all boundary lines of the parcel (and thus the exact geometry of the parcel as it exists on the ground);
- the exact, true area of the parcel;
- the exact, true information on every interest (and all interests) that exists over the parcel, including the person who owns the interest and the exact nature and extent of the interest.

Criteria were developed from the hypothesis to help compare the cadastres. A comparison was made in Table 4 of Cadastre 2014, NILS, the Singapore Co-ordinated Cadastre, LCC1, and LCC2. LCC2 was the cadastre that most completely met all the criteria. Thus the final recommendation is that to meet the needs of the public as outlined in the hypothesis, LCC2 should be instituted.

Thus an interested party should be able to go to the LCC2 (using a computer monitor located anywhere in the world) and be able to determine:

- All interests that currently exist over one point in the surface of the terrain, or for all points within a specified region or area. This would involve querying the cadastre to give a list of all cadastrons whose Zone 1 or Zone 2 includes that point, or a point within the specified region or area.;
- The definitive boundary location of a specified parcel defined by a current fee-simple estate, and all current interests that exist over that parcel.
- All interests and definitive boundary locations of the interest for one point or a specified parcel for any instant of time in the past.

LCC2 is a cadastre for which the hypothesis is true, with certain conditions:

- The determination of the existence of some interests will require going beyond the cadastre. For instance, certain unregistered interests may exist that can only be known by going to the site and observing conditions that exist at that moment such as encroachments or possession by others, or conditions that may affect compliance with regulations and restrictions.
- While geodetic coordinates will legally define the location of a boundary or cadastron corner, it is impossible to see such a coordinate location on the ground. Instead, land surveyors will set physical monuments in the ground to model such legal coordinate locations. In the near future these physical monument locations will have error and thus will not exactly show the location of the legal boundary or cadastron corner. Thus in the near future

LCC2 will have boundary and cadastron lines defined by geodetic coordinates that when staked on the ground are not one-dimensional lines, but rather will have a certain width (called a “no encroachment” zone, also called Zone 2 in this dissertation) within which it will not be certain whether certain interests exist or are valid. In the future, when geodetic coordinates can be staked on the ground with an error that is less than 1mm and thus can be said to have no error and are exact, the Zone 2 in these cases will cease to exist, and boundary and cadastron lines will be one-dimensional.

- Certain cadastron boundary line locations may have a temporal component caused by such things as reliction, accretion, erosion or avulsion, or by seismic activity. These conditions have always affected the location of land boundaries, and will be a part of LCC2.

5.4. Future Research

Current research in sensor technology and augmented reality suggests that there are multiple applications yet to be explored regarding the use of geodetic coordinates and cadastre applications.

5.4.1. Overview of Future Research

In an LCC, geodetic coordinates define boundary corners but geodetic coordinates cannot be seen on the ground. Future research must be performed to aid interested parties in being able to “see” the location of a geodetic coordinate. One future topic is how to use wireless sensor networks to monitor the location of physical monuments set by land surveyors (as described above for LCC2). A second future topic is to investigate how to

advance the existing concept of “augmented reality” to allow interested parties to “see” a geodetic coordinate location on the surface of the Earth without the need for physical monuments to be set in the ground.

5.4.2. Wireless Networks

We now have the opportunity to access information via wireless networks using a variety of “capture” modes. Some of these applications may have use in the development of a legal coordinated cadastre.

5.4.2.1. Overview of Wireless Networks

Wireless sensor networks are currently being used in many fields, such as in monitoring volcanic eruptions (Werner-Allen, Johnson et al. 2005) and the study of plate tectonics and earthquakes(Earth Scope® - EarthScope: An Earth Science Program, 2010). One future research topic might be how to use these wireless sensor networks to determine whether the physical monument set by a land surveyor to model a definitive boundary corner has been disturbed or destroyed in real time. In this way a user of the cadastre could check to see if the physical monument set by a land surveyor is “currently” or “right now” adequate to model the definitive location of the decreed geodetic coordinate of a particular boundary corner. This could be done in several ways.

5.4.2.2. Active Wireless Sensor Networks

The first way would be to create an active wireless sensor network that would miniaturize a CORS station in size, power requirements, and cost so that it could operate after being inserted into the top of a physical monument. This system would be “active” because it would continuously be powered up, monitoring its location. Once a land surveyor has set such a monument to model the location of a boundary corner, then NGS

could monitor the location of the physical monument just as they currently monitor CORS stations. NGS would be able to quickly determine when such a physical monument was disturbed or destroyed.

5.4.2.3. Passive Wireless Sensor Networks

The second way might be a passive wireless sensor network, in which a sensor is inserted into the physical monument but does not operate until told to do so by a master unit. Such a master unit could be a CORS station that itself is being constantly monitored so that its geodetic coordinate is known, but has the capability of broadcasting two carrier waves, each having a different frequency. Two or more of these CORS stations would each be able to broadcast their two carrier waves at the same time according to their corrected clocks. The passive sensor would be able to monitor the two carrier waves from each of the CORS stations in the area. Since the coordinates of the boundary corner and the coordinates of each CORS station are known, the number of full cycles and the partial phase of the last cycle that should be measured can be determined. The passive sensor would compare the frequency of the carrier wave coming from each CORS station and be able to determine the partial phase difference of the last cycle, but would do so for both frequencies of each CORS stations being monitored. With all this information, the passive sensor could determine whether the physical monument has been disturbed, and could probably also state how far off the monument is located from where it should be. (This second system might be used in “urban canyons” where the first system might not work.)

5.4.2.4. GNSS Network

The third way would be to have GNSS receiver/transmitters attached to a mobile unit (either two or more mobile units each with one GNSS receiver/transmitter, or one mobile unit with two or more GNSS receiver/transmitters, or some other like configuration) rather than to have CORS stations with transmitters. This method might work better if there are line-of-sight issues with the transmitted waves, since there might be more opportunities for the passive sensor to be able to track the carrier waves if the transmitter is moving, and if the mobile unit is closer to the passive sensors than might be possible with a CORS transmitter.

5.4.2.5. Advantages of Using Wireless Networks in LCC2

In LCC2 surveyors will stake the location of the definitive geodetic coordinate on the ground with a physical monument. The surveyor will certify that the physical monument was staked on the ground within the tolerances specified in the law, but only for that instant of time. As with all passive physical monuments set in the ground, there is no control as to if and when the monument might be disturbed. With the present design of LCC2, if someone wants to check whether a monument still is in the right place then a surveyor would have to go back out in the field to recertify that the monument is still within the tolerance of location stated in the law at that particular instant of time. Using the wireless network as outlined in this section might allow the public to trust the integrity of physical monuments that purport to show the location of the definitive geodetic coordinate because there will be an active process of determining whether a physical monument has been disturbed. Thus future research on such a wireless network would enhance the LCC2 system.

5.4.3. Augmented Reality

A second future topic is to investigate how “augmented reality” could be used to allow interested parties to “see” a geodetic coordinate location on the surface of the Earth without the need for physical monuments to be set in the ground. A description of the Layar Realty Browser© by SPRX Mobile will help explain the current paradigm of augmented reality. (SPRX Mobile 2010) (See <http://site.layar.com/download/layar> that was accessed on July 3, 2010.)

Layar uses the technology called augmented reality to augment the real world as seen through a mobile phone based on the phone’s location through a free download of their product. The Layar Reality Browser© shows what is around you by displaying real time digital information on top of the real world as seen through the camera of a mobile phone. Layar works by using a combination of the mobile phone’s camera, compass, and GNSS data to identify the user’s location and field of view, retrieve data from the world wide web, based on those geographical coordinates, and overlay the retrieved data over the camera view.



Figure 5.1 Screenshot of LayaR Realty Browser© by SPRX Mobile Application

Figure 5.1 shows a screenshot of a mobile phone camera view when using the LayaR© application. The camera view is looking out an office window. The icons and text on the camera view are supplied by the LayaR© application, and shows where the LayaR© office building is located, 2.9 mi in the distance (the icon showing the LayaR© building is the squiggly polygon in the center of the figure). As the camera view is moved, the icon moves so that it always is pointing towards the LayaR© office building no matter what the orientation of the camera view.

Field	Type	Function	Null	Value
id	int(50)	<input type="text"/>	<input type="checkbox"/>	1
attribution	varchar(50)	<input type="text"/>	<input type="checkbox"/>	The location of Laya Office
title	varchar(50)	<input type="text"/>	<input type="checkbox"/>	Laya office location
lat	decimal(20,10)	<input type="text"/>	<input type="checkbox"/>	52.3741180000
lon	decimal(20,10)	<input type="text"/>	<input type="checkbox"/>	4.9342500000
imageURL	varchar(255)	<input type="text"/>	<input type="checkbox"/>	http://custom.laya.nl/layaimage.jpg
line4	varchar(50)	<input type="text"/>	<input type="checkbox"/>	1019DW Amsterdam
line3	varchar(50)	<input type="text"/>	<input type="checkbox"/>	distance:%distance%
line2	varchar(50)	<input type="text"/>	<input type="checkbox"/>	Rietlandpark 301
type	int(11)	<input type="text"/>	<input type="checkbox"/>	1
actions	varchar(50)	<input type="text"/>	<input checked="" type="checkbox"/>	
dimension	int(1)	<input type="text"/>	<input type="checkbox"/>	1
alt	int(10)	<input type="text"/>	<input checked="" type="checkbox"/>	
relativeAlt	int(10)	<input type="text"/>	<input checked="" type="checkbox"/>	
transform	int(10)	<input type="text"/>	<input checked="" type="checkbox"/>	
object	int(10)	<input type="text"/>	<input checked="" type="checkbox"/>	
distance	decimal(20,10)	<input type="text"/>	<input checked="" type="checkbox"/>	

Figure 5.2 Simulated Entry of Coordinates In Laya© Application

This Laya© application allows a user to create their own object location and then to submit it to the internet for others to use. Figure 5.2 shows the information that was entered so that the application would show the Laya© Office building in the camera view finder. Note that there are fields that allow a latitude and longitude coordinate to be added showing the Laya© Office location. The ability is there to enter a coordinate to the closest 10^{-10} degree, which corresponds to an absolute position on the ground of less than 1 mm.

This system of augmented reality could be used in LCC2 as a way of “seeing” the definitive cadastre on the ground (instead of just on a computer monitor). Boundary corners could be shown. Zone 2 boundary lines and cadastron boundaries could also be shown. In this future concept the mobile phones would retrieve data from LCC2 and would overlay that data onto the camera’s view.



Figure 5.3 Augmented Reality Of Boundary Lines

Figure 5.3 shows what a cadastron showing a fee-simple estate might look like on such a system. The boundary corner is a circle with diameter of four centimeters, and the Zone 2 of the boundary lines are lines with a width of four centimeters.



Figure 5.4 Augmented Reality Of Well-Head Protection Zone

Figure 5.4 shows what the Zone 2 might look like of the cadastron of the well-head protection zone described previously in Figure 4.3.

In summary, Augmented Reality should be researched to see how it could be used to increase the effectiveness of LCC2. In the current design of LCC2 surveyors will stake the location of the definitive geodetic coordinate on the ground with a physical monument. The surveyor will certify that the physical monument was staked on the ground within the tolerances specified in the law. Sometimes the user may not need or want to hire a surveyor to stake a boundary corner or a boundary line in order to see where it is located on the ground. Augmented Reality would allow a user to “see” where a boundary line or boundary corner of a cadastron is located on the ground without having the corner staked with a physical monument. Thus research into how Augmented Reality might increase the effectiveness of LCC2 should be performed.

5.4.4. Virtual Retina Display

The ultimate system might be where the mobile phone with camera view is replaced by a virtual retinal display (or retinal projector) in which the data is displayed directly on the retina of the eye. For instance, Babak Parvis of the University of Washington has created a prototype contact lens augmented with electronic circuitry that has been able to project a pixel of light onto the retina of the user. (Harvey Ho, Ehsan Saeedi et al. 2007) It may be possible in the future to create a system where a user with such contact lenses will be able to view any data in LCC2. With such a system the virtual reality of LCC2 could be seamlessly combined with the physical reality of the real world to create just one “reality” for the user. Thus the user would not only see the real world, but would also see boundary corners and boundary lines from LCC2.

All of the technology needed to use augmented technology to “show” coordinates and Zone 2 boundaries of LCC2 on the ground presently exists. Survey grade GNSS capable of sub-centimeter absolute accuracies currently exist. RTK systems exist that allow a survey grade GNSS receiver to stakeout or measure coordinates with centimeter absolute accuracy in real time. Mobile phones can use the Layar© system to retrieve data from the internet and show it in the camera view. Prototype contact lenses capable of projecting images onto the retina of the wearer’s eye have been created. All that is required for such a product to be developed is for private enterprise to realize a potential market for the product.

In summary, using Augmented Reality with a virtual retinal display should be researched to see how it could be used to increase the effectiveness of LCC2. In the current design of LCC2 a computer monitor is used to “see” the geodetic coordinate that defines a boundary corner while surveyors are needed to stake the location of the definitive geodetic coordinate on the ground with a physical monument. Using Augmented Reality with a virtual retinal display will instead allow the virtual geodetic coordinate to be seen in the real world without a surveyor needed to stake the geodetic coordinate. As the user scans the Earth’s surface with the virtual retinal display it will appear as if the boundary corners and boundary lines are painted on the ground. These boundary lines do not in fact exist on the Earth’s surface, but the virtual boundary lines appear to exist. If in the future it is possible to make such a virtual retinal display show the location of boundary corners and boundary lines with an error of less than 1mm, then the user will be seeing the “true” and “exact” boundary corners and boundary lines on the ground without having to stake them on the ground first.

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APPENDIX A - DEFINITIONS OF TERMS

BLM The United States Department of the Interior Bureau of Land Management

Cadastre 2014 The cadastre proposed by FIG

Cadastron The smallest unit of LCC2 describing every individual interest or estate that exists for any point or area in the cadastre, and which provides the following information about those individual interests and estates:

- What entity holds the interest or estate.
- What are the interests or estates.
- The location of the land over which the interest or estate exists.
- The time interval over which the interest or estate exists (or is effective).

CORS Continuously Operating Reference Station network managed by the National Geodetic Survey providing Global Navigation Satellite System data in support of three dimensional positioning applications throughout the United States.

DOV Deflection of the vertical.

FIG The International Federation of Surveyors

FGDC The United States Department of the Interior Federal Geographic Data Committee

Geodetic Coordinate A two-dimensional coordinate (longitude $\{\lambda\}$ and latitude $\{\varphi\}$) located on the surface of a reference ellipsoid. The reference ellipsoid used in the United States is the Geodetic Reference System of 1980 (GRS 80).

GNSS Global Navigation Satellite System. The standard generic term for satellite navigation systems.

GPS The United States NAVSTAR Global Positioning System

GRS 80 The Geodetic Reference System of 1980 is the reference ellipsoid used in the United States

HTDP Horizontal Time-Dependent Positioning. Software developed by NGS to estimate horizontal velocities of points on the Earth's surface.

LCC1 The name of the first proposed model Legal Coordinated Cadastre .

LCC2 The name of the second proposed model Legal Coordinated Cadastre.

NILS The cadastre called the "National Integrated Land System" proposed for the United States by the FGDC.

NGS The National Geodetic Survey, a component of the Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service.

NSRS The National Spatial Reference System. Defined as the official system of the U.S. federal government, which allows a user to determine geodetic latitude, longitude, and height, plus orthometric height, geopotential, acceleration of gravity, and deflection of the vertical at any point within the United States or its territories.

OPUS Online Positioning User Service. Software developed by NGS in which the CORS network is used to simplify the process of accessing high-accuracy NSRS coordinates.

OPUS-DB Online Positioning User Service Database (Opus-DB) in which information about passive control monuments can be entered into the NGS Integrated Database by using information gathered in the field by surveying professionals who are not necessarily in the employ of NGS.

PMC Physically Monumented Cadastre. A cadastre using physical monuments set in the ground to define the location of boundary corners.

SBSMA Singapore Boundaries and Survey Maps Act (Chapter 25)

SLSA Singapore Land Surveyors Act (Chapter 156)

SLTA Singapore Land Titles Act (Chapter 157)

SPC State Plane Coordinate

APPENDIX B - HISTORY OF NAD83

NAD83 (1986)

By the 1960s the existing geodetic reference system (NAD27) was found to be inadequate. Surveyors using more accurate instruments such as electronic distance measuring devices (EDM) were finding distortions and inconsistencies in NAD27. Misclosures as great as 1 meter in 15 kilometers were occasionally found. (Schwarz 1989) Using these more accurate instruments, misclosures of closed field traverses should have been much better than the 1:15000 misclosures being found at that time. Surveyors realized the problem was with the quality of the NAD27 control points, and were being forced to distort their work in order to fit the NAD27 control. Clearly surveyors saw a need for a better system. The military and others working with space activities also found NAD27 to be lacking. Satellite tracking required that tracking stations located thousands of miles apart be accurately located, both relative to each other and to the center of the mass of the Earth.(Schwarz 1989)

The North American Datum of 1983 (NAD83) was the new horizontal geodetic datum established in a collaboration between the National Geodetic Survey (NGS) of the United States, the Geodetic Survey of Canada, the Danish Geodetic Institute (responsible for Greenland) and the Inter American Geodetic Survey (that collected geodetic data in Mexico and South America). A total of 266,436 stations and 1,785,772 observations were used in a simultaneous least squares adjustment in creating NAD83.(Schwarz 1989)

Four steps are required in creating a terrestrial reference system such as NAD83. (Snay and Soler 1999) The first step is to create a 3D Cartesian coordinate system and link it to physically measured locations on or within the Earth. Most scientists agree that:

the origin of such a 3D Cartesian coordinate system should be located at the center of mass of the Earth; the Cartesian system's Z-axis should pass through the North Pole; and the X-axis should go through the point of zero longitude located on the plane of the Earth's equator.

The second step related the concept of distance to physically measured quantities on the Earth to come up with a unit of length. The meter, being very precisely defined, is the natural unit of distance to use, however measuring devices have inherent uncertainties even after being calibrated to fit this definition of distance. Consequently, distance, after being measured and put through the least-squares adjustment, will not exactly conform to the very precise definition of the length of the meter. Thus, a scale factor must be included in the terrestrial reference system to adjust all measured distances.

The third step is to approximate the Earth's surface in size and shape by creating a geometric surface by rotating an ellipse about its smaller axis. This generated surface is called an ellipsoid. The ellipsoid's geometric center should be located at the origin of the 3D Cartesian coordinate system, and the semiminor axis of the ellipsoid should coincide with the Cartesian Z-axis.

The fourth step is to determine how gravity contributes to the notion of position, most importantly that of height.

Thus in creating this new terrestrial reference system to be known as NAD83, a 3D Cartesian coordinate system had to be created whose origin was at the center of Earth's mass (geocentric), whose Z-axis was parallel to the astronomic pole, and whose X-axis went through the point of zero longitude location on the plane of the Earth's equator. In defining these parameters, measurements and observations used were

Doppler satellite observations (Doppler), very long base radio interferometry (VLBI), satellite laser ranging (SLR) and GPS. (Snay and Soler 2000)

Doppler is a method of determining positions by observing the Doppler shift of radio signals transmitted by satellites in stable orbits. The Applied Physics Laboratory of Johns Hopkins University developed the Transit system to allow Polaris submarines to determine their accurate positions world-wide in all weather conditions using a receiver (the Geceiver PPR-14) to observe Doppler shifts of Transit satellites launched just for that purpose. The first Transit satellite was launched in December 1963, and the first position fix was computed aboard a submarine in July 1964. The Navy released Transit signals for public use in July 1967. (Smithsonian National Museum of American History 2008) The Naval Surface Warfare Center created a new coordinate system that was used in these Doppler position observations, which was the geodetic reference frame named NSWC 9Z-2. Thus Doppler position observations used in the NAD83 adjustment consisted of a 3D coordinate (X,Y,Z) in the NSWC 9Z-2 geodetic reference system. (Schwarz 1989 page 199) Since the Doppler position observations made up the bulk of data used to define the parameters of NAD83, the orientation of NSWC 9Z-2 was the starting point for NAD83. (Schwarz 1989 page 83) The NAD83 adjustment used 655 Doppler position observations at 612 stations located in the conterminous United States (CONUS) and Alaska were used in the adjustment.

VLBI measures the time difference on the arrival of microwave signals from extragalactic radio sources received at two or more radio observatories and is the only technique capable of measuring all components of the Earth's orientation accurately and simultaneously. (International Earth Rotation and Reference Systems Service 2001)

VLBI vectors (distances between radio observatories) are extremely precise, and are internally consistent at the 2-3 cm level even spanning the continent. (Zilkoski, D'Onofrio et al. 1997) Appendix C. For NAD83, 112 VLBI vectors involving 45 stations were used in the adjustment.

SLR is able to determine very accurate distances by measuring the time intervals required for pulses emitted by a laser transmitter to travel to a satellite and return to the observing site. SLR is sensitive to the location of the geocenter (In fact, since 1987 the time history of the movement of the geocenter with respect to the origin of the various terrestrial reference frames has been obtained with an accuracy of a few millimeters. (International Earth Rotation and Reference Systems Service 2001)). Even though SLR is probably the best method to determine the geocenter, there were very few observing stations compared to the Doppler network, and thus it was not feasible to use SLR alone to connect NAD83 to the geocenter. However, SLR could help refine the Doppler geocenter (Schwarz 1989) page 82.

Astronomic azimuths at 4470 stations were available for the NAD83 adjustment, and were used to determine astronomic longitudes for most of the stations by using the adopted longitude of the U.S. Naval Observatory and the accurate time signals provided by the U.S. Naval Observatory. Since it was presumed that these astronomic longitudes were consistent with the meridian of the then accepted international reference frame, these astronomic azimuths were to be used in the NAD83 adjustment to orient the X axis. (Schwarz 1989) pages 83 + 199. (As will be discussed, these azimuths in fact were not held.)

During the mid-1980s NGS adopted the new GPS technology as the method to position new geodetic stations relative to existing stations. Unfortunately only five GPS observations were performed soon enough to be included in the NAD83 adjustment. (Schwarz 1989) page 199.

Geodetic Reference System 1980 (GRS80) is a geocentric ellipsoid that was adopted by the International Union of Geodesy and Geophysics in December 1979 and subsequently adopted by the International Association of Geodesy (IAG). The orientation of GRS80 was specified so that the rotational axis of the reference ellipsoid was to have the direction of the Conventional Terrestrial Pole as defined by the International Earth Rotation Service and the zero meridian (longitude) was to be defined to be the same as the zero meridian defined by the Bureau International de l'Heure (BIH). Also defined as part of GRS80 was a rectangular coordinate system XYZ whose origin was the geocenter, whose Z-axis was the rotational axis of the reference ellipsoid defined by the direction of the CIO and whose X-axis passed through the zero meridian according to the BIH. (Moritz 1980) NGS adopted the GRS80 fundamental and derived parameters exactly as published by IAG ((Schwarz 1989).

World Geodetic System 1984 (WGS84) was developed by the Department of Defense (DoD) specifically to be used to determine the positions of satellites as a function of time. The new GPS system used WGS84 as its reference system. (Snay and Soler 2000) In defining the WGS84 ellipsoid, the DoD:

“...converted the GRS80 dynamic form factor (second zonal harmonic of the equipotential ellipsoid) to normalized form and truncated to eight significant digits before computing the flattening of the ellipsoid. This caused the flattening

of the two ellipsoids to differ beyond the eighth significant digit and the semi minor axes to differ beyond the tenth significant digit. This discrepancy is negligible for practical purposes.” (Schwarz 1989) page83.

A comparison of the two ellipsoids as created in the mid 1980s is as follows (Snay and Soler 1999):

Reference system	Semimajor axis (meters)	Flattening (unit-less) 12 s.d.
GRS80	6,378,137 (exactly)	1/298.257222101
WGS84	6,378,137 (exactly)	1/298.257223563

Table B 1 Ellipsoid Comparison Snay and Solar 1999

The relationship between NSW 9Z-2 and NAD83 is defined by a seven-parameter transformation (three translations, three rotations, and a scale change) (Schwarz 1989 p. 199). In other words, the origin of NSW 9Z-2 is offset from the origin of NAD83 and to move the origin of NSW 9Z-2 so that it would be coincident with the origin of NAD83 would require three translations, one each in the X direction, the Y direction, and the Z direction. The X-axis, Y-axis, and Z-axis of NSW 9Z-2 are not parallel to the corresponding axes of NAD83. In order to make the 3 axes of NSW 9Z-2 parallel to NAD83, the rotations must be performed, one for each of the X-axis, Y-axis, and Z-axis. Finally, since observing Doppler coordinates in the NSW 9Z-2 will have some uncertainty involved, a scale factor is required to make the measured distances associated with NSW 9Z-2 correspond to the defined length of the meter.

Thus the NAD83 adjustment can be thought of as determining these seven global parameters to be used to transform the Doppler coordinates based on the NSW 9Z-2 to the new NAD83 system: X shift, Y shift, Z shift, X rotation, Y rotation, Z rotation, scale.

In 1985 it was time for NGS to start performing the adjustment. When determining the three translation parameters (X shift, Y shift, Z shift) it was decided to use information determined by the BIH, the most authoritative and universally accepted source at that time (Schwarz 1989) page 83:

*“The most current numerical values were those in its (BIH) 1984 Annual Report... this listed the difference between NSW 9Z-2 Doppler system and the BIH Reference System (BTS84) as (BIH minus NSW):
-0.106 m in X;
+0.697 m in Y; and
+4.901 m in Z.”* (Schwarz 1989) page 83

The Defense Mapping Agency (DMA) had already selected the X shift to be 0.000 m, the Y shift to be 0.000 m, and the Z shift to be +4.5 m as the origin shift from NSW 9Z-2 to WGS84. Thus, to make NAD83 compatible with WGS84 (and thus compatible with the GPS system), these same parameters were used for NAD83. (Schwarz 1989) page 83. Thus before NAD83 adjustment would be run, 3 of the 7 parameters would be given a priori values: X shift = 0.000m; Y shift = 0.000m, and Z shift = +4.500meters.

The most accurate determinations of scale at that time were provided by SLR and VLBI. Because there were so few SLR observations, NGS decided to use VLBI to determine the scale parameter. In the first two solutions of the NAD83 adjustment, a parameter was included for the Doppler scale change, but the VLBI scale parameter was held fixed with an a priori value of zero. The results of this preliminary adjustment gave a scale parameter for Doppler observations of -0.65 parts per million (ppm) (for the first solution) and -0.53 ppm (for the second solution). At this point NGS compared these

preliminary scale changes with those determined by BIH and DMA. The BIH had obtained a scale change of -0.604 ppm for Doppler derived distances in comparing them with SLR and VLBI measurements. DMA had already decided to adopt the rounded figure of -0.6 ppm as the scale transformation parameter from NSWC 9Z-2 to WGS84. NGS decided to use the same scale change parameter as used by DMA, mostly so that NAD83 would be compatible with WGS84 but also because BIH results included SLR and thus was more comprehensive than VLBI determination alone. (Schwarz 1989) page 84. Thus, in the third (last) solution for the NAD adjustment, the scale parameter for Doppler positions was held fixed a priori at -0.6 ppm. In this last solution a parameter was added for VLBI scale shift, which was calculated to be -0.075 ppm. Thus the relation between Doppler and VLBI was $-0.6 - (-0.075) = -0.525$ ppm, which checked out well with the second solution scale factor of -0.53 ppm.

In determining orientation of the three axes, the orientation of the pole is represented by rotations around both the X-axis and the Y-axis, while the origin of longitude is represented by a rotation around the Z-axis. The rotations around the X- and Y-axes is well constrained, since the pole is a naturally defined physical position. Since VLBI is the best means of determining the pole orientation, the VLBI X rotation and Y rotation parameters were determined by the NAD83 adjustment. Doppler positioning had no bearing on pole orientation and thus the Doppler X and Y rotation parameters were fixed a priori at zero. (Schwarz 1989) page 83. The final NAD83 adjustment values as calculated were VLBI X axis rotation of +0.022 arc seconds, and VLBI Y axis rotation of +0.026 arc seconds. (Schwarz 1989) page 187.

The final parameter of the NAD83 adjustment is the Z-axis rotation, which determined the longitude origin. The best method of determining the Z-axis rotation was through the use of astronomic azimuth observations and astronomic longitude observations. Since the astronomic longitudes were based on the adopted longitude of the U.S. Naval Observatory and time signals were provided by the U.S. Naval Observatory, the astronomic longitudes were presumed to be consistent with the BIH meridian so the astronomic longitudes were taken as the standard, with their Z-axis rotation parameter fixed with an a priori value of zero. The VLBI Z-axis rotation parameter was allowed to be determined by the NAD83 adjustment. NAD83 adjustment contained a parameter to shift Doppler longitudes to astronomic longitudes and thus the NAD83 adjustment determined the Doppler Z-axis rotation parameter.

The final NAD83 adjustment values as calculated were Doppler Z-axis rotation of -0.449 arc seconds and VLBI Z-axis rotation of +0.375 arc seconds. However, BIH in 1984 listed the Z-axis rotations to get to the BIH meridian as -0.8137 arc seconds for NSWC 9Z-2 (Doppler) coordinate system and -0.0057 arc seconds for the VLBI system. Thus the rotation of the Z-axis from Doppler to VLBI was calculated as -0.8080 arc seconds for BIH determination and as -0.824 arc seconds for NAD83 adjustment, which was judged by NGS to be sufficiently close and thus mutually confirming. However, there was an apparent discrepancy of about -0.365 arc seconds between the BIH meridians (zero longitude) as determined by BIH and as determined from the astronomic longitudes in the NAD83 adjustment. To eliminate this apparent discrepancy would require that all longitudes obtained by the NAD83 adjustment would have to be further rotated by -0.365 arc seconds. NGS proposed this further rotation to DMA and to

Geodetic Survey of Canada, who both agreed. (There was considerable speculation on possible causes of this -0.365 arc second discrepancy, such as observational and systematic errors in the optical star catalog. In the end there was no clear explanation and thus a rotation of -0.814 arc seconds from Doppler to the BIH meridian system was simply adopted.) (Schwarz 1989 p. 84)

Thus NAD83 was a geocentric reference system whose realization relied heavily on Doppler satellite observations. While NAD83 is a 3D reference system, NGS adopted only horizontal coordinates (latitude and longitude) for over 99% of the approximately 250,000 U.S. control points involved in the adjustment (Snay and Soler 2000).

IERSXX

In the late 1980s the International Earth Rotational Service (IERS) began supporting scientific investigations on items that might affect highly accurate position coordinates such as monitoring crustal motion and the motion of the Earth's rotational axis. IERS introduced a new terrestrial reference system called ITRS. The initial realization of ITRS was International Terrestrial Reference Frame of 1988 (ITRF88). ITRF solutions were typically published nearly annually with 10 versions published between 1988 and 2000. (McCarthy and (eds.) 2004) IERS published positions and velocities for a worldwide network of several hundred stations that were derived using highly precise geodetic techniques that included GPS, VLBI, SLR, LLR (lunar laser ranging using retro-reflectors that had been placed on the moon's surface), and DORIS (Doppler orbitography and radio positioning integrated by satellite). ITRS was the first

major international reference system to address crustal motion by publishing velocities of its control points. (Snay and Soler 2000)

NAD83 (HARN)

The NAD83 project extended from July 1, 1974 to July 31, 1986 and was the single largest NGS project during those twelve years. However, within a few years after 1986 GPS, SLR, and VLBI matured, allowing geodesists to locate the geocenter with a precision of a few centimeters. These geodesists also found that the geocenter adopted for NAD83 was displaced by about 2 m from the true geocenter; the X,Y, and Z axes were misaligned by over 0.03 arc seconds relative to their true orientations, and the NAD83 scale differed by about 0.0871 ppm from the true definition of the meter (Snay and Soler 2000). Other discrepancies in the NAD83 system became apparent almost immediately as more and more people used the highly accurate GPS system in their measurements (Snay and Soler 2000). NAD83 was found to have distortions at the one meter level. (Snay and Soler 2000) Almost immediately after releasing NAD83, NGS was looking for ways to address the problems inherent in NAD83.

In 1988 (just two years after NAD83 adjustment had been completed), NGS started the process of upgrading NAD83 coordinates for survey control monuments by performing High Accuracy Reference Network (HARN) GPS surveys (formerly called High Precision Geodetic Networks (HPGN)), which were performed on a state by state basis rather than at the national level. (Zilkoski, D'Onofrio et al. 1997) Appendix C. (The initial realization of NAD83 is known as NAD83 (1986), which will be used from this point on in this paper.)

As stated previously, NGS adopted GRS80 (with the fundamental and derived parameters being exactly as published by IAG) when it created the reference system known as NAD83. Thus NAD83 was a reference system defined as a 3D Cartesian coordinate system whose origin was the geocenter of the Earth, whose Z-axis was to have the direction of the Earth's rotational axis (CIO), whose X-axis was to be defined by the zero meridian of longitude as defined by BIH, and whose fundamental unit of length was to be the meter (Moritz 1980). Once a reference system is defined, a reference frame must be created to show how the reference system is fixed to the Earth. A reference system is "realized" by designating coordinates based on the reference system to several identifiable points on the Earth's surface, and this specific realization of the reference system creates a reference frame. Thus NAD83 (1986) is a reference frame created in 1986 of the NAD83 reference system that was realized by determining coordinates through a least squares adjustment of 612 stations from which Doppler observations were made, 45 stations from which VLBI observations were made, and 4470 stations from which astronomic azimuths were observed. The fundamental unit of length of NAD83 (1986) was the meter.

The reference frame known as NAD83 (HARN) was the second realization of the NAD83 reference system, and was realized by holding the NAD83 (1986) coordinates as previously determined for 12 VLBI stations in North America. Since it was known that the origin of NAD83 was displaced by several meters from the actual geocenter of the Earth as determined by IERS, NGS determined transformation parameters to be able to transform coordinates from ITRF89 (epoch 1988.0) to NAD 83 (1986) (IERS had also published ITRF89 coordinates for the 12 VLBI stations used in the realization). The

resulting seven parameters to transform coordinates from ITRF89 (epoch 1988.0) to NAD83 (1986) are as follows (Zilkoski, D'Onofrio et al. 1997) Appendix C:

$$X \text{ shift} = +0.9191 \text{ m}$$

$$Y \text{ shift} = -2.0182 \text{ m}$$

$$Z \text{ shift} = -0.4835 \text{ m}$$

$$X \text{ rotation} = +0.0275 \text{ arc seconds}$$

$$Y \text{ rotation} = +0.0155 \text{ arc seconds}$$

$$Z \text{ rotation} = +0.0107 \text{ arc seconds}$$

$$\text{scale} = -0.0871 \text{ ppm}$$

Note that VLBI parameters as determined from the final adjustment of NAD83 (1986) were very close to those found in 1988, indicating that the coordinate system of the original VLBI vectors was very similar to the ITRF vectors (Zilkoski, D'Onofrio et al. 1997)Appendix C:

Parameter	VLBI in NAD83 (1986)	VLBI in 1988
X rotation	+0.022 arc seconds	+0.0275 arc seconds
Y rotation	+0.026 arc seconds	+0.0155 arc seconds
Z rotation	+0.010 arc seconds	+0.0107 arc seconds
Scale	-0.075 ppm	-0 0871 ppm

Table B 2 Comparison VLBI 1986 & 1988

As mentioned previously, the meter, being very precisely defined, is the natural unit of distance to use in a reference frame; however measuring devices have uncertainties involved even after being calibrated to fit this definition of distance.

Consequently, distance, after being measured and put through the least-squares adjustment, will not exactly conform to the very precise definition of the length of the meter. Thus, a scale factor must be included in the terrestrial reference frame to adjust all measured distances. Recall that in the third (last) solution for the NAD83 (1986) adjustment, the scale parameter for Doppler positions was held fixed a priori at -0.6 ppm, which in theory meant that after this scale factor had been applied, distances computed by using coordinates in NAD83 (1986) should have a fundamental unit length of exactly a meter. ITRF89 (epoch 1988.0) also had a fundamental unit of length defined as being exactly a meter, however the relationship between these two fundamental units of length of NAD83 (1986) and ITRF89 (epoch 1988.0) differed by a scale factor of -0.0871 ppm.

NGS decided to accept the fundamental unit length associated with ITRF89 (epoch 1988.0) as being equal exactly to a meter, and thus all distances associated with the NAD (1986) needed to be scaled by a factor of 0.0871 ppm. (Zilkoski, D'Onofrio et al. 1997)

{Note that NAD (1986) and NAD (HARN) were supposed to be two different realizations of the same reference system NAD83, however in fact this is not true since each of these realizations used a different reference system (unfortunately both of these reference systems were called NAD83). The assumption made by NGS was that the fundamental unit of length of ITRF89 (epoch 1988.0) was exactly equal to a meter, and that by holding the scale factor transformation parameter between NAD (HARN) and ITRF89 (epoch 1988.0) as zero meant that

NAD83 (HARN) also used a fundamental unit of length that was exactly equal to a meter. However, this would mean that the fundamental unit of length of the reference system used in the realization of NAD83 (1986) was not in fact exactly equal to the meter, but was off by a scale factor of 0.0871 ppm. Thus the reference system used for NAD83 was different in 1986 when the NAD83 (1986) realization was created, than it was in 1988 when the NAD (HARN) realization was created. This change in the scale factor meant that all ellipsoidal heights for points in the original NAD (1986) realization were systematically increased by 0.6 m, while the changes to the horizontal coordinates of latitude and longitude were insignificant. However, this did not seem to be a problem since NGS only adopted horizontal coordinates when NAD83 (1986) was finalized. (Snay and Soler 2000) }

After creating the realization known as NAD83 (HARN), the 12 VLBI stations were used as control for a nationwide A-Order GPS survey of points entitled the “Eastern Strain Network Project”, which was observed in 1987 and 1990. Individual states then tied into this Eastern Strain Network Project for their individual HARN survey. Each state then adjusted their HARN survey separately from other states, constraining their network to hold the coordinates of the Eastern Strain Network Project points that they tied into. (Milbert 1998) Each state created its own NAD83 (HARN) network between 1989 and 1997. (Snay and Soler 2000)

NAD83 (CORSXX)

In the mid 1990s NGS organized a network of continuously operating reference stations (CORS). Each CORS included a GPS receiver whose data NGS collected,

processed and disseminated to the public. By December 1994 there were about a dozen CORS in the network. (Snay and Soler 2000)

Positional coordinates of this early CORS network were first computed in the ITRS realization known as ITRF93. However, in late 1994 NGS introduced the third realization of NAD83, known as NAD83 (CORS93). The reference system used was the new, revised NAD83 system that was used in the realization of NAD (HARN). (As previously noted, this revised NAD83 system had a different scale than the original NAD83 system used in the realization of NAD83 (1986).) Since CORS initially used coordinates in the reference frame known as ITRF93, parameters had to be determined to transform ITRF93 coordinates to NAD (CORS). Nine VLBI stations that each had both NAD83 (HARN) coordinates as well as ITRF93 coordinates were used to determine these transformation parameters (The scale parameter was set a priori to zero).(Snay and Soler 2000)

In the spring of 1996, NGS started to compute positional coordinates of all the CORS stations in the network by using the new ITRS realization known as ITRF94. NGS decided to introduce a fourth realization of NAD83, to be known as NAD83 (CORS94), again based on the NAD83 reference system that was used in the NAD (HARN) realization. Transformation parameters to convert ITRF94 coordinates to NAD83 (CORS94) coordinates were developed by using eight VLBI stations (One of the nine VLBI stations used in the realization of NAD83 (CORS93) became unstable and was not used in the realization of NAD83 (CORS94)). Again, this calculation of transformation parameters was possible because each of the eight VLBI sites had

coordinates in both ITRF94 and NAD (HARN). Once again, the scale parameter was set a priori to zero. (Snay and Soler 2000)

In 1997 NGS started computing positional coordinates for all the then existing CORS stations in the newly issued ITRS realization known as ITRF96. NGS created a fifth realization of NAD83 to be known as NAD83 (CORS96), again based on the revised NAD83 reference system that was used in the NAD (HARN) realization. Transformation parameters to convert ITRF96 coordinates to NAD83 (CORS96) coordinates were developed by using the same eight VLBI sites (which were all located in the United States) as well as four VLBI sites in Canada, for which ITRF96 coordinates and NAD84 (HARN) coordinates were known for each of the 12 total VLBI sites. ITRS in all its realizations had created velocities as well as positions for its control points. For the first time, NGS addressed the fact that ITRFXX positional coordinates changed with time by adding an additional seven transformation parameters that dealt with velocity. These seven new parameters determined how each of the following parameters changes with time: X-shift; Y-shift; Z-shift; X-axis rotation; Y-axis rotation; Z-axis rotation; and scale. Thus there were 14 transformation parameters used to transform ITRF96 coordinates to NAD83 (CORS96) coordinates. The scale factor again was given the value a priori of zero. The three new transformation parameters describing how the X, Y, and Z axes rotations change with time were given values so as to equal those describing the average motion of the North American tectonic plate, effectively making sure that NAD83 (CORS96) coordinates would not change on the ground with time because of movement of the North American plate with time. The new rate of change parameters for

X-shift, Y-shift, and Z-shift as well as the rate of change parameter for scale were given values a priori of zero. (Soler and Snay 2004)

NGS started computing positional coordinates for all existing CORS stations with ITRF97 when it was released by IERS. However, rather than create a new realization of NAD83 in order to transform ITRF97 to NAD83, NGS instead decided to keep the existing realization of NAD83 (CORS96) by using the existing transformation parameters between ITRF96 and NAD83 (CORS96), and then adding a second set of transformation parameters to transform ITRF97 coordinates to ITRF96. The procedure would be to first transform ITRF97 coordinates to ITRF96 coordinates, and then transform these ITRF96 coordinates to NAD83 (CORS96) coordinates. Rather than create their own transformation parameters to transform ITRF97 to ITRF96, NGS decided to use the transformation coordinates determined by the International GPS Service (IGS). (Soler and Snay 2004)

When IERS released ITRF00 (epoch 1997.00), NGS again started to use it to compute positional coordinates of the CORS stations that existed at that time. Rather than create a new realization of NAD83, NGS decided to first transform ITRF00 coordinates to ITRF97 coordinates, then transform ITRF97 coordinates to ITRF96 coordinates, and finally to transform the ITRF96 coordinates to NAD83 (CORS96) coordinates. NGS decided to again hold the transformation parameters developed by IERS to transform ITRF00 (epoch 1997.00) to ITRF97. (Soler and Snay 2004)

Thus transforming ITRF00 (epoch 1997.00) coordinates to NAD83 (CORS96) coordinates requires three distinct transformations applied sequentially in the following way: ITRF00 to ITRF97; ITRF97 to ITRF96; ITRF96 to NAD83 (CORS96). (The

values for the 14 parameters for each of these transformations are listed in (Soler and Snay 2004) Table 1.) However, because the values of the 14 parameters of each of the three transformations are so small, the values of each of the 14 parameters to transform directly from ITRF00 to NAD83 (CORS96) may be computed with sufficient accuracy by adding together the value of the said parameter for each of the three transformations. The parameters adopted by NGS to transform ITRF00 (epoch 1997.00) to NAD83 (CORS96) (epoch 1997.00) are listed in the following table (Soler and Snay 2004):

Parameters Adopted for Transformation ITRF00 to NAD83(CORS96)

Epoch: January 1, 1997 (epoch 1997.00)

X-shift	+0.9956 m
Y-shift	-1.9013 m
Z-shift	-0.5215 m
X-axis rotation	+0.025915 arc seconds
Y-axis rotation	+0.009426 arc seconds
Z-axis rotation	+0.011599 arc seconds
Scale	+0.62 parts per billion
X-shift rate	+0.0007 m/year
Y-shift rate	-0.0007 m/year
Z-shift rate	+0.0005 m/year
X-axis rotation rate	+0.000067 arc seconds/year
Y-axis rotation rate	-0.000757 arc seconds/year
Z-axis rotation rate	-0.000051 arc seconds/year
Scale	-0.18 parts per billion/year

Table B 3 Soler and Snay 2004-Table 2

NGS next updated all CORS coordinates for an epoch date of January 1, 2002 (epoch 2002.00) by using the parameters showing rates of change for transformation from ITRF00 (epoch 1997.00) to NAD83 (CORS96) (epoch 1997.00). Thus, currently NGS disseminates coordinates for all CORS stations in both ITRF00 (epoch 1997.00) and NAD83 (CORS96) (epoch 2002.00). (Soler and Snay 2004)

NAD83 (2007)

Accurate positioning with GPS requires that the technique of differential GPS be used. In this procedure, one survey-grade GPS receiver (the Base Station) is set up over a point with a known coordinate specifying its location on the ground. A second survey-grade GPS receiver (the Rover) is set up over the point for which an accurate coordinate is desired. Both receivers must collect data at the same time. The data from the two receivers is then processed (in real time for an RTK GPS survey and at a future time for a static GPS survey). In this process, if the known coordinate of the base station is not accurate, then the coordinate found for the new station will also not be accurate.

NGS has created two different systems to be used in this differential GPS technique. The first system is the HARN system that nationwide consists of tens of thousands of passive survey monuments set in the ground for which NGS has accurate coordinates that is disseminated to the public. The second system is the CORS system. With the HARN system, a base station is set up over a HARN mark and the rover is set up over the unknown point. If the HARN point has an accurate positional coordinate associated with it, then the coordinate determined by differential GPS for the unknown point will also be accurate.

With the CORS system, NGS has created a procedure where one or more CORS stations can be used as a base station, and thus only the rover is supplied by the user. NGS collects and disseminates the data for the CORS stations, which the user can then process with data from the rover. NGS has also created a process called Online Positioning User Service (OPUS) in which the user sends the data from the rover to NGS over the internet. NGS next picks three CORS stations to be used as base stations and NGS computes the coordinate of the unknown station over which the rover is set.

Thus a coordinate can be determined for an unknown point by using differential GPS in which the base station is either a HARN monument or a CORS station. The coordinate as determined should be the same regardless of whether a HARN monument or a CORS station is used (Note that the realization used for the HARN points was NAD83 (HARN), while the realization for NAD83 (CORS) also was based on using NAD83 (HARN) coordinates for the VLBI stations used in the realization.). However, when CORS stations were used to check the published coordinates of HARN points, discrepancies were revealed. In 1995 a GPS survey in Maine connected several HARN stations to the CORS network, uncovering positional errors in the HARN at the 10 cm level. In 1996 it was discovered that there was an 8 cm misfit between the Virginia HARN and the Georgia HARN. Distortions of these magnitudes were also found in Nevada (Milbert 1998). By 1998 a readjustment of the HARN stations in New England and of most of the HARN stations between Georgia and North Carolina had taken place. After extensive analysis and the 1998 readjustment, HARN positions throughout the conterminous United States were generally in agreement with CORS to within 6 cm. However, at that time accuracies of 1 to 2 cm were being obtained by using CORS alone.

The reason for distortions in the HARN system were generally blamed on the fact that adjustments of each state were performed individually and not on a nationwide basis, and on the fact that each state's individual adjustment was constrained by using a few different stations (rather than all) of the Eastern Strain Network Project. At that time it was determined that a nationwide adjustment of the HARN be performed using CORS as control rather than the Eastern Strain Network Project. (Milbert 1998)

Starting in 1998 and ending in 2005, NGS performed additional GPS geodetic surveys of the various HARN systems. In 2007 NGS performed a new realization of NAD83 that was originally named NAD83 (NSRS2007), which was subsequently shortened to NAD83(2007). For the adjustment, NAD83 (CORS96) (epoch 2002) coordinates of about 700 CORS stations were held fixed. From this adjustment, NAD83(2007) coordinates were determined on about 70,000 nationwide passive geodetic control monuments. This new realization approximates (but is not, and can never be, equivalent to) the more rigorously defined NAD83 (CORS96) realization. (National Geodetic Survey 2008)

Even though the original intent of the NAD83 reference system was that realizations create coordinates that are fixed to the North American tectonic plate, in fact each CORS station has some motion in all of the X, Y, and Z axes. CORS stations can be thought of as being fixed to the Earth's surface, and thus the NAD83 (CORS96) coordinates will change in time when describing such a fixed point. For each CORS station, NGS is monitoring the velocity of this change and publishes the result so that the NAD83 (CORS96) coordinate at any epoch date can be determined. However, NGS has not computed NAD83 (2007) velocities for any of the 70,000 passive HARN marks that

were involved in the adjustment and therefore every such coordinate will reference an epoch date. Thus, as time passes, the coordinate of the passive mark will change, but NGS will only provide NAD83 (2007) coordinates that existed at the epoch date.

(National Geodetic Survey 2008)

The function of NSRS is to provide a consistent coordinate system as the foundation of all surveying, mapping, and charting activities in the United States and its territories. The NSRS must be more accurate than all activities that build upon it, such as surveying boundary corners to the centimeter level and determining the rotation of the North American Plate at mm/year. This means that the geodetic latitude, longitude, and height of points used in defining the NSRS should have an absolute accuracy of 1 mm at any time. Thus a specific point on the Earth's surface should have the same geodetic coordinate associated with it today, next year, or ten years from now.

OPUS and CORS

NGS will no longer monitor the 70,000 passive monuments for which NAD83 (2007) coordinates were calculated and instead will rely on CORS for NSRS. NGS disseminates coordinates of all CORS stations in both ITRF(00) (Epoch 1997.00) and NAD83 (CORS96) (Epoch 2000.00). Thus published NAD83 coordinates are for CORS site positions as they existed on January 01, 2002. The NAD83 site velocity must be applied to find the site's location for any other date.

NGS monitors the quality of these CORS coordinates by calculating daily (24 hour) solutions of the GPS CORS network. They also publish for each CORS station the variation of these daily coordinates spanning a period of 60 days. Checking this 60 day time series can detect problems with the station such as unreported antenna changes or

antenna disturbances. NGS also produces a multi-year solution in which data from the CORS archives from 1994 to the last available year on record is combined into a single solution. (Soler, Snay et al. 2003)

The multi-year solution is used to compute provisional positions and velocities for all CORS ITRF coordinates. If for any station this provisional ITRF positional coordinate differs from the currently adopted ITRF coordinate by more than 1 cm in the North-South or East-West component, then NGS adopts the provisional position and velocity to supersede the previously adopted ITRF position and velocity. This is also performed with respect to NAD83 (CORS96) coordinates except the provisional position coordinates are adopted to supersede the previously adopted position if they differ by more than 2 cm in the North-South or East-West component. (National Geodetic Survey 2010)

NAD83 is designed so that points on the North American tectonic plate will have an average zero horizontal velocities relative to that reference frame. (Snay 2003)

However, crustal motion can create conditions where points on the ground can have NAD83 coordinates that change with time. The major causes of this crustal motion in the horizontal direction are associated with plate tectonics and earthquakes. In the vertical direction significant crustal motion occurs as a result of volcanic/magmatic activity, postglacial rebound, withdrawal of subsurface fluids such as water and oil, sediment compaction, and various types of crustal loading (tidal, atmospheric, hydrologic). NGS developed the Horizontal Time-Dependent Positioning (HTDP) software to estimate horizontal velocities on the Earth's surface in the continental United States and parts of

Alaska. However, currently HTDP only addresses horizontal motions due to plate tectonics and earthquakes. (Snay and Pearson 2010)

One use of HTDP is to update (or backdate) horizontal coordinates measured on one date to corresponding coordinates that would have been measured on another date. A second use is to update (or backdate) the values of certain surveying observations such as GPS baselines, distances, angles and azimuths from the values measured on one date to those that would have been measured on another date. (Snay and Pearson 2010)

NGS has developed the Online Positioning User Service (OPUS) to simplify the process of accessing high-accuracy NSRS coordinates. Rather than having to use passive control monuments, NGS has provided a way to use only the CORS network to access these NSRS coordinates. To find the NSRS coordinate of a point on the Earth's surface by static processing requires that a dual-frequency GPS receiver set over the point collect data for 4 hours or more. OPUS then calculates the NSRD coordinate for the point by averaging the three independent single-baseline solutions computed by double-differencing carrier-phase measurements between the user's data file and 3 surrounding CORS. As described above, NGS has control of the integrity of the CORS coordinates over time to ensure that OPUS solutions are accurate whenever calculated. (Mader, Weston et al. 2003)

Since GPS satellite ephemerides use ITRF coordinates, OPUS first computes coordinates referred to ITRF00. The chronological sequence of events that OPUS follows are:

- For each of the 3 CORS stations, find from the NGS Integrated Data Base (NGSIDB) the ITRF00 (Epoch 1997) coordinates.
- Using the adopted ITRF velocities also found in NGSIDB, update the ITRF00 (Epoch 1997) coordinates to ITRF00 coordinates for the instant of time for the midpoint of the time interval for the 3 CORS stations.
- Calculate the ITRF00 coordinate for the unknown point for the current time for each of the 3 CORS stations.
- Transform each of the 3 ITRF00 solutions (one from each of the 3 CORS stations) to 3 NAD83 (CORS96) coordinates.
- Average the 3 NAD83 (CORS96) coordinates.
- Convert the averaged NAD83 (CORS96) coordinate to NAD83 (CORS96) (Epoch 2002.00) coordinate by using the NAD83 velocity for that point as predicted by HTDP. (Mader, Weston et al. 2003)

Thus NGS uses CORS, HTDP, and OPUS to allow users to access NSRS coordinates. HTDP currently addresses horizontal motion associated with plate tectonics and earthquakes, but does not address the vertical motion caused by other activity. NGS is currently working on a project to estimate the three-dimensional velocities for all CORS, and will then attempt to develop a model to estimate the three-dimensional velocity at any location in continental United States. This program, to be called Time Dependent Positioning (TDP) is anticipated to be released in early 2012. (Snay and Pearson 2010)

FUTURE PLANS

NGS will redefine the vertical datum based on CORS and a gravimetric geoid, which will have an accuracy of 1 centimeter in as many locations as possible. A new gravity interpolation tool will be introduced that works anywhere in the United States or its territories, which will show any aspect of the gravity field (geoid, gravity, geopotential) on or above the surface of the Earth, as well as the temporal changes of that quantity. (This tool could thus be used to determine the equipotential surface (a closed smooth surface formed by a locus of points all having the same gravity potential, and thus the surface is perpendicular to the local gravity for every surface point) for any point on the Earth's surface). NGS anticipates that a new geocentric terrestrial reference system (to replace NAD83) in conjunction with a new geopotential surface will be introduced around the year 2018. NGS does not guarantee that the new terrestrial reference system will be tied to the surface of the North American Plate.

NGS envisions that CORS will consist of two levels. The first level will be made up of NGS-owned or –operated “fundamental” sites, while the second level will be all other sites whose maintenance and quality control fall to the site operators. NGS will compute and make available to the public coordinates of all CORS on a daily basis. NGS will still strive to have CORS users use OPUS to compute coordinates. NGS will regularly test CORS data and OPUS to ensure that identical results (within error tolerances) will be computed whether fundamental NGS CORS stations or CORS operated and maintained by others are used.

NGS fully endorses and recognizes the strength of using CORS as part of an RTK procedure, although it will not create such a system. Instead, NGS' role will be to monitor the RTK systems that others develop to ensure that the base stations of the RTK system have coordinates accurate within NSRS and that coordinates computed by rovers are also accurate within the NSRS. (National Geodetic Survey 2008)

APPENDIX C – PLANS

Cert. 49169

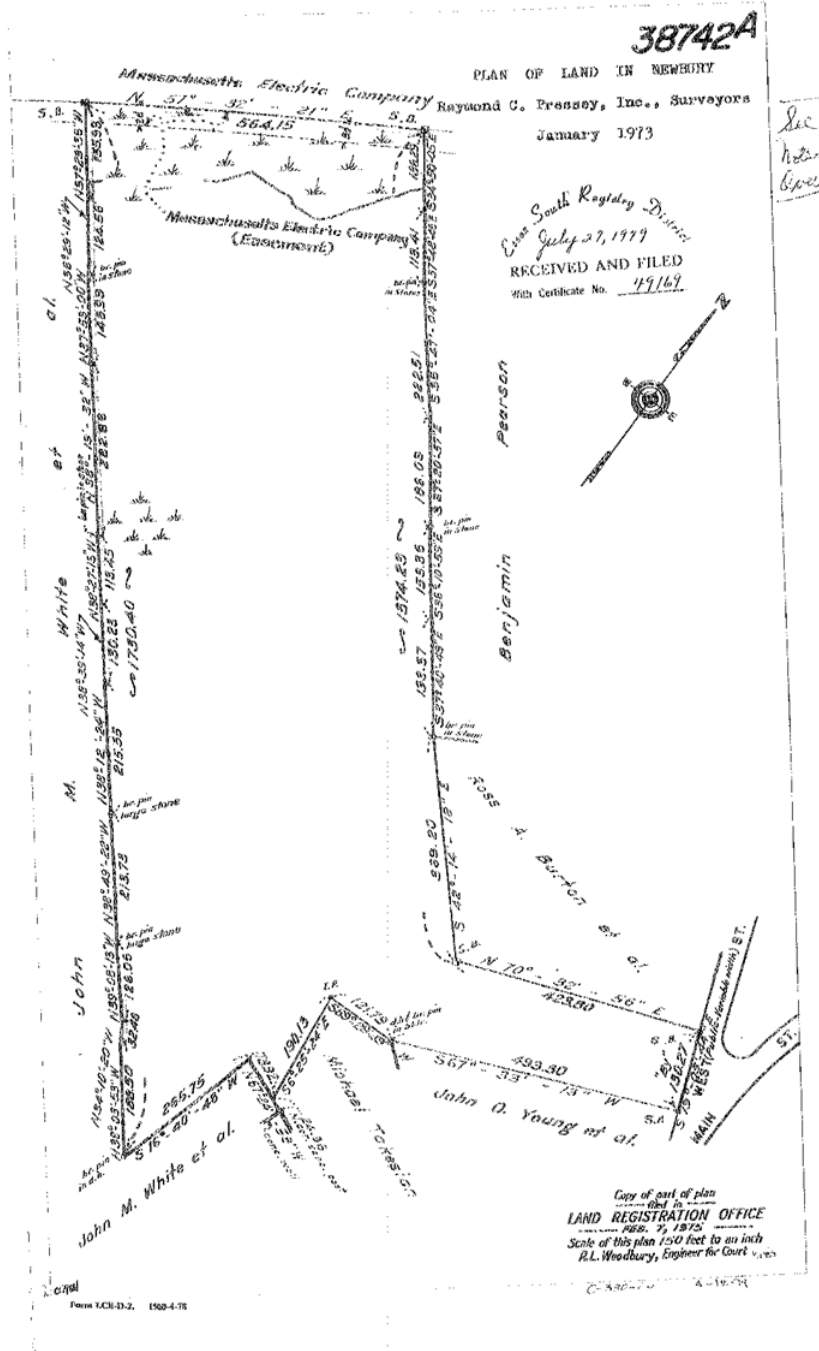
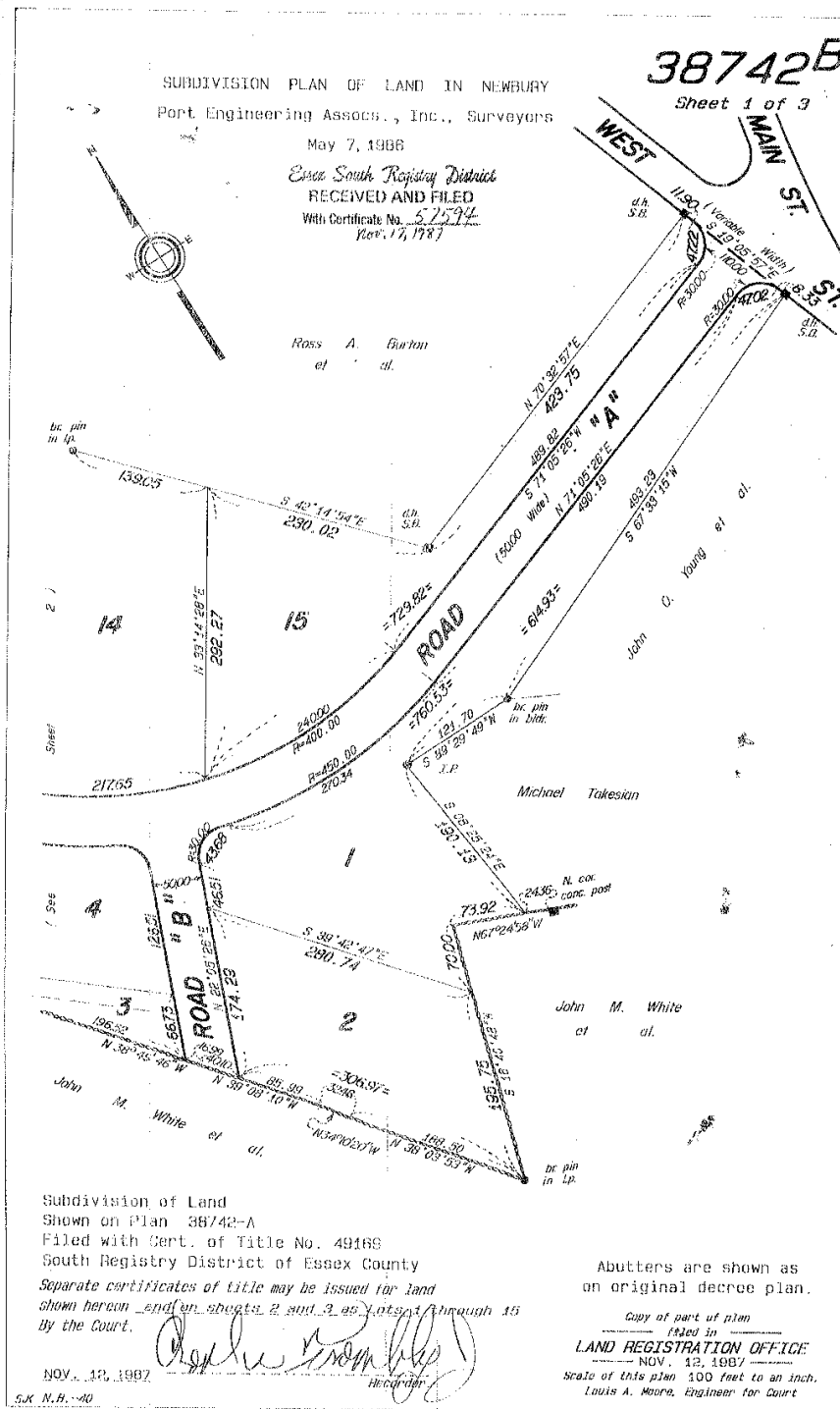


Figure C. 1 Land Court Case 38742 A



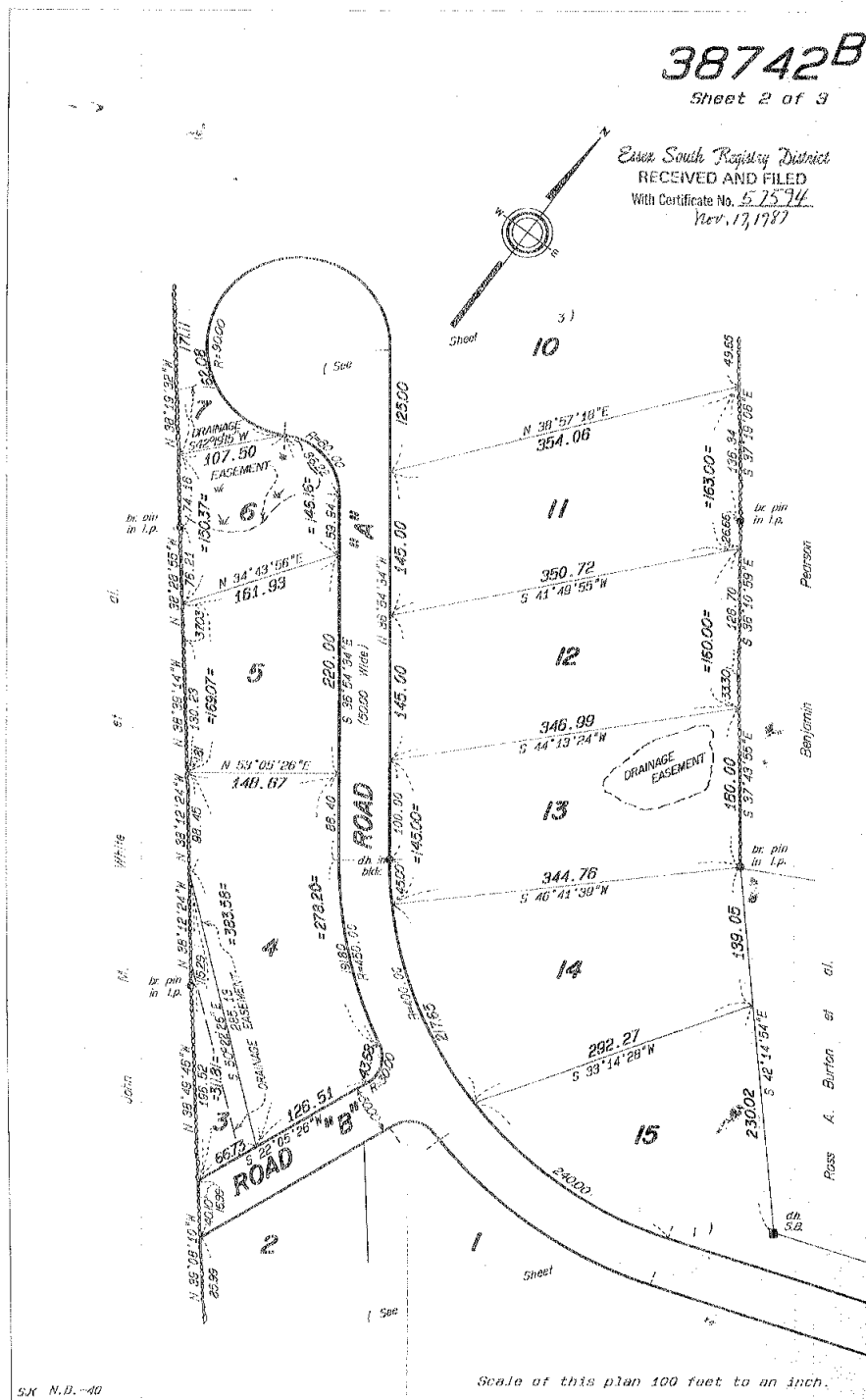


Figure C. 3 Land Court Case 38742B Sheet 2 of 3

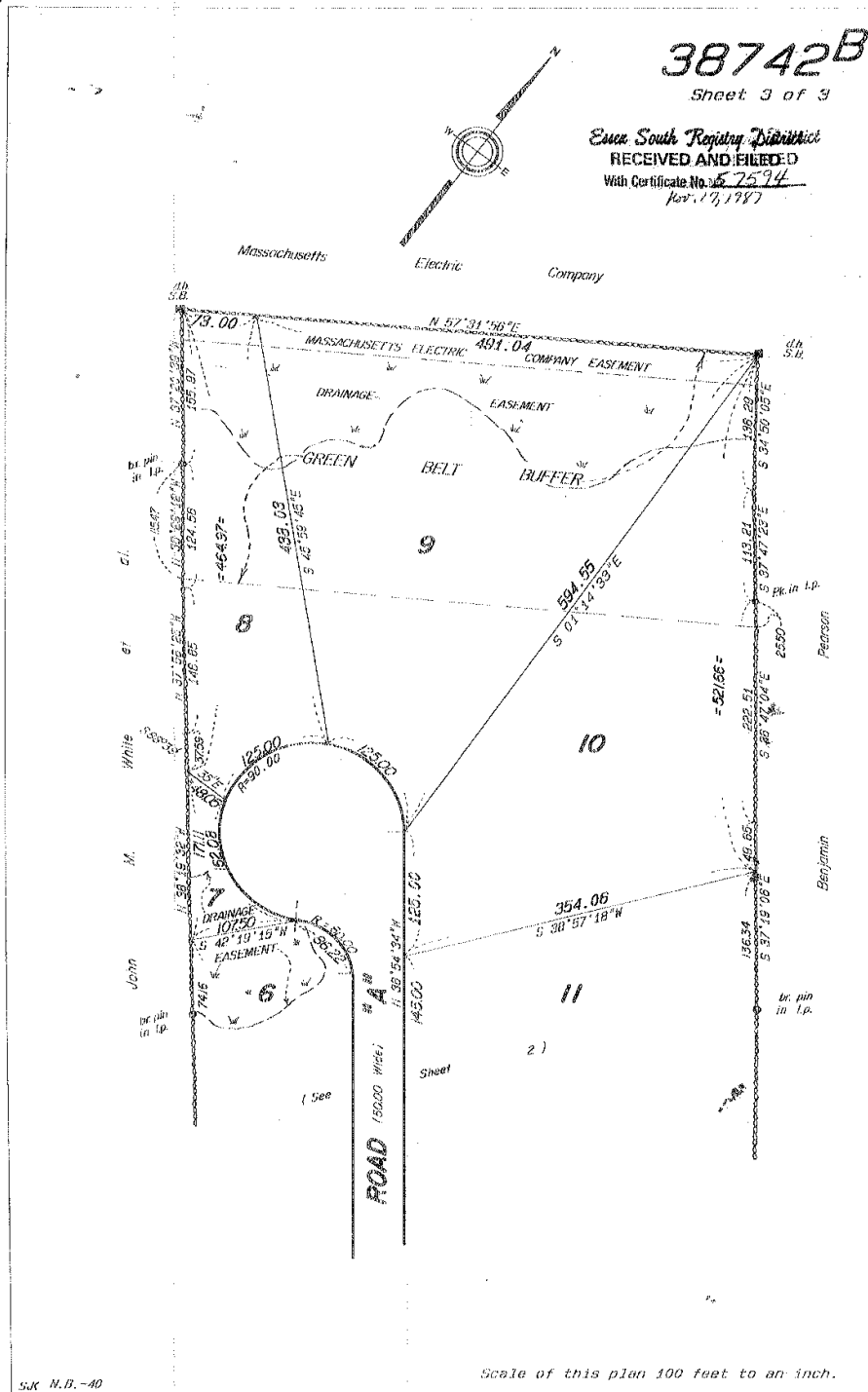


Figure C. 4 Land Court Case 38742 B Sheet 3 of 3

BIOGRAPHY OF THE AUTHOR

Carlton A. Brown was born in Newburyport, Massachusetts on February 10, 1950. He was raised in Newburyport and graduated from Newburyport High School in 1968. He attended Carnegie Mellon University and graduated in 1972 with a Bachelor of Science degree in Civil Engineering. He attended Salem State College and graduated in 1999 with a Master of Science Degree with Highest Honors in Geo-Information Science. He moved to Maine and entered the Spatial Information Science and Engineering graduate program at The University of Maine in the fall of 2000, transferring to the Civil Engineering graduate program at The University of Maine in 2003.

Carlton is currently an assistant professor in the Surveying Engineering Technology program, School of Engineering Technology at The University of Maine. He is a candidate for the Doctor of Philosophy degree in Civil Engineering from The University of Maine in May, 2011.