

**ANALYZING THE ROLE OF COORDINATES AND ERROR ESTIMATES
IN THE RULES OF CONSTRUCTION IN RELATION TO
BOUNDARY EVIDENCE COLLECTION AND LAND SURVEY PLANNING**

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Abstract

The role of coordinates and error estimates in land boundary determination has long been regarded as secondary to other forms of evidence in the hierarchy of importance. Land surveyors are tasked with identifying and evaluating various forms of evidence to formulate professional opinions on record boundaries. However, the extent to which coordinates and error estimates are analyzed during evidence collection remains ambiguous. Additionally, the application of error estimation to historic measurements during the preplanning phase of land surveys is not well understood. This research aims to address these gaps by investigating the viability of coordinates and error estimates as integral components of boundary evidence collection and determination.

The outcome of this research will provide the surveying community with a deeper understanding of how coordinates and error estimations can be effectively utilized to enhance the precision and reliability of land boundary surveys. The findings are expected to inform best practices and promote more rigorous methodologies in error analysis and boundary determination.

Dedication

To my beloved wife, whose unwavering support and encouragement have been an anchor throughout this journey. Your patience, understanding, and belief in me have made the challenges bearable and the successes sweeter. For every late night, every word of encouragement, and every sacrifice you have made to help me pursue my dreams, thank you. This work would not have been possible without you by my side.

To my son, whose understanding and patience as I dedicated time to my studies have meant more to me than words can express. Your support, curiosity, and willingness to share in this journey have been a source of motivation and strength. Knowing that you recognize the value of education and hard work makes this accomplishment even more meaningful. Thank you for your love and understanding.

1 I. Introduction

2 Above and beyond all expectations of the human imagination, the indomitable human spirit has
3 faced adversity time and time again; yet, resolute in innovation and steeped in stubbornness,
4 mankind sought scientific solutions to those presented challenges. The land surveyor, forged in
5 the pillars of time and history, are as pioneers that aided in the establishment of the foundations of
6 new frontiers. When one traces the origins of the United States, an independent wild frontier,
7 untamed and abundant with resources enters the mind; thus, a frontiersman, or surveyor, is the
8 dedicated tamer. Daniel Boone is one of such notoriety, and this frontiersman-surveyor is not the
9 only person who contributed to the founding of this great country and profession. Many notable
10 names, such as George Washington, Thomas Jefferson, and Abraham Lincoln donned the title of
11 land surveyor, and each of these braved unexpected frontiers to establish the boundaries held dear
12 today.

13 The determination and demarcation of boundaries is a foundational element of land
14 surveying; the location of physical markers, researching historical records, and the analysis of legal
15 descriptions played a vital role in society's past and will continue as a crucial role in future
16 development. As land development and technology advances, the use of coordinates has become
17 an increasingly valuable tool in defining and resolving land boundary challenges. However, the
18 legal acceptance and interpretation of coordinates as boundary evidence varies across jurisdictions.
19 A land surveyor's understanding on how coordinates and error estimates have been viewed, the
20 application of error estimates in boundary evidence collection, and how analyzing both elements
21 simultaneously is paramount for the protection of the public and boundary determination. A land
22 surveyor asked the question at a professional conference and it stated, "is there a mathematical
23 model or formula that can provide an absolute certain boundary opinion?"

24 1.1 Statement of the Problem – In the field of land surveying, the determination of land
25 boundaries relies on a hierarchical evaluation of evidence, traditionally prioritizing physical
26 monuments, historical records, and witness testimony over coordinate-based data and error
27 estimates. While coordinates and error estimates have long been considered secondary forms of
28 evidence, their role in boundary determination remains ambiguous, particularly in how they are
29 integrated into the decision-making process of land surveyors. The extent to which land surveyors
30 analyze and apply these numerical metrics during evidence collection and evaluation has not been
31 systematically studied, leading to inconsistencies in professional practice and the sparse use of
32 error estimates in historical data in boundary evidence collection.

33 A critical gap exists in understanding how error estimation can be applied to both historical
34 and modern measurement data during the preplanning phase of land surveys. Each piece of
35 boundary evidence carries an inherent level of uncertainty, yet there is no standardized
36 methodology for assigning and incorporating error estimates into the preplanning decision-making
37 process. As a result, surveyors often rely on professional judgment rather than a structured,
38 evidence-based approach when weighing different forms of evidence. Without a clearer
39 framework for integrating coordinate data and error metrics, land boundary determinations may
40 lack consistency, increasing the risk of disputes, legal challenges, and potentially creating
41 boundary monument "pincushions." The problem is, can a systematic analysis be developed to

42 evaluate historical and modern boundary evidence, incorporating error estimates and legal
43 precedent in the land boundary survey preplanning phase, to establish a structured mathematical
44 approach that enhances consistency and accuracy in land boundary evidence collection and
45 identification?

46 1.2 Historical Context of Surveying – Land boundary surveying is an old profession that is
47 steeped in the concept of land ownership and boundaries. Land boundary surveying has played a
48 pivotal role in human civilization, serving as the foundation for land ownership, economic
49 development, and legal governance. Since ancient times, societies have relied on surveying to
50 delineate property boundaries, resolve disputes, and facilitate infrastructure development. One of
51 the earliest known applications of land surveying dates back to the Egyptian civilization, where
52 surveyors, known as "rope stretchers," used basic geometry to reestablish land boundaries after the
53 annual flooding of the Nile River.¹ As economic development and technology progressed, so did
54 the profession and science of the land survey.

55 The Romans significantly advanced land surveying techniques by employing precise
56 measurement tools and designing a systematic land division method; most notably the centuriation
57 system. This method, known as centuriatio or limitatio, involved the regular layout of a square
58 grid using land surveying instruments and the grid was characterized by roads, canals, and
59 agricultural plots arranged in a systematic manner.² Boundaries, even in ancient times, held
60 significance and the ancient Romans designated Terminus as the god of boundaries.³ The
61 progression of land surveying did not cease with the Roman Empire, it continued onward and
62 upward. Time passed and the foundation laid down by historical land surveyors was built upon.
63 In medieval Europe, the feudal land tenure systems required accurate surveying to define the rights
64 and responsibilities of landowners, contributing to the establishment of legal land records, and in
65 the 17th to 19th century, the age of exploration and colonization saw extensive use of land
66 surveying for mapping newly acquired territories. Yet, Native Americans did not possess the land
67 as we possess it today; rather, certain tribes claimed certain tracts or regions, and as possession of
68 the United States grew, English common law was the basis of boundary ownership which evolved
69 to statute and Case law.⁴

¹ Paulson, Bruce. "Ancient Egyptian Surveying: The Origins of Geometry." FIG Proceedings, 2005. 2

² Palet, J. M., and J. Orengo. "The Roman Centuriated Landscape: Conception, Genesis, and Development as Inferred from the Ager Tarraconensis Case." American Journal of Archaeology 115, no. 3 (2011)

³ Robillard, Walter G., Donald A. Wilson, and Curtis M. Brown. *Brown's Boundary Control and Legal Principles*, 6th edition. Hoboken, NJ: John Wiley & Sons, 2009. 6

⁴ Sipe, F. Henry. *Compass Land Surveying*. Parsons, West Virginia: McClain Printing Company, 1974. 1

70 The idea of territorial boundaries is not a new one; the Egyptians, Romans, the native
 71 inhabitants of the Americas were well aware of their boundary limits; thus, the concept of markers,
 72 landmarks, or monuments to identify those limits is historical. “Boundaries enjoy a long history
 73 in both mythology and Judaic-Christian history.”⁵ Yet with each one of those historical
 74 measurements came along error and the possibility of uncertainty in boundary evidence and
 75 demarcation, and with that uncertainty came the potential for the disturbance of monumentation.
 76 The Holy Bible clearly states that a boundary monument shall not be disturbed. “Thou shalt not
 77 remove thy neighbour's landmark, which they of old time have set in thine inheritance, which thou
 78 shalt inherit in the land that the Lord thy God giveth thee to possess it.”⁶

79 1.3 The Boundary Land Survey and the Relevance in Modern Land Use – Accurate
 80 boundary surveys are essential for legal certainty, protecting landowners' rights and the possibility
 81 of preventing land boundary disputes. Land boundary surveys also play a vital role in urban
 82 planning and infrastructure development, assisting governments and municipalities by providing
 83 land boundary data for the designing of roads, utilities, and regulatory zoning. Additionally, land
 84 boundary surveying supports environmental and resource management by aiding land
 85 conservation efforts and promoting sustainable resource use while balancing development needs
 86 that are required for the land boundary.

87 Land development is the process of transforming raw or underutilized land into a functional
 88 and usable space for residential, commercial, industrial, or recreational purposes. It involves a
 89 series of planning, engineering, and construction activities, including zoning approvals,
 90 infrastructure installation, and environmental assessments and successful land development
 91 requires collaboration between surveyors, engineers, urban planners, and government agencies to
 92 ensure compliance with regulations, sustainability considerations, and community needs. The land
 93 needs to be converted from raw and wild to economic fruitful and the conversion of this raw state
 94 is primarily understood to be land development.⁷ Yet, with the increase in economic value of land
 95 comes the boundary dispute. Disputed boundaries will always be present in society, especially
 96 when there is profit in land and land development. Prior to the development of modern maps, as
 97 we understand them, communities depended on spoken, or word of bond, to identify the location
 98 of boundaries and possession.⁸ Land conversion will continue to be an integral economic
 99 cornerstone in the world and the land surveyor will be the professional to identify the record land
 100 boundary for that conversion.

⁵ Robillard, Walter G., Donald A. Wilson, and Curtis M. Brown. *Brown's Boundary Control and Legal Principles*, 6th edition. Hoboken, NJ: John Wiley & Sons, 2009. 7

⁶ Deut. 19:14 (KJV)

⁷ The Dewberry Companies, Sidney Dewberry, and Philip Champagne. 2002. *Land Development Handbook*. McGraw Hill Professional. 3 – 4

⁸ Robillard, Walter G., Donald A. Wilson, and Curtis M. Brown. *Brown's Boundary Control and Legal Principles*, 6th edition. Hoboken, NJ: John Wiley & Sons, 2009. 9

101 **II. Surveying and Boundaries**

102 2.1 Surveying – Land surveying in the United States is a regulated profession that
 103 involves measuring, mapping, and defining land boundaries to establish legal property ownership
 104 and support land development. Each state has specific legal definitions and requirements for
 105 land surveying, but generally, it encompasses the practice of determining property lines,
 106 subdividing land, conducting topographic mapping, and providing geodetic and construction
 107 layout services.

108 The profession is governed by state licensing boards, which establish education,
 109 experience, and examination requirements for surveyors to ensure accuracy and compliance with
 110 legal standards. Professional land surveying is essential for real estate transactions, infrastructure
 111 projects, and environmental planning, ensuring that land use aligns with federal, state, and local
 112 regulations.

113 Many states base their definitions on national guidelines, such as those provided by the
 114 National Council of Examiners for Engineering and Surveying (NCEES) and the National
 115 Society of Professional Surveyors (NSPS), but variations exist. For example, some states
 116 emphasize boundary retracement and cadastral surveys, while others incorporate hydrographic or
 117 forensic surveying within their legal scope; yet, regardless of the specific definitions, land
 118 surveyors across the U.S. play a vital role in property rights, land management, and
 119 development. According to the United States Department of Agriculture, in 2017, “the major
 120 uses of land, owned by the United States, were grassland pasture and rangeland at 659 million
 121 acres (29 percent of the U.S. total), forest-use land at 622 million acres (28 percent), cropland at
 122 390 million acres (17 percent), special uses (primarily parks and wildlife areas) at 318 million
 123 acres (14 percent), miscellaneous other uses (such as wetlands, tundra, and unproductive
 124 woodlands) at 197 million acres (9 percent), and urban land at 74 million acres (3 percent).”⁹

125 2.1.1 Land Surveying Definitions – The discussion regarding land boundary and
 126 development cannot stand along without defining the art and science of land surveying. Surveying
 127 is the art of making such measurements as will determine the relative positions of any points on
 128 the surface of the earth; so that a map of any portion of that surface may be drawn, and its content
 129 calculated.¹⁰ Boundary delineation, both new boundary creation and retracement boundary
 130 identification, in land surveying follows a set of established rules known as rules of construction.
 131 A rule of construction is applied to a specific element of land surveying law when the intent is
 132 unclear or ambiguous. Land surveyors provide an opinion on a land boundary location, and “a
 133 survey is the plat and the field-note record of the observations, measurements, and monuments

⁹ U.S. Department of Agriculture, Economic Research Service, (2024, September). *Major Uses of Land in the United States 2017*. United States Department of Agriculture.

¹⁰ Gillespie, W; Stanley, C. 1887. *A Treatises on Surveying, Comprising the Theory and the Practice* 1

134 descriptive of the work performed.”¹¹ These definitions and rules guide the land surveyors in
 135 interpreting and establishing property boundaries accurately by analyzing historic records and
 136 applying modern measurement techniques to discover and interpret data.

137 However, as each land surveyor can provide their professional unique opinion on a land
 138 boundary opinion, as it is with the definition of land surveying. Another definition of surveying
 139 is “the process of acquiring or accumulating qualitative information and quantitate data by
 140 observing, counting, classifying, and recording according to need.”¹² Land surveying is steeped
 141 in history and opinion, yet, is continually called upon to establish coordinates, which have error
 142 associated with them, and “when a surveyor is employed to establish the position of a point or line
 143 in which two or more persons are interested, he should act as an honorable, unprejudiced party and
 144 seek to find the true position, regardless of consequences.”¹³ Finding the true position of the
 145 boundary is truly where the question of error estimates begin; what was the accumulated error in
 146 the historic land measures and how has it evolved over time?

147 2.1.2 Boundary Retracement Survey Purpose – The science of surveying correlates to the
 148 measurements utilized in the creation and identification of a boundary and a boundary means every
 149 natural and/or artificial demarcation of the bounds or territorial extent of a federal interest asset.¹⁴
 150 This one definition of a boundary may set a limit on Federal interest; however, it is not the only
 151 definition that the surveyor may lean upon. Land boundaries are integral in life, and a “boundary
 152 is every separation, natural or artificial, which marks the confines or line of division of two
 153 contiguous estates.”¹⁵ The boundary is only one element that must be described and the question
 154 that needs to be addressed is what is a boundary survey? The boundary survey is a foundational
 155 pillar of the profession and a “boundary survey means a survey, in which property lines and corners
 156 of a parcel of land have been established by a survey and a description of survey has been written
 157 and a plat has been prepared for the property.”¹⁶ The land surveyor is inclined and required to
 158 establish the lines and corners set forth in an operative description. There is an old moniker that
 159 land surveyors have donned, and it states that land surveyors should be expert measurers. The
 160 emerging issue that looms is what if technology, placed in the layman’s hands, can provide an
 161 accuracy that is comparable to that of the land surveyor? Analyzation of historic and current
 162 measurements must be performed to produce an original or retracement survey that is of

¹¹ Department of the Interior, Bureau of Land Management. (1980), *Glossary of Cadastral Surveying Terms*. United States Department of the Interior. 65

¹² American. 1994. *Glossary of the Mapping Sciences*. ASCE Publications. 505

¹³ Robillard, W., *Clark on Surveying and Boundaries* (2023), LexisNexis

¹⁴ Department of the Interior, Bureau of Land Management. (2014, November 21). Department Manual, *Standards for Federal Lands Boundary Evidence*. United States Department of the Interior.

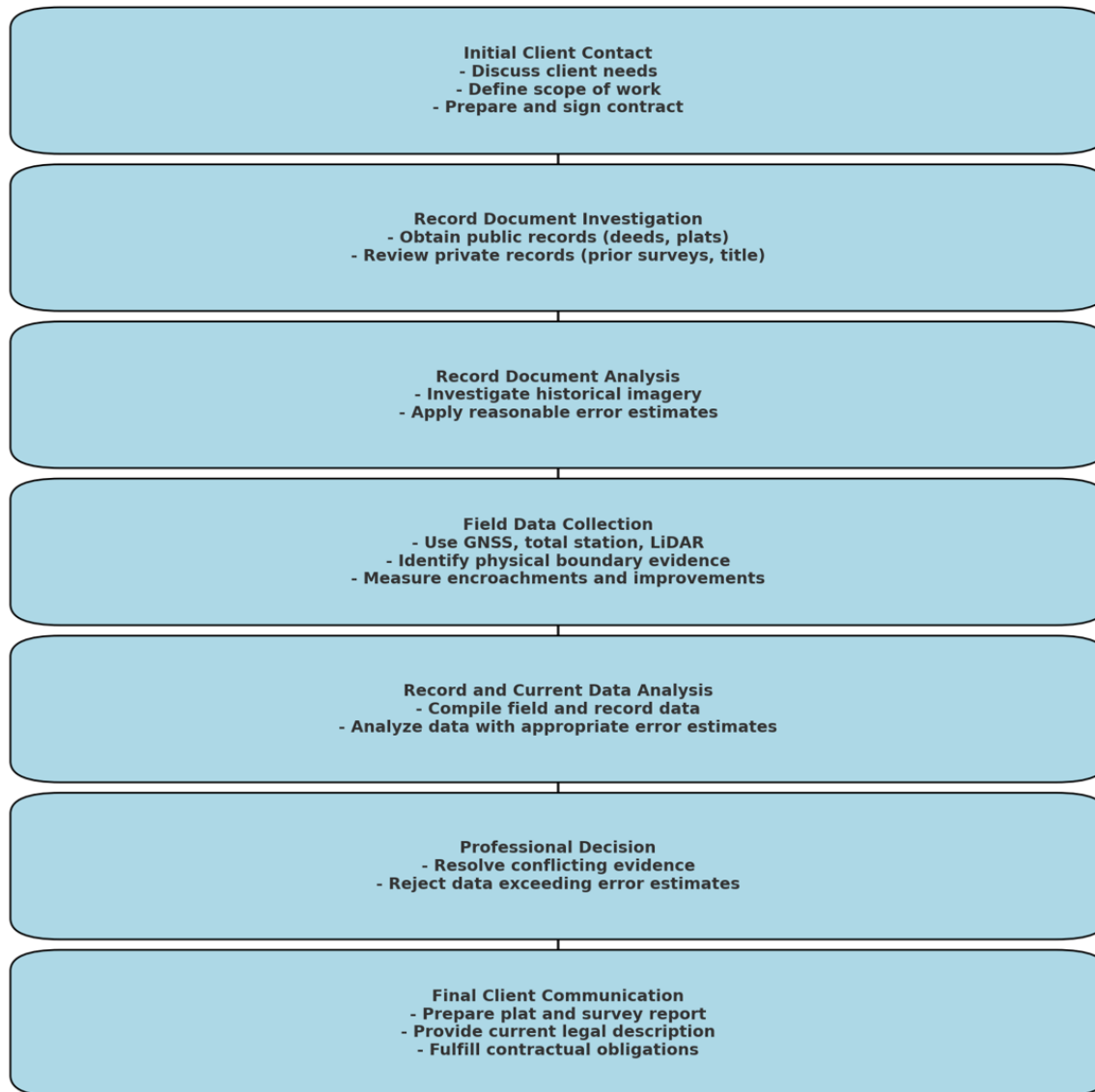
¹⁵ Black, H. C. (1968). *Black's law dictionary*. 4th ed. St. Paul, Minn., West Group 232

¹⁶ W. Va. Code §30-13A-3 (2024)

163 professional opinion. This analysis for retracement is not to place new monuments in lieu of
164 original, but to “verify the directions and lengths of lines, and to identify monuments and markers
165 of an earlier, established survey.”¹⁷ Yet, the land surveyor must realize the extent as to what
166 evidence is needed and what boundary retracement evidence encompasses, and not simply rely on
167 the mere lines a boundary creates. Coordinates alone have no true meaning, unless referenced to
168 an established reference datum; however, there are situations where coordinates have been used to
169 define boundary lines, in a conditional sense “the east-west conditional line was defined using
170 state plane coordinates.”¹⁸ The operational format of a land retracement survey varies amongst
171 each individual land surveyor; however, a base model must be utilized, and Figure 2.1 outlines a
172 model that could be utilized.

¹⁷ American. 1994. *Glossary of the Mapping Sciences*. ASCE Publications. 453

¹⁸ *Burlison v. United States*, 2011 U.S. Dist. LEXIS 26726, *8, 2011 WL 1002808 (Western Dist. Tenn. March 15, 2011)



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Figure 2.1: Base Operational Model for Land Retracement Survey

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2.2 Boundary and Boundary Survey – A land boundary defines the legal opinion extents of a parcel of land based on the land surveyor’s analysis of the available evidence and distinguishing it from adjacent properties. The land boundary opinion is established through analysis of record legal descriptions, often found in deeds, plats, or government land records and these boundaries may dictate ownership rights, land use, and cause potential disputes between neighboring landowners. The determination of a land boundary can include physical markers such as fences, walls, or survey monuments, as well as legal descriptions derived from historical documents and geographic references. However, over time, land boundaries may become unclear due to missing or displaced markers, ambiguous or vague legal descriptions, or natural changes in the landscape. This is why accurate and professional boundary opinions are crucial, especially when buying, selling, or developing land.

186 A land boundary survey is a precise measurement and analytical process conducted by
 187 licensed land surveyors to establish, retrace, or verify the record boundary lines of a given parcel
 188 in conjunction with the adjacent or adjoining properties. The purpose of a boundary survey is to
 189 deliver a professional opinion that depicts the location of boundary limits based on legal records
 190 and physical evidence found onsite.

191 2.2.1 Legal Definitions of Boundaries – A legal definition of a boundary is presumed to be
 192 the officially recognized limit of a property as described in record deeds, plats, or government
 193 records. It is established through written legal descriptions embedded in operative documents,
 194 which generally references natural landmarks, survey monuments, metes and bounds, or
 195 coordinate-based systems. In legal disputes, courts generally presume that boundaries align with
 196 the most reliable evidence available; however, when discrepancies arise, it is generally due to
 197 misinformed intent or an ambiguous boundary. Thus, original survey intent must be determined,
 198 if possible, to provide a legal defensible opinion on the boundary and final determination. The
 199 surveyor only provides a professional opinion and “has no authority to establish boundaries.”¹⁹
 200 The land surveyor establishes physical evidence based on the intent of the original operative parties
 201 to the boundary and a survey is performed to “measure a parcel of land and ascertain its boundaries,
 202 corners and contents or make any other authoritative measurements.”²⁰ Thus the land surveyor
 203 themselves do not establish the boundary, rather it is the intent of the operative parties that
 204 establishes the boundary and the original land survey monuments those positions on the Earth.

205 2.2.2 Boundary Disputes – A boundary dispute is a legal conflict between neighboring
 206 property owners regarding the location, extent, or ownership of a land boundary. Such disputes
 207 often arise due to conflicting or vague deed descriptions that do not clearly convey the intent of
 208 the original parties, inaccurate surveys, misplaced or missing boundary monuments, or potential
 209 long-term encroachments, whether intentional or unintentional. Legally, boundary disputes are
 210 resolved through a combination of historical record research, professional land surveys, and
 211 applicable legal doctrines that follow rules of construction based on court precedence. The element
 212 of a dispute that is present in a land boundary dispute is that there is “a conflict of claims or
 213 rights.”²¹ The conflict of claims or rights is due to an uncertainty of intent of the real property
 214 boundary and “real property descriptions are controlled by the descriptions of their boundary lines,
 215 which are themselves controlled by the terminal points or corners as established on the ground by
 216 the original surveyor creating those lines.”²²

217

¹⁹ *Rivers v. Lozeau*, 539 So. 2d 1147, 1989 Fla. App. LEXIS 904, 14 Fla. L. Weekly 523 (Court of Appeal of Florida, Fifth District, February 23, 1989)

²⁰ W. Va. Code §30-13A-3 (2024)

²¹ Black, H. C. (1968). Black's law dictionary. 4th ed. St. Paul, Minn., West Group, 558

²² *Rivers v. Lozeau*, 539 So. 2d 1147, 1989 Fla. App. LEXIS 904, 14 Fla. L. Weekly 523 (Court of Appeal of Florida, Fifth District, February 23, 1989)

218 III. The Pincushion

219 3.1 Definition and Causes – In land boundary retracement surveying, the pincushion effect
220 refers to a scenario where multiple survey monuments or markers are found clustered near a
221 boundary corner but fail to align precisely. Meaning, this effect creates a situation where the true
222 boundary corner is uncertain, with various markers representing past survey attempts, each slightly
223 different position due to different survey methodologies, random errors, instrumentation errors,
224 and a general misunderstanding of land boundary law and error estimate integration into record
225 and current measures. One of the primary causes of the pincushion effect is measurement
226 discrepancies between historic (record) and current survey techniques. Historical, or record
227 surveys, often relied on measurement instruments, which had lower precision than modern land
228 surveying tools, and as technology improved, newer surveys introduced small variations in
229 calculated positions, leading to overlapping but inconsistent boundary markers. The failure to
230 comprehend how historic measures and their error estimates can impact the uncertainty of the
231 coordinate of a monument when compared to current measures is the issue, and “the amount of
232 measurement error allowed is dependent on how permeant the monument is and the certainty of
233 identification of the spot occupied by the monument as of the date of the description that is
234 contained in the deed when it was created.”²³

235 Another contributing factor is datum and coordinate system shifts. If surveyors use
236 different geodetic datums or reference frameworks over time, even precise measurements can
237 result in minor positional differences when plotted on a modern coordinate system. Additionally,
238 human factors and procedural inconsistencies play a role. Surveyors working in different eras,
239 under varying legal standards, may interpret legal descriptions differently, and errors in
240 transcription, misinterpretation of historical records, or physical obstructions affecting
241 measurements can all contribute to misaligned, or differing, monument placements. The
242 pincushion effect is a significant challenge in boundary retracement. To resolve these
243 discrepancies, surveyors must carefully analyze historical records, legal descriptions, and past
244 survey methods while applying modern precision techniques to determine the most legally
245 defensible boundary location.

246
247 3.2 Impact on Trust and Reliability – When a pincushion corner is encountered in land
248 boundary surveying, it can create significant issues regarding trust and boundary reliability in the
249 eyes of a landowner. This situation erodes confidence in land records, the land surveyor, and can
250 lead to boundary disputes among property owners. For landowners, the presence of multiple
251 markers at a boundary corner raises concerns about the accuracy of their property lines, the quality
252 of the professionals performing the land survey, and it can lead to potential conflicts with
253 neighbors. It can also complicate legal interpretations of ownership, as different surveys may
254 recognize different markers as the correct corner, and these inconsistencies can result in costly
255 litigation and delays in land development.

256

²³ Robillard, W., Wilson, D., & Brown, C. (2006). *Evidence and Procedures for Boundary Location* (5th ed.). John Wiley & Sons, Incorporated. 149

257 For professionals, a pincushion corner undermines the credibility of past surveys and
 258 challenges the reliability of the existing land records, when in fact, the current land surveying
 259 professional should be following the footsteps of the previous land surveying professionals. As
 260 with any measurement value, error will always be present and there is not perfect measurement;
 261 thus, it is the responsibility of the land surveying professional land boundary law principles and
 262 “ascertain the types and magnitude of the known and unknown errors present in every
 263 measurement.”²⁴ When encountered, surveyors must reconcile the discrepancies by conducting
 264 thorough research, applying reasonable error estimates to historic and current measures, retracing
 265 original survey work, and applying sound professional judgment to determine the most defensible
 266 boundary location. Ultimately, the presence of a pincushion corner disrupts the integrity of the
 267 land tenure system and adding to that disruption only assists in further degrading the profession of
 268 the land surveyor.

269
 270 3.3 Potential Mitigation Strategy – The presence of a pincushion corner, highlights the
 271 critical need for consistency in survey practices, adherence to legal boundary principles, and a
 272 clear understanding of land boundary law and error analysis of measures to maintain public trust
 273 in boundary reliability. Land boundary disputes and inconsistencies often arise from multiple
 274 monumentations marking the same corner in different locations and this issue is particularly
 275 prevalent in areas with a long history of resurveys or in jurisdictions where surveyors have relied
 276 on different datasets, control points, or methods of measurement over time. To mitigate this, an
 277 effective strategy must include error analysis and meticulous land survey preplanning to ensure
 278 consistency, reduce ambiguity, and establish a legal defensible boundary solution. Below is a
 279 potential method for analyzing historic measures that also integrates error estimates in obtained
 280 measures, for the possibility of land evidence collection.

281

282 General Steps for Land Boundary Data Analysis – Land Survey Preplanning:

- 283 1. Obtain the record measures for parcels, main parcel and neighboring parcels.
- 284 2. Inspect the measures from the operative descriptions to discern possible blunders.
 - 285 a. Document potential blunders and discrepancies
- 286 3. Identify and label common corners for redundant measure identification.
- 287 4. Convert directional values to angular values between lines.
- 288 5. Generate an angle and distance data set which creates redundancy amongst the
 289 common monumentation.
- 290 6. Obtain aerial imagery for the parcels.
 - 291 a. Google Maps
 - 292 b. Google Earth
 - 293 c. USGS aerial photography
- 294 7. Analyze aerial imagery to determine if there is any visible evidence of possession on
 295 or near estimated boundary lines.
- 296 8. Should evidence of possession or boundary be visibly noticeable on aerials, generate
 297 line work from imagery.
 - 298 a. Angles and Distances

²⁴ Robillard, W., Wilson, D., & Brown, C. (2006). *Evidence and Procedures for Boundary Location* (5th ed.). John Wiley & Sons, Incorporated. 140

- 299 9. From the line work, both record and estimated aerial imagery, extract measurement
 300 data.
- 301 10. Input the measurement data into a least squares analysis with appropriate error
 302 estimates for the respective data set.
- 303 11. Examine error ellipses at terminus of lines to determine search patterns. The error
 304 ellipses generated should provide a reasonable error search pattern for boundary
 305 evidence collection.

306 **IV. Error Estimation**

307

308 4.1 Definitions – In land surveying, error refers to the unavoidable discrepancies that arise
 309 between measured values and true values. Despite advancements in technology and precision
 310 instruments, no measurement is ever perfectly accurate due to limitations in equipment,
 311 environmental factors, and human observation. Meaning, that the true value of the measurement
 312 will never be known. Errors in surveying can be classified into three main categories: systematic
 313 errors (predictable and correctable, such as instrument calibration issues), random errors (small,
 314 unpredictable variations due to human or environmental influences), and blunders (gross mistakes
 315 caused by human oversight or procedural errors).²⁵ Recognizing, minimizing, and compensating
 316 for these errors is essential to producing reliable, legally defensible land boundaries and spatial
 317 data.

318

319 4.2 Sources of Error – Land boundary surveying is a precise science, yet it is inherently
 320 influenced by various sources of error that can impact the accuracy and consistency of
 321 measurements. These errors stem from historical measurement practices, the diligence of the
 322 surveying crew, the terrain, and the measuring instruments themselves. Understanding these
 323 sources is crucial to minimizing discrepancies and ensuring legally defensible boundary
 324 determinations.

325

326 *Historical Measurement Discrepancies:* Many modern boundary surveys are built upon
 327 historical records that may contain inherent inaccuracies. Early land surveys relied on chains,
 328 rods, compasses, and rudimentary angular or directional measurement tools that lacked the
 329 precision of contemporary total stations and GNSS technology. Additionally, historical surveys
 330 were often conducted under challenging field conditions with less rigorous error preventing
 331 procedures. Over time, discrepancies can arise due to:

- 332 1. Use of Different Measurement Standards – Early surveys used instruments such as the
 333 Gunter’s chain, which may have stretched or worn over time, leading to slight variations
 334 in measurement.
- 335 2. Unreliable Initial Points of Beginning or Monumentation – Some original surveys were
 336 based on imprecise astronomical or magnetic observations, local landmarks, or
 337 approximate alignments rather than geodetically referenced points; furthermore, many of
 338 the monuments throughout the survey may have been stated as merely a point and have no
 339 describing information referencing the location.

²⁵ Robillard, W., Wilson, D., & Brown, C. (2006). *Evidence and Procedures for Boundary Location* (5th ed.). John Wiley & Sons, Incorporated. 141 – 142

340 3. Boundary Interpretations and Adjustments – Landowners and surveyors may have adjusted
 341 or changed boundaries based on physical markers and natural monuments, rather than
 342 following previous survey monumentation or notes, leading to inconsistencies over time
 343 and perhaps the monument being lost or multiple monuments being viewed as the boundary
 344 terminus of lines.

345 *Human Error and the Care Taken by the Survey Crew:* The accuracy of any survey is only
 346 as good as the care and attention exercised by the surveying crew. Errors due to human oversight
 347 include:

- 348 1. Reading and Recording Errors – Misreading angles, distances, or elevations could lead to
 349 incorrect data that may propagate throughout the survey.
- 350 2. Incorrect Instrument Setup – Even minor error in the setting up of a transit, compass, or
 351 theodolite over a point can introduce errors that affect all subsequent measurements.
- 352 3. Fatigue and Environmental Distractions – Long field hours, extreme weather, and difficult
 353 terrain can impact concentration and lead to mistakes in measurement or notation.
- 354 4. Improper Handling of Equipment – Rough handling of sensitive instruments can lead to
 355 misalignments or calibration drift, reducing overall accuracy.

356 *The Influence of Terrain and Environmental Factors:* Surveying in varied terrains
 357 presents additional challenges that can introduce measurement errors. Terrain-related errors
 358 include:

- 359 1. Slope and Elevation Effects – Surveys conducted in hilly or mountainous regions require
 360 careful correction for slope distances, as failure to do so can lead to inaccurate horizontal
 361 measurements. Many times, the lay of the land was utilized in the rough mountainous
 362 regions whereas in the Public Land Surveys a horizontal distance was utilized.
- 363 2. Vegetation and Obstructions – Dense forests, brush, or buildings can obstruct line-of-sight
 364 measurements, requiring estimations or multiple instrument setups that increase potential
 365 error. This breaking of the line introduced error in the land survey which is carried
 366 throughout time.
- 367 3. Soil Movement and Settlement – Over time, natural ground movement, erosion, frost
 368 heave, subsidence, or human disturbance, can cause benchmarks and boundary monuments
 369 to shift, leading to discrepancies between past and present measurements.
- 370 4. Weather Conditions – Atmospheric refraction, temperature variations, and humidity can
 371 impact light waves used in electronic distance measurement (EDM) devices, leading to
 372 small but significant distortions.

373 *The Land Surveying Instrument:* Even the most advanced surveying instruments are subject
 374 to mechanical limitations and calibration constraints. Instrument-related errors include:

- 375 1. Instrument Calibration and Wear – Over time, components can degrade or fall out of
 376 calibration, leading to systematic errors.
- 377 2. Accuracy Limitations of Equipment – Each instrument has a defined precision threshold,
 378 and exceeding these limits can result in measurement inaccuracies.
- 379 3. Temperature-Induced Expansion or Contraction – Steel tapes and other measuring
 380 instruments can expand or contract due to temperature fluctuations, subtly affecting linear
 381 measurements.

382 Understanding and applying error estimates in land boundary surveying requires a combination of
 383 historical analysis and mathematical modeling. By recognizing these sources of error and applying
 384 appropriate error estimates, surveyors can enhance the reliability of land boundary measurements
 385 and establish accurate, legally defensible boundary determinations.

386 4.3 Error Estimates on Historic Measures – The following is a brief listing, not fully
 387 encompassing, of historic land surveying instruments with respective measurement allowances:

- 388 1. Gunter’s Chain (Surveyor’s Chain)
 - 389 a. Accepted measurement: 66 feet
 - 390 b. One chain consists of 100 links, or 0.66 feet, or 7.92 inches
- 391 2. Rod, Pole, Perch
 - 392 a. Accepted measurement: 16.5 feet
- 393 3. Steel tape
 - 394 a. Accepted measurement: 100 feet
 - 395 b. Division: feet, tenth, and hundredths
- 396 4. Stadia Rod
 - 397 a. Used in conjunction with the transit to determine distances
 - 398 b. Accepted measurement: nearest tenth of a foot
- 399 5. Surveyor’s Compass (Magnetic or Solar)
 - 400 a. Accepted measurement: Directional values, generally to the nearest ¼ degree
- 401 6. Theodolite and Transit
 - 402 a. Accepted measurement: Angular value, generally to the nearest 10 seconds and
 403 higher precision models to the nearest second.

404 These tools were historically used in land boundary demarcation and the accuracy of varying
 405 tools impacts the accuracy of the survey. However, if the lines in the field, were actually
 406 measured and monumented, then the measurement are valid evidence and should be treated with
 407 appropriate weight.

408 **V. Evidence**

409 5.1 Law – When researching to establish or retrace a land boundary the land surveyor
 410 follows the law; yet, what is law? Law is “that which is laid down, ordained, or established. A
 411 rule or method according to which phenomena or actions co-exist or follow each other. That which
 412 must be obeyed and followed by citizens, subject to sanctions or legal consequences, is a ‘law.’”²⁶
 413 Statutory laws, or standards of practice for land surveying, are followed to ascertain evidence to
 414 examine and provide a boundary opinion; thus, the evidence collected could be construed as
 415 boundary evidence.

416 Record evidence refers to either written or graphical documentation, or oral testimony
 417 regarding the location of the property. Record evidence may include printed or written
 418 material, such as deeds, wills, plans, road docket, court records, but it may also include
 419 parol evidence from competent parties. Physical evidence is found in the field during the

²⁶ Black, H. C. (1968). Black's law dictionary. 4th ed. St. Paul, Minn., West Group

420 retracement, and can include the geometric position, material, size, age, and condition of
421 the monument or other object recovered.²⁷

422 5.2 Evidence – The law leads the surveyor to establish factual opinions based on evidence
423 and “boundary evidence involves the compilation, examination, and evaluation of title documents
424 and boundary documents combined with the physical inspection of the boundary.”²⁸ Furthermore,
425 evidence for the identification of a land boundary can encompass much more than the title
426 documents, and “evidence is any medium that furnishes or tends to furnish proof of a fact. In a
427 court of law, the location of a land boundary constitutes an issue of fact.”²⁹ A land surveyor must
428 establish a foundation of evidence, record and physical, to aid in the establishment of a legal
429 defensible land boundary opinion, and this foundation must be built upon relevant evidence.
430 Evidence is relevant if it has a tendency to make the existence of any fact that is of consequence
431 to the determination of the action more probable or less probable than it would be without the
432 evidence and the fact is of consequence in determining the action.³⁰ The boundary retracement
433 surveyor follows the footsteps of the original creating surveyor, to the best of their abilities, and
434 the boundary, or the original survey as it was actually run on the ground controls.³¹ The land
435 surveyor identifies and analyzes the operative description from the operative legal instrument, and
436 then utilizes modern measurements to aid them in the recovery of relevant evidence. However,
437 the land surveyor shall not apply modern measures to reestablish operative locations. Whenever
438 it can be proved that there was a line actually run by the surveyor, or was marked, and a corner
439 made, the party claiming under the grant or deed shall hold accordingly, notwithstanding a
440 mistaken description of the land in the grant or deed.³²

441 Should the recovery and analysis of the evidence lean towards it being original, then the
442 land surveyor has taken a step in a potential legal defensible boundary opinion. Analysis of the
443 collected evidence is the first step in the formulation of an opinion and “the positive position of
444 the original corner locations (position) must be predicated on the recovery, identification, and
445 interpretation of original evidence and not on applying modern measurements by the retracing

²⁷ (Knott 1998, 2)

²⁸ Department of the Interior, Bureau of Land Management. (2014, November 21). Department Manual, *Standards for Federal Lands Boundary Evidence*. United States Department of the Interior.

²⁹ Department of the Interior, Bureau of Land Management. (2014, November 21). Department Manual, *Standards for Federal Lands Boundary Evidence*. United States Department of the Interior.

³⁰ Federal Rules of Evidence § 401

³¹ *United States v. Doyle*, 1972

³² *Martin v. Patton*, 225 Ga. App. 157, 163, 483 S.E.2d 614, 621, 1997 Ga. App. LEXIS 223, *16, 97 Fulton County D. Rep. 909 (Ga. Ct. App. February 19, 1997)

446 surveyor.”³³ The measurements a land surveyor utilizes only aids in the recovery and
 447 establishment of evidence; furthermore, in land boundary disputes, the rules of evidence are
 448 generally more liberal than those dictating other actions. “Ancient maps and plats, long and
 449 publicly recognized, with reference to which it may be presumed that the parties and the general
 450 public have acted, are usually admissible in evidence to show the location of boundaries.”³⁴
 451 However, what would happen should there be no evidence found, no trace of the original operative
 452 footsteps? The answer therein lies in the measurements collected; “when evidence fails to prove
 453 the original corner position, then and only then can the surveyor disregard the evidence and rely
 454 on measurements alone.”³⁵ It is the original position that is the true corner position, and “the
 455 monuments themselves need not exist, for where they are gone they may be supplied by proofs of
 456 their former existence.”³⁶

457 5.3 Footsteps – There are many questions that a land surveyor will address in the
 458 establishment and reestablishment of a boundary; however, the primary one, if performing a
 459 retracement survey, will be, “what actions did the original land surveyor perform?” This question
 460 looms in the mind of the surveyor as analysis begins and “the question of where boundaries are on
 461 the ground is a question of fact to be determined from the evidence. When finding the lines of a
 462 survey, the cardinal rule is that the footsteps of the original surveyor, if they can be ascertained,
 463 should be followed.”³⁷ Those followed footsteps lead to evidence discovered, and at times, there
 464 may be varying level of evidential importance.

465 Boundaries can be ambiguous and “in determining disputed boundaries, resort is to be had
 466 first to natural objects or landmarks, because of their very permanent character; next, to artificial
 467 monuments or marks, then to the boundary lines of adjacent landowners, and then to courses and
 468 distances. This rule of construction is to aid in determining the intention of the parties to a deed
 469 which is to be determined, if possible, from the instrument in connection with the surrounding
 470 circumstances.”³⁸ Land retracement surveyors prioritize natural and artificial landmarks and pre-
 471 existing monuments over measurements, ensuring continuity and consistency in boundary

³³ Robillard, W., Wilson, D., & Brown, C. (2004). *Evidence and Procedures for Boundary Location* (6th ed.). John Wiley & Sons, Incorporated. 120

³⁴ *Carroll Indep. Sch. Dist. v. Northwest Indep. Sch. Dist.*, 2021 Tex. App. LEXIS 5255, *1, 2021 WL 2761605 (Tex. App. Fort Worth July 1, 2021)

³⁵ Robillard, W., Wilson, D., & Brown, C. (2004). *Evidence and Procedures for Boundary Location* (6th ed.). John Wiley & Sons, Incorporated. 121

³⁶ Mulford, A.C. (1912) . *Boundaries and Landmarks, a Practical Manual*. 25 Park Place: D. Van Nostrand Company. 11

³⁷ *Carroll Indep. Sch. Dist. v. Northwest Indep. Sch. Dist.*, 2021 Tex. App. LEXIS 5255, *1, 2021 WL 2761605 (Tex. App. Fort Worth July 1, 2021)

³⁸ *Ezell v. Duncan*, 2004 Tenn. App. LEXIS 839, *15-16, 2004 WL 2916139 (Tenn. Ct. App. December 15, 2004)

472 interpretation. The hierarchy of evidence, as stated, in boundary delineation usually begins with
473 natural boundaries and original monuments placed during initial surveys, followed by artificial
474 features, then course and distance, then coordinates, and finally area.³⁹ All of these measurements
475 have importance in determining the intent of the operative instrument and “where the lines are so
476 short as evidently to be susceptible of entire accuracy in their measurement, and are defined in
477 such a manner as to indicate an exercise of care in describing the premises, such a description is
478 regarded with great confidence as a means of ascertaining what is intended to be conveyed.”⁴⁰
479 Documented maps, deeds, and survey records are also essential, with measurements typically
480 serving as supporting evidence. If ambiguities arise, surveyors often defer to these guiding
481 principles to clarify intent and maintain historical continuity. Yet, with the increased reliability of
482 measurements and accuracy in which they can be obtained, why wouldn’t the land surveyor turn
483 to coordinates, when they have been established with the appropriate care necessary, to establish
484 the original position of the monument as described in the operative instrument? This thought itself
485 leans to the realization that it is not the monument itself that holds, but rather the original position
486 of the monument; thus, “what is most material and most certain in a description shall prevail over
487 that which is less material and less certain...”⁴¹ The materials that are described in the operative
488 description, should it be the most certain, may prevail; thus, it could be construed that coordinates,
489 if established and verified within a standardized datum, may be the most certain of evidence.
490 Therein lies the most alarming question, how would a retracement surveyor know if the proper
491 procedure was utilized in the creation of the coordinates presented? The answer lies in the
492 verification and analyzation of the evidence recovered when compared to the error tolerances at
493 the time of evidential creation, along with the reliance of statutory law. No coordinate, purporting
494 to define the position of a land boundary, shall be presented in any record available to the public
495 unless that point has been connected by a land survey to a monumented control station established
496 in conformance with the standards and accuracy as regulated.⁴² Therefore, the land surveyor must
497 continually analyze measurements taken and evaluate the consistency of reproducibility. The
498 ability to be accurate and precise in measurements is vital, and “when one can locate on the ground
499 with certainty and without inconsistency the objects or monuments designated by the original
500 surveyor as marking the lines he actually traced, the survey must be laid out from those points.”⁴³

³⁹ *Hammons v. Adair*, 2002 Ark. App. LEXIS 449, *7, 2002 WL 1980352 (Ark. Ct. App. August 28, 2002)

⁴⁰ *White v. Luning*, 93 U.S. 514, 523, 23 L. Ed. 938, 939, 1876 U.S. LEXIS 1404, *12, 3 Otto 514 (U.S. December 18, 1876)

⁴¹ *Martin v. Patton*, 225 Ga. App. 157, 163, 483 S.E.2d 614, 621, 1997 Ga. App. LEXIS 223, *16, 97 Fulton County D. Rep. 909 (Ga. Ct. App. February 19, 1997)

⁴² GA Code § 44-4-24 (2024)

⁴³ *Carroll Indep. Sch. Dist. v. Northwest Indep. Sch. Dist.*, 2021 Tex. App. LEXIS 5255, *1, 2021 WL 2761605 (Tex. App. Fort Worth July 1, 2021)

501 5.4 Lost and Obliterated – When evidence is lacking and the rules of construction must be
502 applied, then perhaps the corner is lost or obliterated. According to the Manual of Surveying
503 Instructions, 2009, a lost and obliterated corner are defined as follows:

504 A lost corner is one whose original position cannot be determined by substantial evidence,
505 either from traces of the original marks or from acceptable evidence or reliable testimony
506 that bears upon the original position, and whose location can be restored only by reference
507 to one or more interdependent corners; whereas an obliterated corner is an existent corner
508 where, at the corner’s original position, there are no remaining traces of the monument or
509 its accessories but whose position has been perpetuated, or the point for which may be
510 recovered, by substantial evidence from the acts or reliable testimony of the interested
511 landowners, competent surveyors, other qualified local authorities, or witnesses, or by
512 some acceptable record evidence.”⁴⁴

513 Of those two, the lost corner is the most problematic and whose location must be restored by one
514 or more interdependent corners. Therein lies the question of fact, and the actual location of a
515 disputed boundary line is a question of fact.⁴⁵

516 **VI. Surveyor Testimony**

517 6.1 Expert Witness – A licensed land surveyor plays a critical role as an expert witness in
518 land boundary court cases, providing professional testimony based on their technical expertise and
519 professional opinion on the factual evidence presented. When property boundaries are contested,
520 the court relies on the surveyor’s analysis of historical records, legal descriptions, and field surveys
521 to determine the precise limits of ownership. As an expert witness, the surveyor presents findings
522 in a clear and unbiased manner, explaining complex surveying principles, measurements, and
523 methodologies to judges, juries, and attorneys who may not have technical backgrounds. Their
524 testimony often includes interpretations of deeds, subdivision plats, historical land records, and
525 analysis of record and physical evidence.

526 Beyond testifying, the surveyor may also assist in preparing legal exhibits, maps, and
527 reports that illustrate boundary determinations. Their professional opinion can influence case
528 outcomes by clarifying uncertainties, resolving disputes, and ensuring that land boundary
529 demarcations are accurately defined according to legal and technical standards.

530 However, coordinates, as presented by a surveyor, would not hold weight unless that
531 evidence is admissible. Expert opinions are allowed many times in litigation, and “the court stated
532 that expert opinion based on a scientific technique is inadmissible unless the technique is

⁴⁴ U.S. Department of the Interior. 2009. “*Manual of Surveying Instruction: For the Survey of the Public Lands of the United States*”. Bureau of Land Management. Denver, CO.

⁴⁵ *Cupps v. Pioneer Canal-Lake Hattie Irrigation Dist.*, 2023 U.S. App. LEXIS 18295, *1, 2023 WL 4618334 (10th Cir. Wyo. July 19, 2023)

533 "generally accepted" as reliable in the relevant scientific community."⁴⁶ The generation of
 534 coordinates is relevant within the profession and established by statute; thus, the presenting
 535 coordinates as viable evidence is within expert witness testimony and potential litigation. A land
 536 surveyor, called to provide an expert opinion, may use coordinates as factual evidence in the
 537 determination of the land boundary, and "the location of a boundary line was a question of fact."⁴⁷
 538 A coordinate itself may hold more weight than a course, distance, or even monument, should it be
 539 regarded as more certain "... there is such magic in a monument called for that it will be made to
 540 control in construction invariably. If it controls it is only because it is to be regarded as more
 541 certain than course or distance."⁴⁸

542 VII. Statutory Rules

543 The following states have adopted statutory language with regards to coordinates and legal
 544 descriptions; however, this is not an all-encompassing listing: Tennessee, Georgia, Kentucky,
 545 Virginia, and West Virginia. The language is paraphrased as follows:

546 A provided coordinate shall be considered a complete, legal, and satisfactory description
 547 of such location to give the position of such survey station or land boundary corner in
 548 Tennessee, Kentucky, Virginia, or West Virginia, as long as the provided coordinate can be
 549 satisfactorily described by referencing its position on the state's respective system of plane
 550 coordinates, as defined by law. This framework ensures standardized and accurate land
 551 boundary descriptions while accommodating state-specific requirements. Tenn. Code Ann.
 552 § 66-6-105 (2024); GA Code § 44-4-24 (2024); KRS § 1.020 Kentucky State Plane
 553 Coordinate System (2024); Va. Code Ann. § 1-609 (2024); W. Va. Code §1-1-5 (2024)

554 The underlying logic of a coordinate, as it pertains to the physical universe we occupy, is that that
 555 coordinated value is unique in its position, as it cannot occupy any other position simultaneously.
 556 "Without following the witness through the complexities of this method of locating a description
 557 on the surface of the earth, we quote his ultimate statement that by the use of the system, "it boils
 558 down to the condition that only one position can have the coordinate as stated."⁴⁹ Thus, should
 559 the statutory rules constitute that a coordinate, established by proper accuracy techniques, be
 560 satisfactory and complete as a legal description, then it could be construed that a mathematical

⁴⁶ *Daubert v. Merrell Dow Pharms., Inc.*, 509 U.S. 579, 584, 113 S. Ct. 2786, 2792, 125 L. Ed. 2d 469, 477, 1993 U.S. LEXIS 4408, *10, 27 U.S.P.Q.2D (BNA) 1200, 1202, 61 U.S.L.W. 4805, 93 Cal. Daily Op. Service 4825, 93 Daily Journal DAR 8148, 23 ELR 20979, CCH Prod. Liab. Rep. P13,494, 7 Fla. L. Weekly Fed. S 632 (U.S. June 28, 1993)

⁴⁷ *Hammons v. Adair*, 2002 Ark. App. LEXIS 449, *1, 2002 WL 1980352 (Ark. Ct. App. August 28, 2002)

⁴⁸ *Pritchard v. Rebori*, 135 Tenn. 328, 333-334, 186 S.W. 121, 122-123, 1916 Tenn. LEXIS 29, *4-6, 8 Thompson 328 (Tenn. April 1, 1916)

⁴⁹ *Smith v. Rickards*, 149 Cal. App. 2d 648, 653, 308 P.2d 758, 761, 1957 Cal. App. LEXIS 2081, *8 (Cal. App. 3d Dist. April 1, 1957)

561 model can be applied to assist in discovering the potential location of historic land boundary
562 evidence.

563 **VIII. Boundary Evidence and Error Estimation**

564 8.1 Intent – The primary element of the land boundary retracement surveyor is to establish
565 intent. The intent of the operative parties is the truly binding element in the boundary; however,
566 many times, the operative parties cannot be asked the intent; thus, it is the surveyor that has
567 measured the intent and monumented it on the ground. The usage of the following language, as
568 extracted from the statutory language researched, “shall be considered a complete, legal, and
569 satisfactory description of the location to give the position of the land boundary corner,” give
570 construct to the notion that a coordinate value, when established by industry standard accepted
571 procedures and statutory means, is a complete and legal description. Therefore, the description
572 could be construed to provide the intent of the parties to the operative instrument if disputed. Intent
573 of the parties is paramount and “this rule of construction is to aid in determining the intention of
574 the parties to a deed which is to be determined, if possible, from the instrument in connection with
575 the surrounding circumstances.”⁵⁰

576 A coordinated position itself is a mere mathematical combination of measurements, and all
577 corner locations or positions are a product of two measurements: course and distance.⁵¹ However,
578 to be established as viable, the procedure must be subjected to peer review and tested for
579 falsification, and “scientific methodology today is based on generating hypotheses and testing
580 them to see if they can be falsified; indeed, this methodology is what distinguishes science from
581 other fields of human inquiry. Another pertinent consideration is whether the theory or technique
582 has been subjected to peer review and publication.”⁵² Peer review and the establishment of a legal
583 description that can be followed by subsequent land surveyors is the elemental task of an original
584 and retracement surveyor; thus, coordinates have a more prevalent role in today’s land surveying
585 profession more than ever. Utilizing the technology, with the reproducibility and accuracy, is
586 critical in preserving and creating evidence, yet “technology is not evidence, but evidence depends
587 on technology in its creation and future retracement.”⁵³ Providing an accurate and sufficient legal
588 description of the land boundary is paramount and will aid in the elimination of ambiguous
589 instruments. Should part of the instrument be found in err, it is rejected; hence, the land surveyor

⁵⁰ *Ezell v. Duncan*, 2004 Tenn. App. LEXIS 839, *15-16, 2004 WL 2916139 (Tenn. Ct. App. December 15, 2004)

⁵¹ Robillard, W., Wilson, D., & Brown, C. (2004). *Evidence and Procedures for Boundary Location* (6th ed.). John Wiley & Sons, Incorporated. 122

⁵² *Daubert v. Merrell Dow Pharms., Inc.*, 509 U.S. 579, 582, 113 S. Ct. 2786, 2791, 125 L. Ed. 2d 469, 476, 1993 U.S. LEXIS 4408, *1, 27 U.S.P.Q.2D (BNA) 1200, 1201, 61 U.S.L.W. 4805, 93 Cal. Daily Op. Service 4825, 93 Daily Journal DAR 8148, 23 ELR 20979, CCH Prod. Liab. Rep. P13,494, 7 Fla. L. Weekly Fed. S 632 (U.S. June 28, 1993)

⁵³ Robillard, W., Wilson, D., & Brown, C. (2004). *Evidence and Procedures for Boundary Location* (6th ed.). John Wiley & Sons, Incorporated. 65

590 should strive for the creation a less ambiguous legal description. “Where the description in the
 591 deed is true in part, but not true in every particular, so much of it as is false is rejected, and the
 592 instrument will take effect if a sufficient description remains to ascertain its application.”⁵⁴

593 8.2 Boundary Evidence Collection and Error Estimation – Land boundary surveying is not
 594 a simple algebraic problem, such as $x + 3 = 6$; however, simple through complex mathematics can
 595 be utilized to approach the fundamental to solving any mathematical challenge. It has been
 596 established that the pioneering land surveyor monumented the intent of the operative parties and
 597 that a coordinated position, on whatever original datum, is the true position; thus, the retracement
 598 land surveyor is tasked with discovering where that monumented coordinated position is located
 599 on the Earth. By breaking it the above problem down into logical steps, a solution can be derived.
 600 Start by isolating the variable, x , by subtracting 3 from both sides, then with the variable isolated,
 601 and equal to a solved number, the solution is provided, $x = 3$. By no means is a land boundary
 602 solution this simple to arrive at, yet, a structured approach, identifying the problem, applying
 603 mathematical operations systematically, and verifying the results, is the same methodology used
 604 in land survey data analytics.

605
 606 In land boundary survey data analytics, the problem is often vague at first, and land
 607 surveyors must define the objective “finding the land to the surveyed.”⁵⁵ Identification of the key
 608 unknown variables is what drives decision-making and land survey analytics.

609
 610 Once the problem is defined, land survey data must be collected, ensuring all measurements
 611 for the potential unknowns are accounted for. Data analysis is like simplifying an equation,
 612 removing outliers or inconsistencies to ensure accuracy. After the data has been verified as
 613 complete, comes the analytical process, using statistical models and applying algebraic rules to
 614 transform the formulated equations into a solvable form. However, many times, error estimates
 615 are not applied to generate a search perimeter for boundary evidence recovery. It is more akin to
 616 the land surveyor who inspects the surrounding area to determine evidence of possession, but, to
 617 an untrained eye, a search perimeter would be extremely advantageous as valuable evidence could
 618 possibly be missed.

619
 620 In both mathematics and land survey data analytics, the core principles remain the same:
 621 define, simplify, compute, and verify the evidence and provide a solution. However, the
 622 formulation of the problem, or the development of the process, must evaluate the evidence and not
 623 merely manipulate land survey data.⁵⁶ A simple algebraic equation is not just a classroom exercise,
 624 it’s a blueprint for problem-solving in the data-driven world of land boundary retracement
 625 surveying.

626

⁵⁴ *White v. Luning*, 93 U.S. 514, 523, 23 L. Ed. 938, 939, 1876 U.S. LEXIS 1404, *12, 3 Otto 514 (U.S. December 18, 1876)

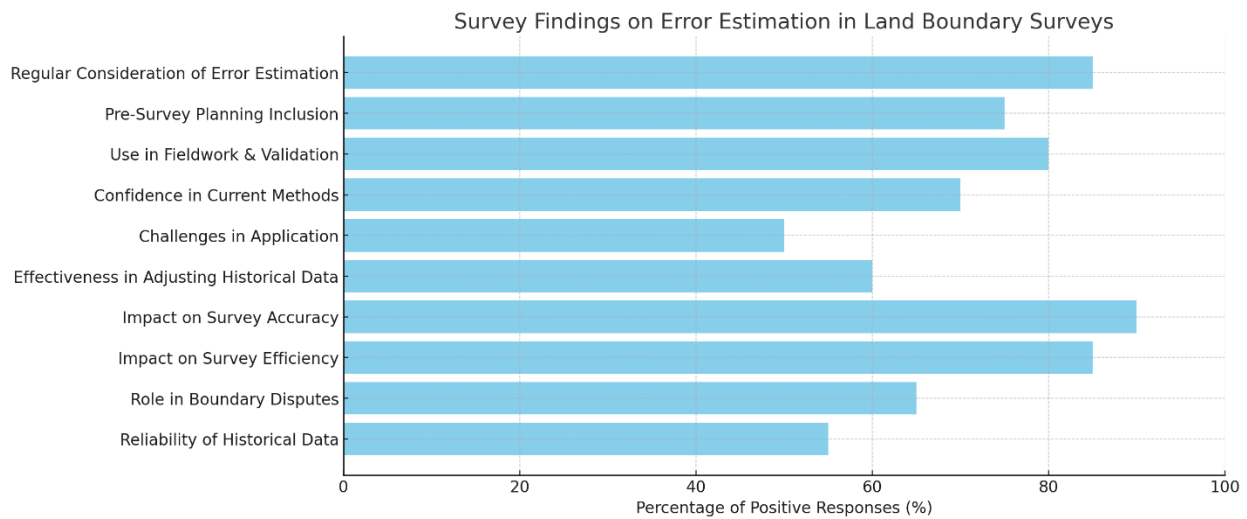
⁵⁵ Mulford, A.C. (1912) . *Boundaries and Landmarks, a Practical Manual*. 25 Park Place: D. Van Nostrand Company. 1

⁵⁶ (Knott 1998, 9)

627 8.3 Error Estimate Integration – Understanding error estimates and applying them on
 628 record measurements is truly a key component to developing a mathematical model for land
 629 boundary evidence recovery; however, the first step is the understanding, or educating, the
 630 professional community on the importance of error estimation. Based on responses by the
 631 professional community, error estimation in land boundary survey planning is summarized as
 632 follows: *Error estimation is widely recognized as a crucial component in boundary retracement*
 633 *and decision-making; while many surveyors integrate it into their workflow, inconsistencies in*
 634 *application and effectiveness highlight areas for improvement; a more systematic approach to*
 635 *error estimation could enhance the reliability of land boundary determinations and reduce*
 636 *disputes.*

637

638



639

640

641

Figure 8.1 – Key Findings on Error Estimation in Land Boundary Surveys

642 **IX. Boundary Survey Preplanning**
643

644 9.1 Current Methodology – The land boundary survey is the foundation of the profession;
645 however, there are many processes to perform such a task. Land surveying in itself is both an art
646 and science; thus, many processes of the professional land surveyor are tailored to the individual
647 licensee. However, the following is a current process for the land boundary retracement survey
648 based on professional opinions and processes:
649

650 *General Land Boundary Retracement Survey Process*

- 651 1. Research and Preparation
652 a. Obtain historical records, including:
653 i. Deeds, plats, and legal descriptions
654 ii. Surveyor notes and previous boundary surveys
655 iii. County, state, or federal land records
656 b. Compare adjacent property records for consistency
657 c. Identify original survey methods and reference datum
658 d. Review past land conveyances and legal changes affecting boundaries
659 2. Field Investigation and Monument Recovery
660 a. Locate and verify known control points and boundary markers
661 b. Search for physical evidence of past surveys, such as:
662 i. Stone piles, tree markings, fences, or old monuments
663 ii. Remnants of boundary features mentioned in historical records or possible
664 evidence of possession
665 c. Evaluate discrepancies between historical records and field conditions
666 3. Data Analysis and Boundary Reconstruction
667 a. Compare field data with historical records to determine original intent
668 b. Apply geodetic and legal principles to align with prior surveys
669 c. Cross-reference recovered monuments with legal descriptions
670 d. Address any conflicts with adjacent property boundaries
671 4. Documentation and Reporting
672 a. Prepare updated survey plats and reports with:
673 i. Field notes, coordinate data, and identified markers
674 ii. Supporting historical documents and legal references
675 iii. Boundary conclusions and justifications for retracement decisions
676 b. Submit findings to relevant authorities or property owners
677 c. Ensure documentation aligns with state and local surveying regulations
678 5. Final Verification and Stakeout
679 a. Mark retraced boundaries with appropriate monuments
680 b. Confirm the accuracy of retraced lines with the property owner
681 c. Provide plat, report of survey, and legal descriptions for any required filings or
682 updates
683

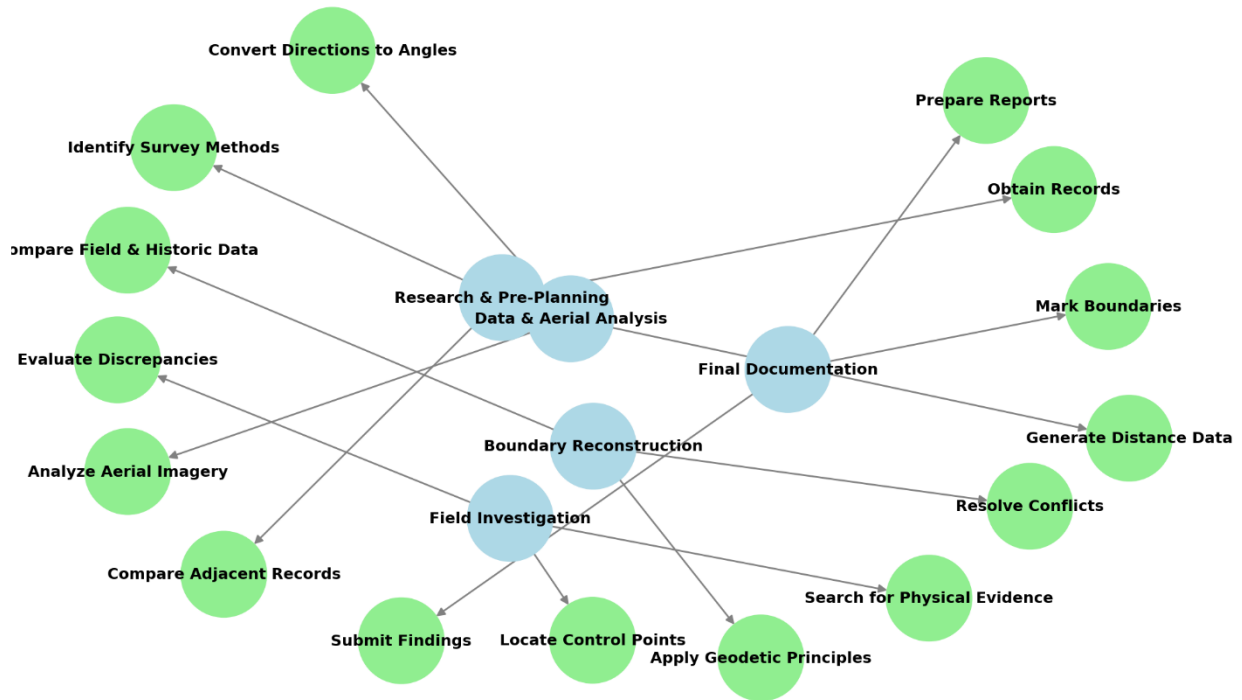
684 9.2 Preplanning for the Field – Using the General Land Boundary Retracement Survey
685 Process in section 9.1 and the General Steps for Land Boundary Data Analysis – Land Survey
686 Preplanning in section 3.3, a combined process could be formulated to potentially create a
687 preplanning evidence corridor phase.

- 688 1. Research, Preparation, and Pre-Planning
- 689 a. Obtain historical records, including:
- 690 i. Deeds, plats, and legal descriptions
- 691 ii. Surveyor notes and previous boundary surveys
- 692 iii. County, state, or federal land records
- 693 b. Compare adjacent property records for consistency
- 694 c. Identify original survey methods and reference datum
- 695 d. Review past land conveyances and legal changes affecting boundaries
- 696 e. Obtain record measures for the main parcel and neighboring parcels
- 697 f. Inspect operative descriptions to discern potential blunders and discrepancies
- 698 i. Document any inconsistencies for further evaluation
- 699 g. Identify and label common corners for redundant measure identification
- 700 2. Preliminary Data Analysis and Aerial Evaluation – Pre-planning
- 701 a. Convert directional values to angular values between lines
- 702 b. Generate an angle and distance data set to establish redundancy among common
- 703 monumentation
- 704 c. Obtain aerial imagery from sources such as:
- 705 i. Google Maps
- 706 ii. Google Earth
- 707 iii. USGS aerial photography
- 708 d. Analyze aerial imagery for visible evidence of possession or boundary markers near
- 709 estimated boundary lines
- 710 e. If visible possession or boundary markers are detected, generate line work from
- 711 imagery
- 712 i. Include angles and distances to support further analysis
- 713 f. Extract measurement data from both record sources and aerial imagery
- 714 g. Input record and generated measurement information into least squares processing
- 715 i. Analyze error ellipse measures for potential relevancy
- 716 3. Field Investigation and Monument Recovery – Field Survey
- 717 a. Locate and verify known control points and boundary markers
- 718 b. Search for physical evidence of past surveys, including:
- 719 i. Stone piles, tree markings, fences, or old monuments
- 720 ii. Remnants of boundary features mentioned in historical records or possible
- 721 evidence of possession
- 722 c. Evaluate discrepancies between historical records and field conditions
- 723 4. Data Integration and Boundary Reconstruction – Record and Field Measure Analytics
- 724 a. Compare field data with historical records to determine original surveyor intent
- 725 b. Apply geodetic and legal principles to align findings with prior surveys
- 726 c. Cross-reference recovered monuments with legal descriptions
- 727 d. Address any conflicts with adjacent property boundaries

728

- 729 5. Documentation, Reporting, and Final Verification – Final Platting
 730 a. Prepare updated survey plats and reports, including:
 731 i. Field notes, coordinate data, and identified markers
 732 ii. Supporting historical documents and legal references
 733 iii. Boundary conclusions and justifications for retracement decisions
 734 b. Submit findings to relevant authorities or property owners
 735 c. Ensure documentation aligns with state and local surveying regulations
 736 d. Mark retraced boundaries with appropriate monuments
 737 e. Confirm the accuracy of retraced lines with the property owner
 738 f. Provide plats, reports, and legal descriptions for required filings or updates

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Figure 9.1 – Land Boundary Evidence Acquisition Process

744 X. Survey Data Analysis

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746 10.1 – Statement of Problem:

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748 The problem as stated is, can a systematic analysis be developed to evaluate historical and modern
749 boundary evidence, incorporating error estimates and legal precedent in the land boundary survey
750 preplanning phase, to establish a structured mathematical approach that enhances consistency and
751 accuracy in land boundary evidence collection and identification? While retracement land
752 boundary surveying is not understood to be a mathematical solution, statistical analysis can be
753 employed to provide a search pattern.

754

755 The process of boundary determination by integrating legal, historical, and geospatial analyses to
756 assess land descriptions and their reliability is paramount in assisting the determination of the legal
757 operative land description. In conjunction with legal document analysis, the assessment of
758 available aerial imagery for evidence of possession and occupation may influence boundary
759 retracement. Historical and/or contemporary imagery will be used to identify physical features,
760 improvements, or encroachments that provide insight into land use and potential discrepancies in
761 boundary interpretations.

762

763 The analysis must apply appropriate error estimates in the measures recorded in the original
764 instruments and apply respective error estimates to these measurements. Given that boundary
765 retracement follows the principle that the intent embedded in these measures is legally correct, a
766 preassessment or analysis can provide a static approach that can be applied only to the
767 quantitative aspects of measurement and not the intent itself. The measures will be treated as
768 independent, with error propagation techniques employed to establish an error ellipse at the
769 terminus of boundary lines. This statistical approach provides a refined understanding of
770 measurement uncertainty while maintaining adherence to legal boundary law and.

771

772 The analysis is grounded in the fundamental surveying principle that boundary retracement follows
773 the footsteps of the original surveyor. By synthesizing legal analysis, aerial evidence, and
774 measurement error estimation, the analysis aims to enhance the reliability and precision of
775 boundary determination while upholding the legal doctrines that govern land ownership and
776 boundary resolution.

777

778 10.2 – Hypothesis Statement:

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780 A systematic mathematical procedure can be developed using recorded boundary measurements,
781 additional obtained measurement data, and statistical error estimation techniques to generate a
782 structured search corridor for land boundary retracement evidence. This model will integrate
783 historical and contemporary geospatial analyses, legal precedents, and error propagation methods
784 to enhance the consistency and accuracy of land boundary evidence collection. By employing
785 statistical techniques to evaluate measurement uncertainties while preserving legal boundary
786 principles, the proposed approach will provide a quantifiable framework for guiding boundary
787 retracement investigations.

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10.3 – Data Analysis Procedure:

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General Steps for Land Boundary Data Analysis – Land Survey Preplanning:

1. Obtain the record measures for parcels, main parcel and neighboring parcels.
2. Inspect the measures from the operative descriptions to discern possible blunders.
 - a. Document potential blunders and discrepancies
3. Identify and label common corners for redundant measure identification.
4. Convert directional values to angular values between lines.
5. Generate an angle and distance data set which creates redundancy amongst the common monumentation.
6. Obtain aerial imagery for the parcels.
 - a. Google Maps
 - b. Google Earth
 - c. USGS aerial photography
7. Analyze aerial imagery to determine if there is any visible evidence of possession on or near estimated boundary lines.
8. Should evidence of possession or boundary be visibly noticeable on aerials, generate line work from imagery.
 - a. Angles and Distances
9. From the line work, both record and estimated aerial imagery, extract measurement data.
10. Input the measurement data into a least squares analysis with appropriate error estimates for the respective data set.
11. Examine error ellipses at terminus of lines to determine search patterns. The error ellipses generated should provide a reasonable error search pattern for boundary evidence collection.

816 10.4 – Parcel I: Google Maps Data and Record Data:

817

818 Upon investigation of the operative document and description, record year 1890, the directional
 819 values stated in generalized directions; NE, SE, SW, NW. The distances were provided to form
 820 rectangular lots and the subdivision plan, pre-1900, showed no measured distances, only record
 821 platted distances. More recent descriptions, 1940s, also did not provide an adequate description
 822 of the parcels. Lot 15 referenced a 1986 survey and upon discussion with the landowner, a copy
 823 was obtained. The distances were stated to the hundredth of a foot and the directional values to
 824 the nearest minute. Upon analysis of the boundary, my presumption is that the survey was not a
 825 true land survey; it simply stated the measures as recorded in the original plat. The lot had a
 826 perfect closure from the point of beginning, which is not representative of reporting what you
 827 measure.

828

829 An error analysis on the record measures proved to not be of use as the measures were simply
 830 created on paper, not reporting what was measured; thus, not creating measurable data to analyze
 831 for evidence recovery. However, Google Maps provided an aerial map along with estimated lot
 832 lines for the parcel.

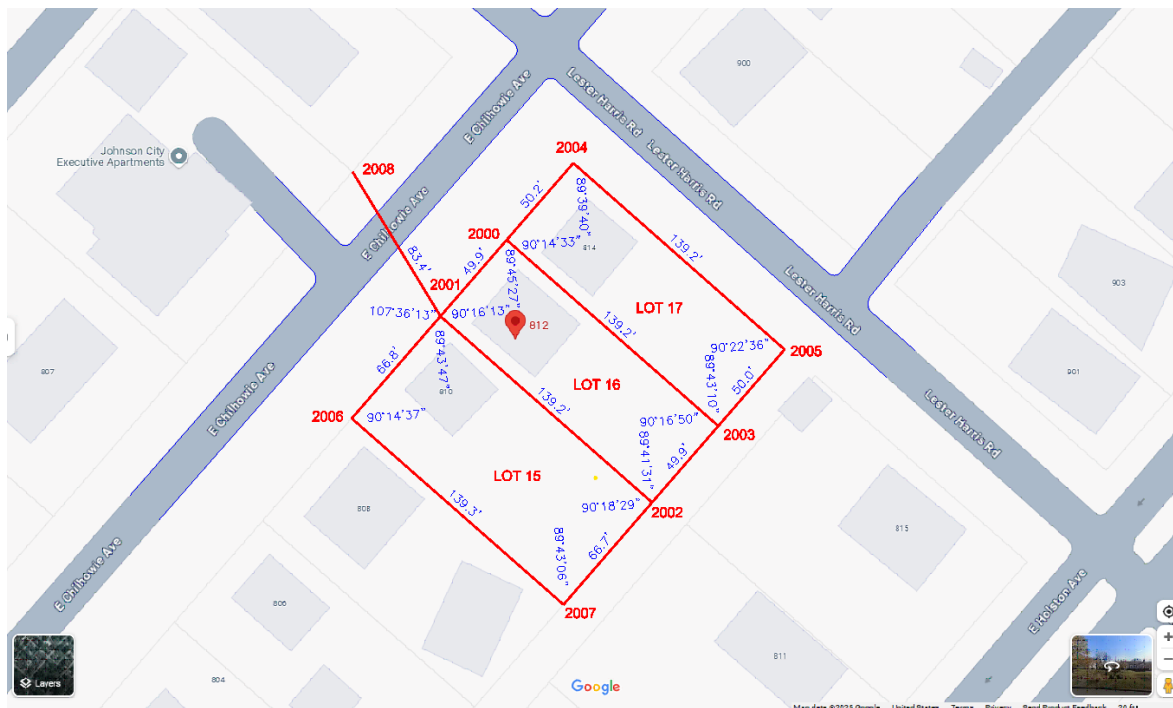
833

834 *Measures Scaled from Google Maps Imagery:* Image obtained from Google Maps and scaled
 835 using the provided image scale. Lines were drawn corresponding to the visible lot estimates
 836 available. Angles and distances were obtained from the digitized lines.

837

838 Converting the directions to angles eliminates a need to correct for directional meridians; thus,
 839 creating a focus on the measures that can be initially analyzed for boundary evidence recovery.

840



841 Figure 10.1 – Parcel I: Google Earth Imagery with Line work Overlay

842

843

844

845 The measurement data was input and analyzed by Carlson software SurvNet and the following is
846 portions of the error report that depict the standard errors, measurements, and error ellipses
847 generated from the imagery.

848

849 Default Standard Errors:

850

851 *Distance: Constant 0.500, PPM: 5.000*

852 *Horiz. Angle: Pointing 120.0", Reading: 120.0"*

853 *Vert. Angle: Pointing 120.0", Reading: 120.0"*

854 *Total Station: Centering 0.005, Height: 0.010*

855 *Target: Centering 0.005, Height: 0.010*

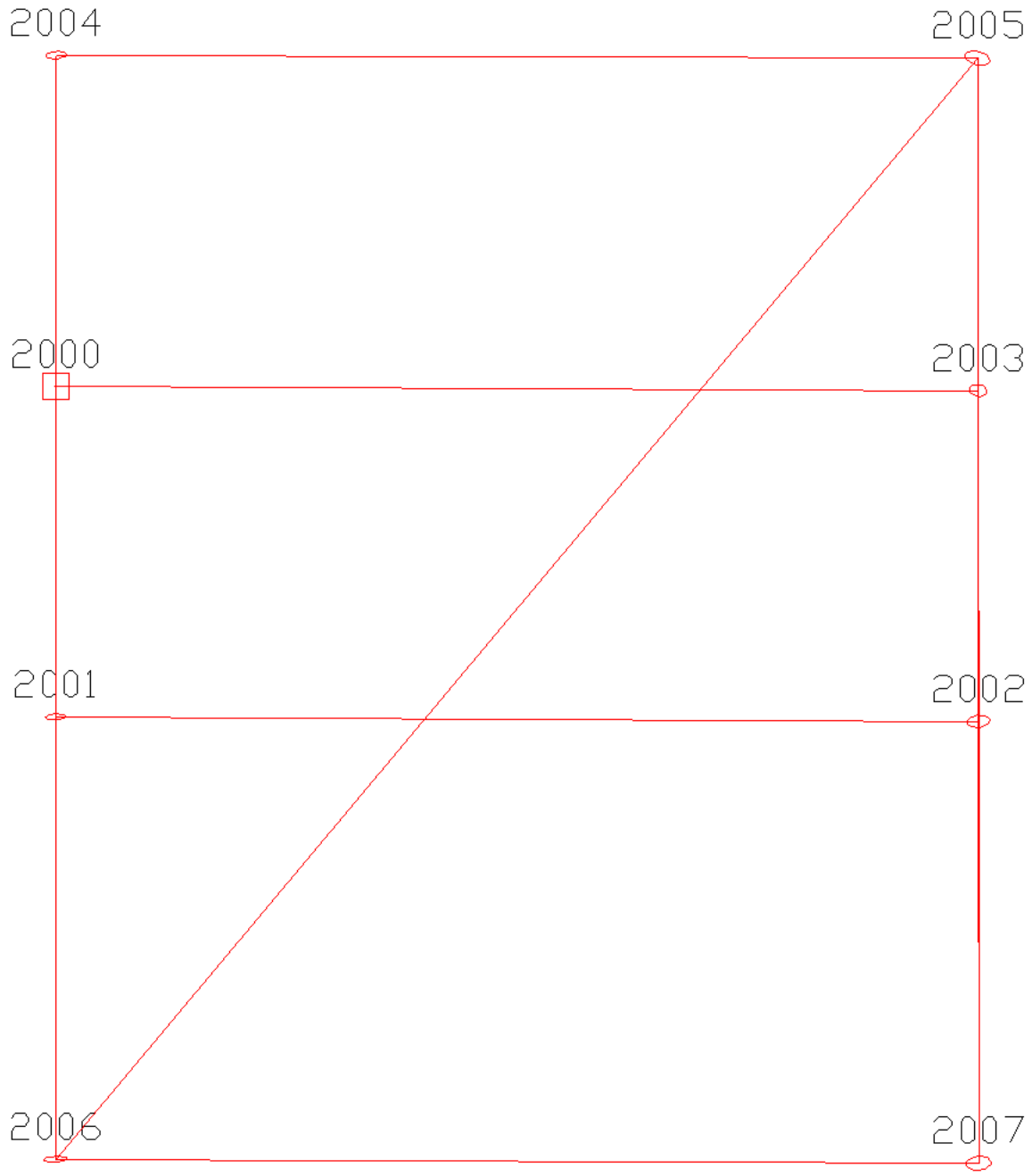
856 *Azimuth: 5"*

857 *Coordinate Control: N:0.010, E:0.010, Z:0.020*

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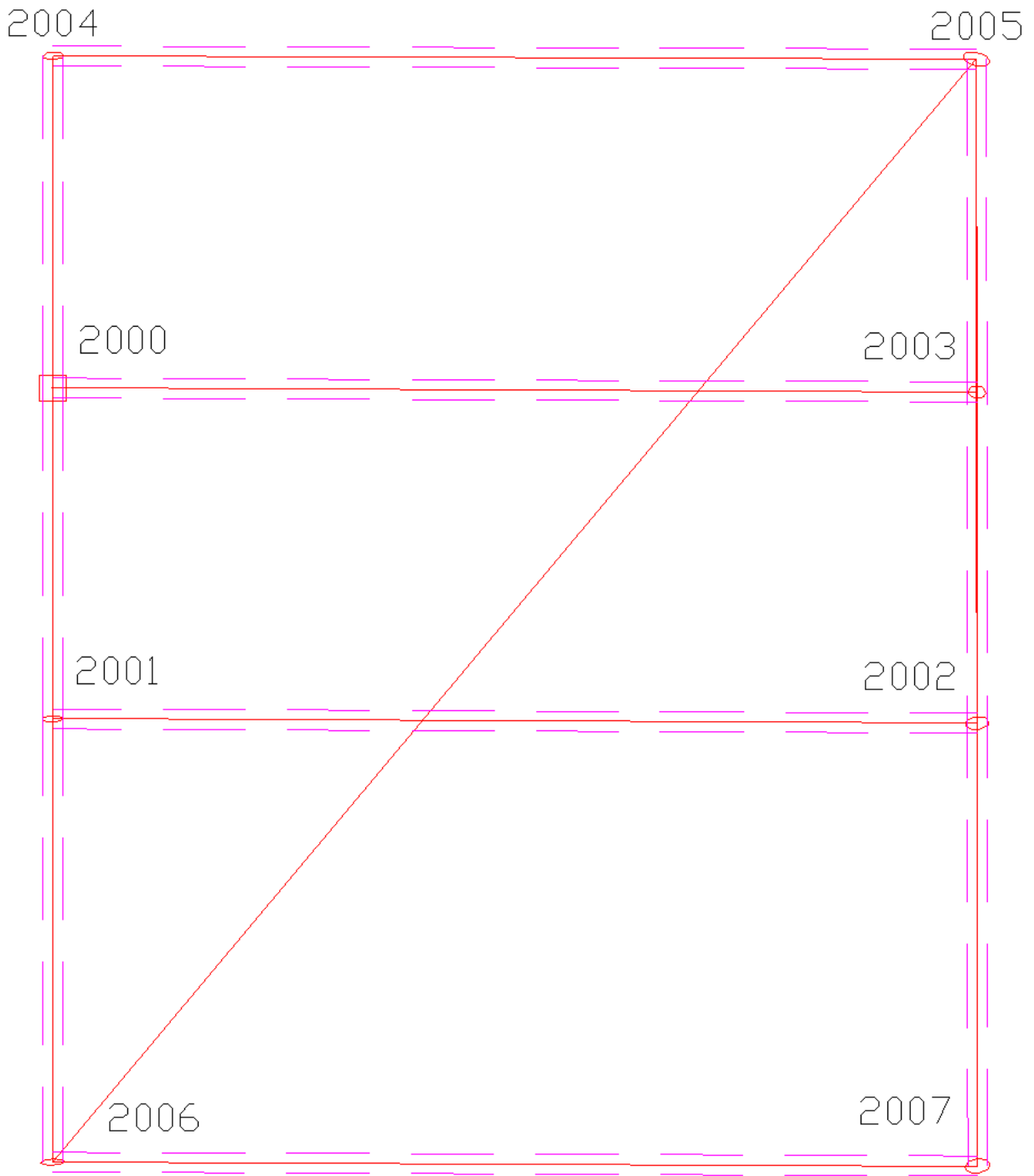


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Figure 10.2 – Parcel I: Error Ellipse Representation



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Figure 10.3 – Parcel I: Error Ellipse with Potential Boundary Evidence Corridor

867 Parcel I – Presurvey Analysis:

868 Based on the analysis of the data, the generated semi-major axes of the error ellipses produced,
869 and taking the average of those axes, which is 0.293 feet, it could be construed that if evidence is
870 found within a radius of 0.3 feet, such evidence, or monuments, could be considered within error
871 tolerances for this survey and should be analyzed for originality and inclusion in the boundary
872 opinion. However, based on the original plat (1890) and recovered survey (1986), all of which
873 did not report what was measured, but rather created a fictitious parcel to be surveyed, then a more
874 reasonable reporting of the errors could be an additional multiplier of five (5), from the original
875 average of the error ellipses of 0.3 feet; thus, monument evidence should fall within 1.5 feet of
876 the respective coordinated location. A 1.5-foot offset buffer was generated based on the average
877 of the error ellipses and multiplier; thus, boundary evidence should be discovered within the
878 corridor generated.

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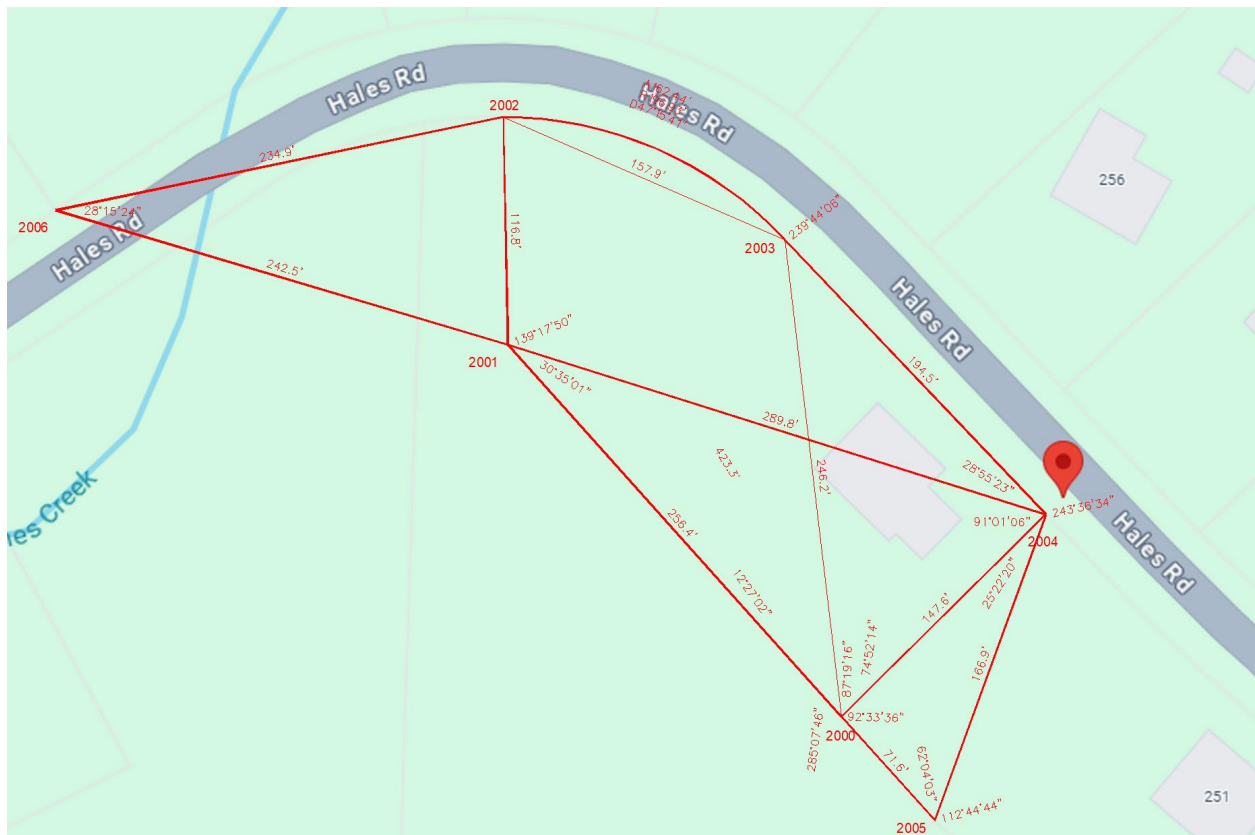
10.5 – Parcel II: Google Maps Data and Record Data:

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Upon investigation of the operative document and description, record year 1997 subdivision plat, the directional values reported to the nearest angular second and the distances to the nearest hundredth of a foot.

Measures Scaled from Google Maps Imagery: Image obtained from Google Maps and scaled using the provided image scale. Lines were drawn corresponding to the visible lot estimates available. Angles and distances were obtained from the digitized lines.

Converting the directions to angles eliminates a need to correct for directional meridians; thus, creating a focus on the measures that can be initially analyzed for boundary evidence recovery.



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Figure 10.4 – Parcel II: Google Map Imagery with Line work Overlay

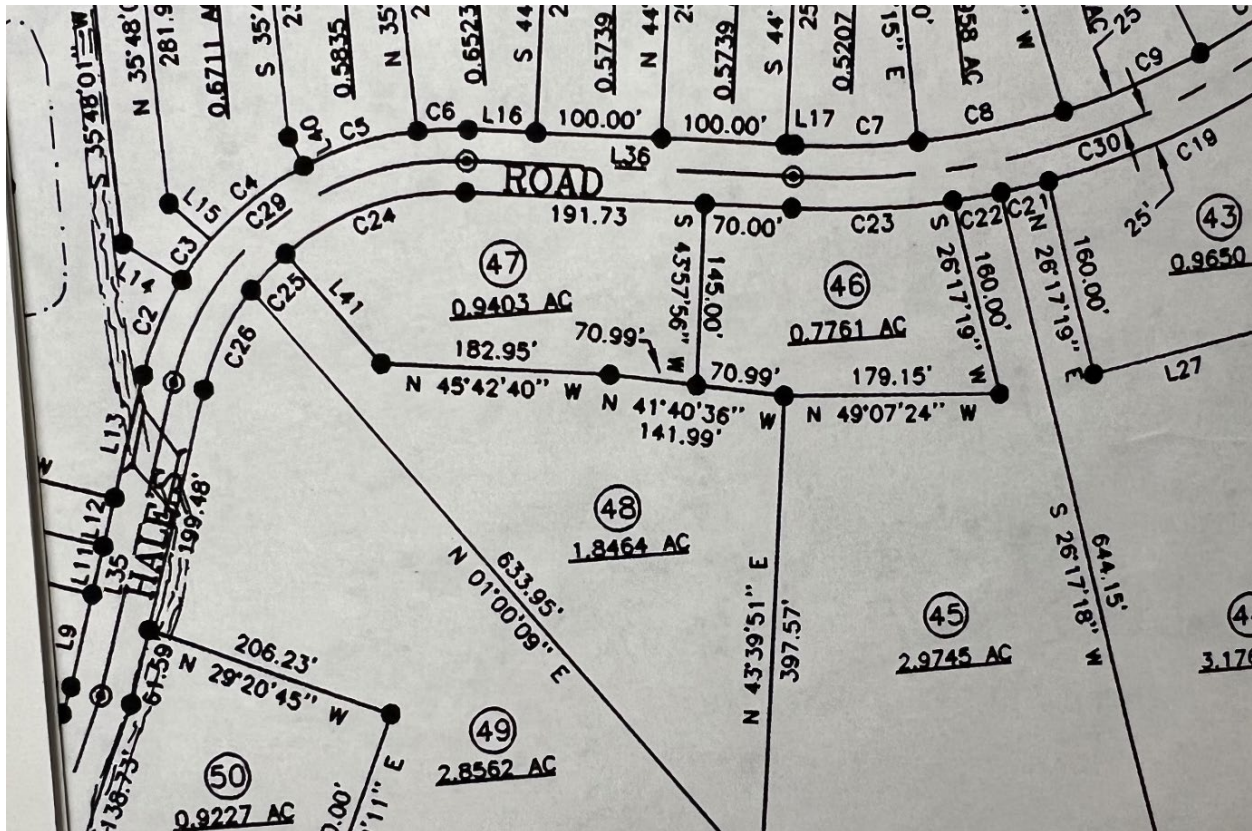


Figure 10.5 – Parcel II: Subdivision Plat Record Measures

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899 The first analysis of the measurement data was performed and analyzed by Carlson software
900 SurvNet on the Google measures, and the following are portions of the error report that depict
901 the standard errors, measurements, and error ellipses generated from the imagery.

902

903 Default Standard Errors:

904

905 *Distance: Constant 0.500, PPM: 5.000*
906 *Horiz. Angle: Pointing 120.0", Reading: 120.0"*
907 *Vert. Angle: Pointing 120.0", Reading: 120.0"*
908 *Total Station: Centering 0.005, Height: 0.010*
909 *Target: Centering 0.005, Height: 0.010*
910 *Azimuth: 5"*
911 *Coordinate Control: N:0.010, E:0.010, Z:0.020*

912

913 Parcel II: Presurvey Analysis 1:

914 Based on the first analysis of the data, aerial Google Map imagery, the generated semi-major
915 axes of the error ellipses produced, and taking the average of those axes, which is 0.079 feet, it
916 could be construed that if evidence is found within a radius of 0.1 feet, such evidence, or
917 monuments, could be considered within error tolerances for this survey and should be held,
918 based on the Google Map imagery. However, this is not truly representative of the measures.
919 Additional information was required.

920 The operative record instrument, the 1997 plat, provided additional measures that additionally
 921 need to be analyzed with the imagery data.

922 The second analysis of the measurement data was performed and analyzed by Carlson software
 923 SurvNet on the Google and Record measures, and the following are portions of the error report
 924 that depict the standard errors, measurements, and error ellipses generated from the imagery and
 925 operative instrument.

926

927 Default Standard Errors:

928

929 *Distance: Constant 0.500, PPM: 5.000*

930 *Horiz. Angle: Pointing 120.0", Reading: 120.0"*

931 *Vert. Angle: Pointing 120.0", Reading: 120.0"*

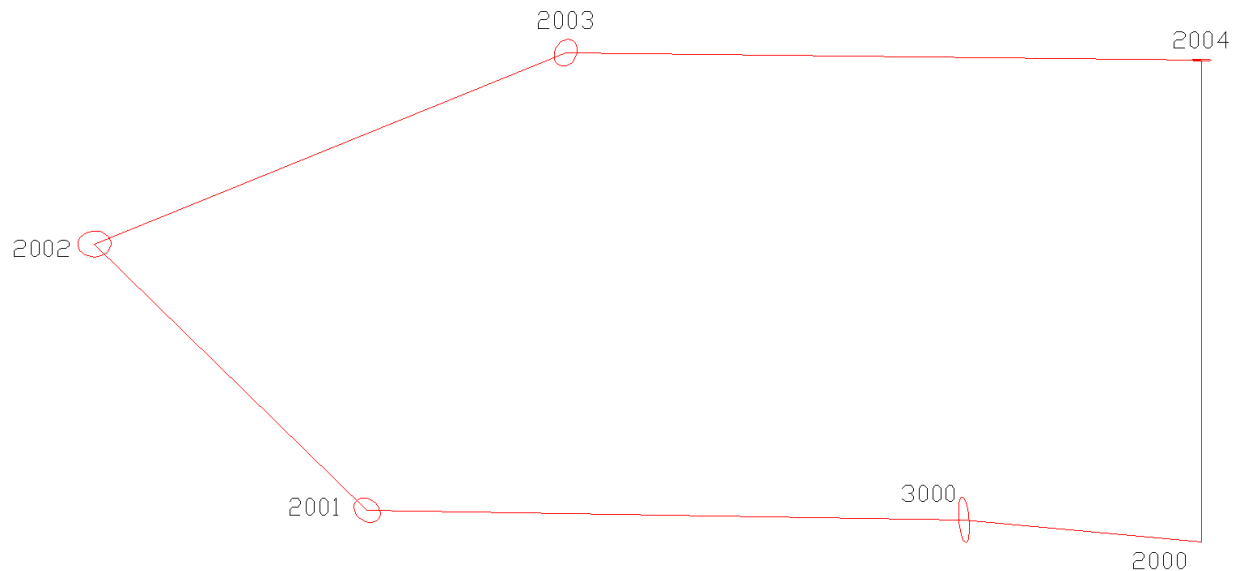
932 *Total Station: Centering 0.005, Height: 0.010*

933 *Target: Centering 0.005, Height: 0.010*

934 *Azimuth: 5"*

935 *Coordinate Control: N:0.010, E:0.010, Z:0.020*

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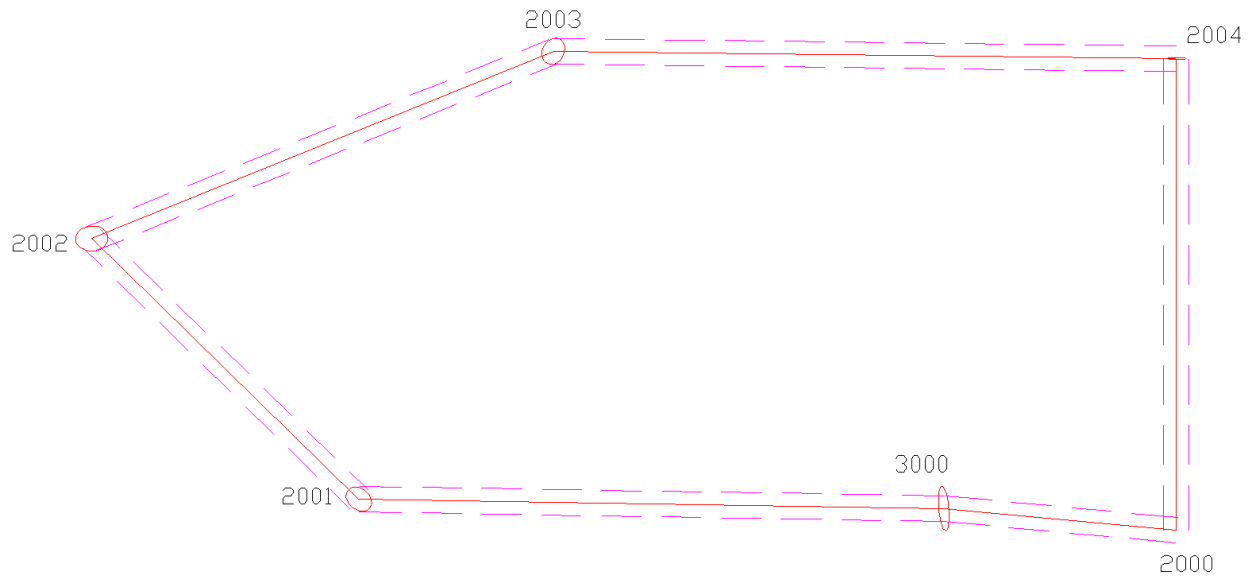


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Figure 10.6 – Parcel II: Error Ellipse Representation

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Figure 10.7 – Parcel II: Error Ellipse with Potential Boundary Evidence Corridor

942 Parcel II: Presurvey Analysis 2:

943 Upon further analysis of the data, and taking the average of the error ellipses on points 2000 –
944 2004, and 3000, providing an average of 4.01 feet, monument evidence should be found within
945 the average ellipse of those coordinated positions. It could be construed that if evidence is found
946 within said radius it could be considered within error tolerances for this survey and should be
947 analyzed for originality and inclusion in the boundary opinion.

948 An error multiplier was not utilized in this analysis due to the record information being more
949 accurate and providing additional measurement information.

950 The evidence corridor was produced from the average of the above stated points and in theory,
951 evidence of boundary should be discovered within the corridor.

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955 **XI. Conclusion**

956

957 The results of the analysis confirm that a structured land boundary evidence search corridor can
958 be developed through the integration of historical and modern geospatial data, legal precedent,
959 and statistical error estimation techniques. By systematically applying error propagation
960 methods to recorded and newly acquired boundary measurements, the model effectively
961 delineates areas of probable boundary evidence locations, thereby improving the efficiency and
962 accuracy of retracement investigations in the land survey preplanning phase.

963 The incorporation of statistical uncertainty assessments in measurement data allows for a refined
964 understanding of positional tolerances, enabling surveyors to define search corridors that align
965 with the intent of original boundary definitions while recognizing inherent measurement
966 limitations. The generation of an error ellipse at boundary terminus points provides a
967 quantifiable framework that accounts for potential discrepancies arising from historical survey
968 practices, environmental changes, and measurement precisions.

969 Furthermore, the integration of aerial imagery analysis enhances boundary determination by
970 identifying historical occupation patterns, encroachments, and physical features that serve as
971 supplementary evidence in retracement surveys. This geospatial component supports the
972 validation of documentary evidence, strengthening the reliability of boundary positioning in
973 complex or disputed cases.

974 The findings demonstrate that while land boundary retracement remains fundamentally a legal
975 and interpretative process, the application of mathematical and statistical techniques to
976 measurement data enhances the consistency and rigor of boundary evidence collection. The
977 structured search corridor approach offers a systematic methodology that aligns with established
978 legal principles while leveraging quantitative analysis to refine evidence acquisition strategies.

979 Ultimately, this research affirms that statistical modeling of boundary measurements, coupled
980 with legal and geospatial analysis, provides an effective tool for optimizing land boundary
981 retracement efforts. The methodology developed in this study contributes to the advancement of
982 land surveying practices by offering a reproducible, mathematically sound approach to
983 evaluating and identifying land boundary evidence.

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1093