

DRAFT

GEOREFERENCING

QUICK REFERENCE GUIDE

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Introduction

This is a practical guide for georeferencing. It describes the methods to determine the shapes of features and how to use them as the basis for georeferencing with the **point-radius georeferencing method** (Wieczorek 2001, Wieczorek *et al.* 2004, Chapman & Wieczorek 2020) using the [Georeferencing Calculator](#) (Wieczorek & Wieczorek 2019), accompanied by its *Georeferencing Calculator Manual* (Wieczorek *et al.* 2019), maps, **gazetteers**, and other resources from which coordinates and spatial boundaries for places can be found. The *Guide*, in its first version (Wieczorek *et al.* 2012), was an adaptation of *Georeferencing for Dummies* (Spencer *et al. n.dat.*). It explains the recommended georeferencing procedures for the most commonly encountered type of localities. This *Guide* should be used in parallel with *Georeferencing Best Practices* (Chapman & Wieczorek 2020), which contains the theoretical background and more detailed information about concepts used here. Throughout this document there are terms in **bold**. These signify that there is a very specific meaning for the term as it is being used here, and these are defined in detail in the <<*Glossary*>> of the *Georeferencing Best Practices*.

1.1 Objectives

This document provides guidance to georeferencers using the **point-radius method** to **georeference locations** for new records in the field or through retrospective georeferencing of historic **locations** of biological records.

1.2 Target Audience

This document is a practical guide for anyone who needs to determine **georeferences** for use in research, education, or the maintenance of biological collections data.

1.3 Scope

This document is one of three that cover recommended requirements and methods to **georeference locations**. It provides a practical how-to guide for putting the theory of the **point-radius georeferencing method** into practice.

The *Guide* relies on the *Georeferencing Best Practices* for background, definitions, more detailed explanations, definitions of terms, and information on how to deal with a wide variety of specific cases.

The *Georeferencing Calculator* is a browser-based javascript application that aids in **georeferencing** descriptive **localities** and provides methods to help obtain **geographic coordinates** and **uncertainties** for **locations**.

These documents DO NOT provide guidance on georectifying images or **geocoding** street addresses.

1.4 Changes from Previous Version

There are a few changes in terminology since the previous edition of the *Guide*. These include:

- **extent** of the previous version has been changed to **radial**. **Extent**, where retained, is used in a more traditional way.
- named place has been replaced with **feature**.
- where geographic center was used in the past, **corrected center** is now used. This is an important change because the geographic center did not necessarily yield the smallest **uncertainty** due to the **extent** of a feature; the **corrected center** does.

This version of the *Guide* includes graphical examples of each type of location and how to georeference them.

1.5 Using Darwin Core

Georeferences using the methods in this *Guide* will be the most useful if as much information as possible is captured about and during the **georeferencing** process in the following fields defined in the **Darwin Core** Standard (TDWG 2018). For additional community discussion and recommendations, see the Darwin Core Project wiki (Wieczorek 2017), the *Darwin Core Hour Webinars* (<https://github.com/tdwg/dwc-qa/wiki/Webinars>) and *Georeferencing Best Practices*.

Darwin Core georeferencing terms:

- [decimalLatitude](#), [decimalLongitude](#), [geodeticDatum](#) – the combination of these fields provide the reference for the center of the **point-radius** representation of the georeference.
- [coordinateUncertaintyInMeters](#) – The horizontal distance in meters from the given **decimalLatitude** and **decimalLongitude** that describes the smallest circle that contains the whole of the **location**. Leave the value empty if the uncertainty is unknown, cannot be estimated, or is not applicable (because there are no coordinates). Zero is not a valid value for this term.
- [georeferencedBy](#), [georeferencedDate](#) – individual(s) who last modified the georeference and when.
- [georeferenceProtocol](#) – A description or reference to the methods used to determine the **shape** using the **shape georeferencing method**, or the **coordinates** and **uncertainty** using the point-radius method. .
- [georeferenceSources](#) – A list (concatenated and separated) of maps, **gazetteers**, or other resources used to **georeference** the **location**, described specifically enough to allow anyone in the future to use the same resources. Example: "USGS 1:24000 Florence Montana Quad; Terrametrics 2008 Google Earth™".

- [georeferenceVerificationStatus](#) – A categorical description of the extent to which the **georeference** has been verified to represent the best possible spatial description. Recommended best practice is to use a controlled vocabulary.

Examples: "requires verification", "verified by collector", "verified by curator".

- [georeferenceRemarks](#) – Notes or comments about the spatial description determination, explaining assumptions made in addition or opposition to those formalized in the method referred to in **georeferenceProtocol**.

Example: "assumed distance by road (Hwy. 101)".

1.6 Georeferencing Concepts

One of the goals of georeferencing following best practices is to be sure that enough information is provided in the output so that it is repeatable (see <<1.5 *Principles of Best Practice*>> in *Georeferencing Best Practices*). To that end, this document provides a set of recipes for **georeferencing** various **locality types** using the *Georeferencing Calculator*. The *Georeferencing Calculator* allows you to choose a **locality type** to make a calculation. When you make that choice, the calculator presents input boxes for all of the parameters needed for the calculation. Note that the **locality type** is for the most specific **clause** in the **locality** description (see <<3.2a *Parsing the Locality Description*>> in *Georeferencing Best Practices*), but there may be information for other **clauses** or other parts of the **location** record that help to constrain the **location** and come into play when a **feature boundary** is determined. Some *Calculator* parameters are used for more than one **locality type**. Rather than repeat the explanation for each **locality type**, they are collected here for common reference. Some **locality types** require specific parameters, for which the corresponding explanations are included in each subsection of <<*Locality Types*>>. Refer to the *Georeferencing Calculator Manual* (Wieczoreak *et al.* 2019) for details about the *Calculator* not answered in this document.

a. Locality Type

The pattern of the most specific part of a **locality** description to be **georeferenced**. The *Calculator* has options to compute **georeferences** for six basic **locality types**:

- Coordinates only.
- Geographic feature only.
- Distance only.
- Distance along a path.
- Distance along orthogonal directions.
- Distance at a heading.

Selecting a **Locality Type** will configure the *Calculator* to show all of the parameters that need to be set to perform the **georeference** calculation for the chosen **Locality Type**. This *Guide*

gives specific instructions for how to set the parameters for many different examples of each of the **Locality Types**.

b. Corrected Center

The point within a location, or on its **boundary**, that minimizes the **geographic radial** of the **location**. This point is obtained by making the smallest circle that contains the entire **feature**, and then taking the center of that circle (Figure 1A). If that center does not fall on or inside the **boundaries** of the **feature**, make the smallest circle that contains the entire **feature** that has its center on the **boundary** of the **feature** (Figure 1B). Note that in the corrected case, the new circle, and hence the **radial**, will always be larger than the uncorrected one. In the *Calculator*, the **coordinates** corresponding to the **corrected center** are labelled as "Input latitude" and "Input longitude".

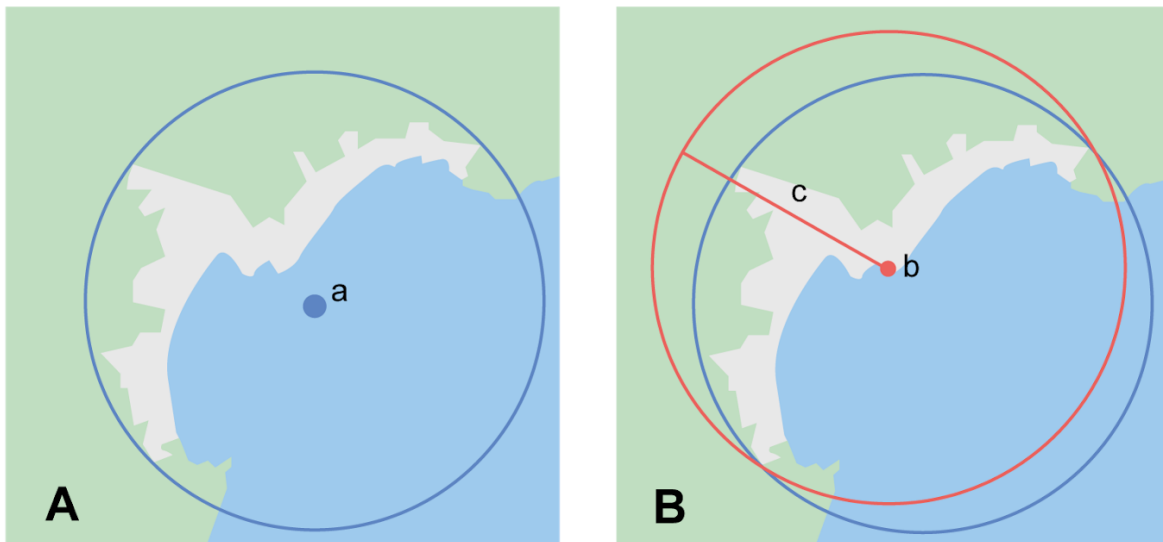


Figure 1. A: Determination of the **center** (a) of the smallest circle encompassing a **feature** (highlighted), note that the center does not fall within the **boundary** of the **feature**. **B:** Determination of the **corrected center** (b), which is on the **boundary** of the **feature**, and the corresponding **geographic radial**

c. Radial of Feature

A **feature** is a place in the **locality** description that has an **extent** and can be delimited by a **boundary**. The **geographic radial** of the **feature** (shown as "Radial of Feature" in the *Calculator*) is the distance from the **corrected center** of the **feature** to the furthest point on the **geographic boundary** of that **feature** (see <<2.3 Extent of a Location>> in *Georeferencing Best Practices*). Note that this was called "extent" in early versions of the *Calculator*.

d. Latitude

Labelled as **Input Latitude** in the *Calculator*. The **geographic coordinate** north or south of the equator (where **latitude** is 0) that represents the **feature**, or point, described in the locality (may need to be determined as a **corrected center**). **Latitudes** in decimal degrees north of the equator are positive by convention, while **latitudes** to the south are negative. The *Calculator* supports degree-based **geographic coordinate formats** for **latitude** and **longitude**: degrees minutes seconds (e.g., 35° 22' 24" N), decimal degrees (e.g., 35.3733333), and degrees decimal minutes (e.g., 35° 22.4 N).

e. Longitude

Labelled as **Input Longitude** in the *Calculator*. The **geographic coordinate** east or west of the **prime meridian** (an arc between the north and south poles where **longitude** is 0) that represents the **feature**, or point, described in the locality (may need to be determined as a **corrected center**). **Longitudes** in decimal degrees east of the **prime meridian** are positive by convention, while **longitudes** to the west are negative. The *Calculator* supports degree-based **geographic coordinate** formats for **latitude** and **longitude**: degrees minutes seconds (105° 22' 24" W), decimal degrees (-105.3733333), and degrees decimal minutes (105° 22.4 W).

f. Coordinate Source

The kind of resource (map, **GPS**, **gazetteer**, **locality** description) from which the starting **coordinates** were derived. Note, more often than not, the original **coordinates** are used to find the general vicinity of the **location** on a map, after which the process of determining the **corrected center** provides new **coordinates**. The **Coordinate Source** to use in the *Calculator* in this case is the map from which the **corrected center** was determined, not the original source used to determine the general vicinity on the map.

For example, suppose the original **coordinates** came from a **gazetteer**, but the **boundary** and **corrected center** of the **feature** were determined from Google Maps™, the **Coordinate Source** would be "Google Earth/Maps >2008", not "gazetteer".

This term is related to, but **NOT** the same as, the Darwin Core term *georeferenceSources*, which requires the specific resources used rather than their nature. Note that the **uncertainties** from the two sources "gazetteer" and "locality description" can not be anticipated universally, and therefore do not contribute to the global **uncertainty** in the calculations. If the **error** characteristics of these sources are known, they can be added in the **Measurement Error** field before calculating. If the source "GPS" is selected, the label for **Measurement Error** will change to **GPS Accuracy**, which is where **accuracy** distance of the GPS at the time the **coordinates** were taken should be entered. For details on **GPS Accuracy** see <<2.6 Using a GPS>> in *Georeferencing Best Practices* (Chapman and Wieczorek 2019).

g. Coordinate Format

Defines the original geographic **coordinate format** (decimal degrees, degrees minutes seconds, degrees decimal minutes) of the **coordinate source**. Note that, more often than not, the original **coordinates** are used to find the general vicinity of the **location** on a map, after which the process of determining the **corrected center** provides a new **coordinate**. The **Coordinate Format** to use in the *Calculator* in this case is the **coordinate format** on the map from which the **corrected center** was determined, not the **coordinate format** on the original source used to determine the general vicinity on the map. For example, suppose the original **coordinates** came from a **gazetteer** in degrees minutes seconds, but the **boundary** and **corrected center** of the **feature** were determined from Google Maps™, the **Coordinate Format** would be "**decimal degrees**", not "**degrees minutes seconds**".

This term is equivalent to the Darwin Core term *verbatimCoordinateSystem*. Selecting the original **coordinate format** allows the **coordinates** to be entered in their native format and forces the *Calculator* to present appropriate options for **coordinate precision**. Changing the **coordinate format** will reset the **coordinate precision** value to "nearest degree". Be sure to correct this for the actual **coordinate precision**. The *Calculator* stores **coordinates** in decimal degrees to seven decimal places. This is to preserve the correct **coordinates** in all formats regardless of how many transformations are done.

h. Coordinate Precision

Labeled in the *Calculator* as "**Precision**" in the first column of input parameters, this drop-down list is populated with levels of **precision** in keeping with the **coordinate format** chosen for the verbatim original **coordinates**. Note, more often than not, the original **coordinates** are used to find the general vicinity of the **location** on a map, after which the process of determining the **corrected center** provides a new **coordinate**. The **Coordinate Precision** to use in the *Calculator* in this case is the **coordinate precision** of the map from which the **corrected center** was determined, not the **coordinate precision** of the original source used to determine the general vicinity on the map. For example, suppose the original **coordinates** came from a **gazetteer**, but the **boundary** and **corrected center** of the **feature** were determined from Google Maps™, the **Coordinate Precision** would be determined by the number of digits of decimal degrees you captured from the **corrected center** on Google Maps™, not the **Coordinate Precision** of the **coordinates** from the original **gazetteer** entry.

This term is similar to, but **NOT** the same as, the Darwin Core term *coordinatePrecision*, which applies to the output **coordinates**. A value of "exact" is any level of **precision** higher than the otherwise highest **precision** given on a list. Sources of **coordinate precision** may include paper or digital maps, digital imagery, **GPS's**, **gazetteers**, or **locality** descriptions. Example: for 35° 22' 24", the **Coordinate Precision** would be "nearest second".

i. Datum

Defines the position of the origin and orientation of an **ellipsoid** upon which the **coordinates** are based for the given **Coordinate Source**. Note, more often than not, the original

coordinates are used to find the general vicinity of the **location** on a map, after which the process used to determine the **corrected center** provides a new **coordinate**. The **Datum** to use in the *Calculator* in this case is the **datum** (or **ellipsoid**) of the map from which the **corrected center** was determined, not the **datum** (or **ellipsoid**) of the original source used to determine the general vicinity on the map.

For example, suppose the original **coordinates** came from a **gazetteer** with an unknown datum, but the **boundary** and **corrected center** of the **feature** were determined from Google Maps™, the **Datum** would be "WGS84", not "datum not recorded".

The term "Datum" is equivalent to the Darwin Core term *geodeticDatum*. The *Calculator* includes **ellipsoids** on the **Datum** drop-down list, as sometimes that is all that **coordinate** source shows. The choice of **datum** has two important effects. The first is the contribution to **uncertainty** if the **datum** of the input coordinates is not known. If the **datum** and **ellipsoid** are not known, "datum not recorded" must be selected. **Uncertainty** due to an unknown **datum** can be severe and varies geographically in a complex way with a worst-case contribution of 5359 m (see the section <<2.5 *Coordinate Reference System*>> in *Georeferencing Best Practices*). The second important effect of the **datum** selection is to provide the characteristics of the **ellipsoid** model of the earth, on which the distance calculations depend.

j. Direction

The **heading** given in the **locality** description, either as a standard compass point (see http://en.wikipedia.org/wiki/Boxing_the_compass) or as a number of degrees in the clockwise direction from north. True North is not the same as Magnetic North (see <<2.8 *Headings*>> in *Georeferencing Best Practices*). If a **heading** is known to be a magnetic **heading**, it will have to be converted into a true heading (see NOAA's Magnetic Field Calculator at <https://www.ngdc.noaa.gov/geomag/calculators/magcalc.shtml>) before they can be used in the *Georeferencing Calculator*. If "degrees from N" is selected a text box will appear to the right of the selection into which the degree **heading** should be entered. Note: Some marine **locality** descriptions reference a direction (azimuth) toward a landmark rather than a **heading** from the current **location** (e.g., "327° to Nubble Lighthouse"). To make a **Distance at a heading** calculation for such a **locality** description, use the compass point 180 degrees from the one given in the **locality** description (147° in the example above) as the **Direction**.

k. Offset Distance

The linear distance from a point of origin. **Offsets** are used for the **Locality Types** "Distance at a heading" and "Distance only". If the **Locality Type** "Distance along orthogonal directions" is selected, there are two distinct **offsets**:

North or South Offset Distance - The distance to the north or south of the **Input Latitude**.

East or West Offset Distance - The distance to the east or west of the **Input Longitude**.

l. Distance Units

Denotes the real world units used in the **locality** description. It is important to select the original units as given in the description. This is needed to incorporate the **uncertainty** from **distance precision** properly. If the **locality** description does not include distance units, use the distance units of the map from which measurements are derived.

Examples: select "mi" for "10 mi E (by air) Bakersfield"; select "km" for "3.2 km SE of Lisbon"; select "km" for measurements in Google Maps™ where the distance units are set to "km".

m. Distance Precision

Labeled in the *Calculator* as "**Precision**" in the second column of input parameters. Refers to the **precision** with which a distance was described in a locality (see <<3.4g *Uncertainty Related to Offset Precision*>> in *Georeferencing Best Practices*). This drop-down list is populated in keeping with the **Distance Units** chosen and contains powers of ten and simple fractions to indicate the **precision** demonstrated in the verbatim original **offset**.

Examples: select "1 mi" for "6 mi NE of Davis"; select "1/10km" for "3.2 km SE of Lisbon".

n. Measurement Error

Accounts for **error** associated with the ability to distinguish one point from another using any measuring tool, such as rulers on paper maps or the measuring tools on Google™ Maps or Google™ Earth. The units of the measurement must be the same as those for the **locality** description. The **Distance Converter** at the bottom of the *Calculator* is provided to aid in changing a measurement to the **locality** description units.

o. GPS Accuracy

When "GPS" is selected from the **Coordinate Source** drop-down list, the label for the **Measurement Error** text box changes to **GPS Accuracy**. Enter the value given by the **GPS** at the time the **coordinates** were captured. If **GPS Accuracy** is not known, enter 100 m for standard hand-held **GPS coordinates** taken before 1 May 2000 when Selective Availability was discontinued. After that, use 30 m as a default value.

p. Uncertainty

The resulting combination of all sources of **uncertainty** (**coordinate precision**, unknown **datum**, data source, **GPS accuracy**, measurement error, **feature extent**, distance **precision**, and **heading precision**) expressed as a linear distance - the radius in the **point-radius method** (Wieczorek *et al.* 2004). Along with the **Output Latitude**, **Output Longitude**, and **Datum**, the radius defines a circle containing all of the possible places a **locality** description could mean. In the *Calculator* the **uncertainty** is given in meters.

Locality Types

2.1 Geographic feature only

Definition:

The simplest **locality** descriptions consist of only a named place, or more generally, a **feature**, which is often listed in a standard **gazetteer** and can probably be located on a map of the appropriate scale.

Despite how they might be presented in a **gazetteer** or on a map, **features** are not points; they are areas that have a spatial **extent**. Some **features** can have an obvious spatial **extent**, while others may not. All variations of **features** are treated in this *Guide* as special cases of these two main categories. The important thing is to try to capture the information that describes the location of the **feature**, its center and a measure of how specific the **feature** is (defined here by the **geographic radial**).

NOTE: **Coordinates** from geographic indexes such as **gazetteers** often use reference points that are not necessarily in the center of the **feature**. For example, a river may be referenced by its mouth, and a town by its main post office, courthouse, or main plaza. It is best to use a visual reference to determine **boundaries**, **extents**, centers, and **radials**. For this reason, it is a good idea to use the **gazetteer coordinates** to find the **feature** on a map, and then use the map to find the **boundaries** and **corrected center** of the **feature**.

a. Feature - with an obvious spatial extent

The **locality** refers to a geographic **feature** with discernible spatial **extent**, *i.e.*, the **boundaries** of the **feature** can be determined easily (Figure 2).

Examples: see Table 1

Locality Type: "Geographic feature only"

Feature boundary: Delimit the feature **boundaries**, typically by drawing a polygon around it (Figure 2A). Note: **boundaries** may change over time, so it is important to record the source used to determine them and the date of issue (*e.g.*, if using a printed map).

Coordinates: Use the **coordinates** of the **corrected center** of the **feature** ("a" in Figure 2B).

Geographic radial: Measure the distance from the **corrected center** to the furthest point within the **feature** ("b" in Figure 2B).

Additional parameters: Coordinate Source, Coordinate Format, Datum, Coordinate Precision, Radial of Feature, GPS Accuracy/Masurement Error, and Distance Units (see

<<1.6 Georeferencing Concepts>>).

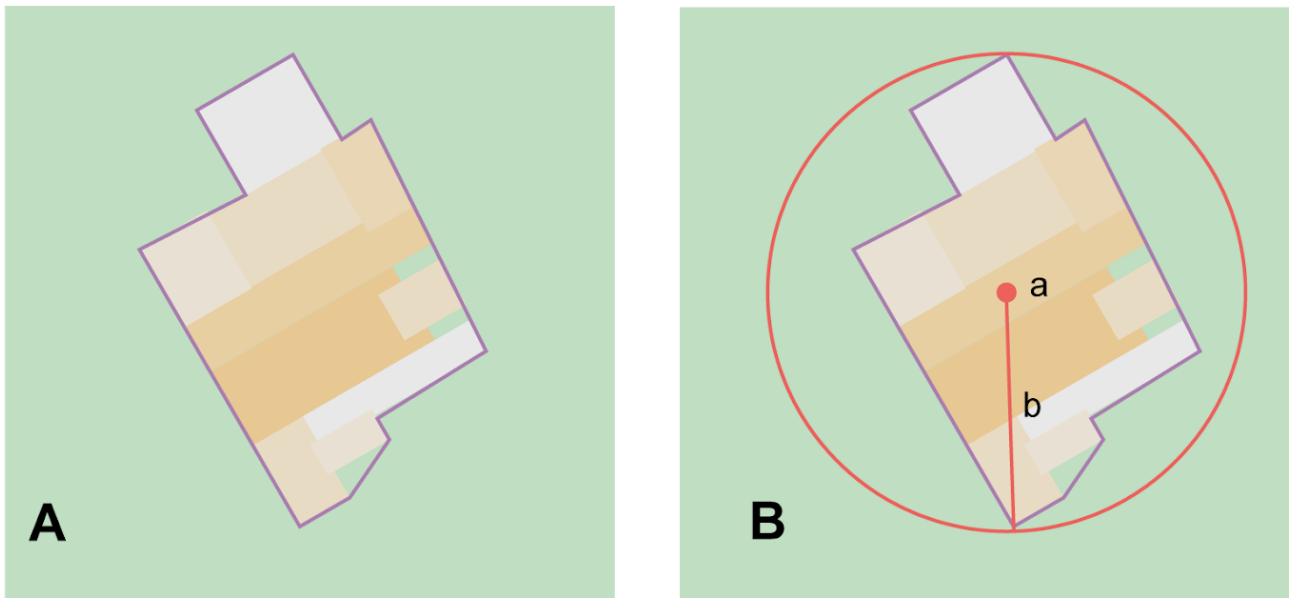


Figure 2. A. Boundary only, and B. boundary, center (a) and geographic radial (b) of a feature with obvious spatial extent. The circle is the smallest that contains the entire feature. The center (a) falls within the boundaries and thus needs no correction.

b. Feature - without an obvious spatial extent

Locality refers to a geographic feature that does not have an easily discernible spatial boundary. Some features may have indistinct boundaries (e.g., mountains, unincorporated towns, etc.). Other features may only have a label with no apparent boundaries or size on a map (Figure 3C), or might only have coordinates from a gazetteer, usually because they are small or obscured on satellite imagery (e.g., a spring, monument, etc.).

Examples: see Table 1

Locality Type: "Geographic feature only"

Feature boundary: Determine the boundaries of the feature as well as possible using visible evidence for the feature on a map. As a georeferencer, try to get into the mind of the person who recorded the locality. Imagine yourself there. What circumstances influenced the recorded choice and what circumstances would have encouraged them to choose a different feature?

For large features it should be possible to circumnavigate the feature (e.g., a mountain, Figure 3) on the map. Some questions to ask yourself as a georeferencer, "Would I

describe this area as the mountain or would I describe it differently?" The **boundaries** of a mountain may be laborious to determine, but terrain indicators that separate one mountain from another (valleys and saddles) can be useful to help clarify the boundary of one mountain from another. The **boundaries** between towns without obvious borders can be thought of similarly. A georeferencer can use the presence of buildings near the **coordinates** of the town to decide where a town ends or the location of the **boundary** between towns. Other cases might not have such indicators and will require more subjective judgment. For this reason it is particularly important to document the rationale, including how decisions were made, for the selection of the **locality** with unclear **boundaries**.

A reasonable criterion to use in the absence of clearer indicators is half the distance between **coordinates** given for the **feature** and for other similar **features** (or **features** of similar relative importance, or similar geographic size) in all directions, the reasoning being that otherwise they would have chosen one of the other **features** as a reference instead. Using this criterion will suggest a rough **boundary** (Figure 3A). Though this rough **boundary** may not represent the actual **feature** very well, it will represent the **uncertainty** of where the locality is, and that is the goal of the **georeference**.

For small **features**, where the only indicator on a map is a label and possibly a marker, or where all you have are **coordinates** from a **gazetteer** (and no indicator at those **coordinates** on a map), a good strategy would be to use a predefined default size based on the **feature type** (Table 2).

Always use **georeferenceRemarks** to document the decisions made, and the reasons for them, as well as possible, including the neighboring **features** used for reference.

Coordinates: Once the **boundary** has been determined, proceed as for <<1.1 Feature - with an obvious spatial extent>> and use the **coordinates** of the **corrected center** (Figure 3B).

Geographic radial: Once the rough **boundary** and the coordinates of the **corrected center** have been determined, use the same method to determine the **geographic radial** as for <<1.1 Feature - with an obvious spatial extent>> and measure the distance from the **corrected center** to the furthest point within the **feature**.

Additional parameters: Coordinate Source, Coordinate Format, Datum, Coordinate Precision, Radial of Feature, GPS Accuracy/Measurement Error, Distance Units (see <<1.6 Georeferencing Concepts>>).

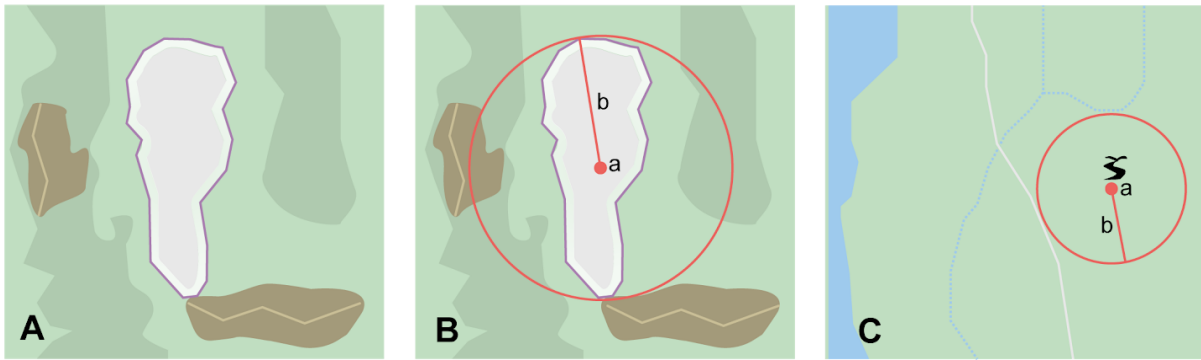


Figure 3. **A.** rough **boundary** of a mountain (**feature** without obvious **spatial extent**) with the mountains and other neighboring features that were used to define that rough boundary. **B.** The **corrected center** (a) and **geographic radial** (b) of the mountain based on the uncertain boundary. **C:** A **boundary** for a spring determined from the location of its icon on a map (a) and a geographic radial (b) determined by a default size for the feature type in the absence of any other size information.

c. Feature - Special cases

The following are special cases of **features** that might or might not have an obvious **spatial extent**, depending on the completeness of the information available.

i. Feature - Street Address

The **locality** is a street address – usually with a number, a street name, and an administrative **feature** name.

Examples: see Table 1

Feature boundary: Locate the address using sites such as [Google Maps](#)[™], [Mapquest](#)[™] or [OpenStreetMap](#).

Address **extent** evident - if the map shows the **extent** of the address clearly, determine the **boundary** exactly as you would for a **feature** with an obvious **spatial extent** (Figure 4A; see <<1.1 Feature - with an obvious spatial extent>>).

Address **extent** not evident - if the exact address cannot be found, estimate the **boundary** as well as possible, such as the block that it must be on (Figure 4B), as for <<1.2 Feature - without an obvious spatial extent>>. Many addresses reflect a **grid** system of labeling addresses. For instance, addresses between 12th Street and 13th Street would lie between 1200 and 1300. Be aware, however, that street names and address numbering can change over time.

Coordinates and geographic radial: Once the **boundary** has been determined, use the

same method to determine the **coordinates** and **geographic radial** as for <<1.1 Feature - with an obvious spatial extent>>, namely, measure the distance from the **coordinates** of the **corrected center** to the furthest point within the **feature**.

Additional parameters: Coordinate Source, Coordinate Format, Datum, Coordinate Precision, Radial of Feature, GPS Accuracy/Measurement Error, Distance Units (see <<1.6 Georeferencing Concepts>>).

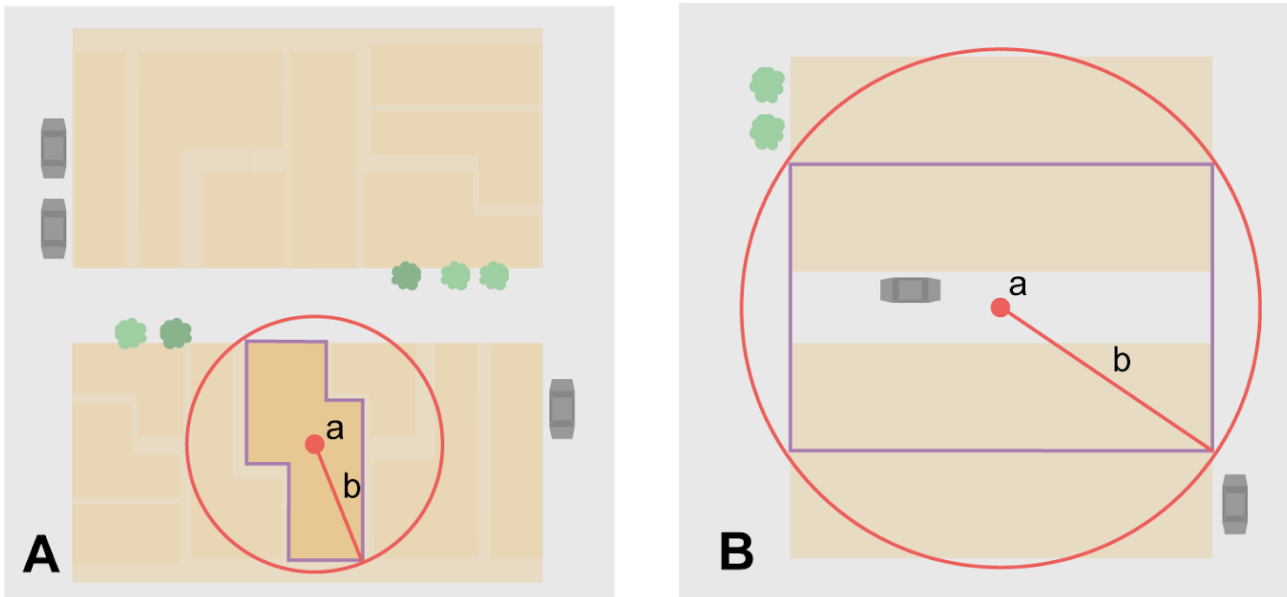


Figure 4. Boundary, corrected center (a) and geographic radial (b) of a street address, A: with evident extent; B: with no evident extent, and where it is not possible to tell from the source map whether the location is on one side or the other of the street.

ii. Feature - Property

The **locality** is a property - a ranch, rancho, station, farm, finca, grange, granja, estância, plantation, hacienda, fazenda, manor, holding, estate, spread, acreage, orchard, steading, etc.

Examples: see Table 1

Feature boundary: Locate the property using whatever sources you can. You may have to resort to a **cadastral map**.

Property **extent** evident - if the map shows the **extent** of the property, determine the **boundary** exactly as you would for a **feature** with an obvious spatial **extent** (see <<1.1 Feature - with an obvious spatial extent>>).

Property **extent** not evident - if the full **extent** of the property cannot be found, it should

still be possible to determine some part of it confidently, and the rest with less certainty. Delimit the outer, uncertain feature **boundaries** as usual by following <<1.2 Feature - without an obvious spatial extent>>. In addition, determine the **boundaries** of the part of the property that is clearly evident following <<1.1 Feature - with an obvious spatial extent>>.

For example, there might be a label for the property on a map, but no **boundaries**. On a satellite image in Google Maps™ a conglomeration of buildings is visible where the label is and an entry road to them from a main road passing by. On the opposite side of the buildings from the main road is a similar arrangement, with no road connecting the two, suggesting another property. In between them it is not clear which fields belong to which property. There might be similar patterns in other directions as well. It would seem clear that one **boundary** is along the main road, and another contains the buildings at the end of the entrance road. Beyond that, the **boundaries** are not evident, but lie somewhere between pairs of conglomerations of buildings.

Coordinates and geographic radial:

Property **extent** evident - once the **boundary** is determined, determine the **coordinates** and **geographic radial** as for <<1.1 Feature - with an obvious spatial extent>>, namely, measure the distance from the **coordinates** of the **corrected center** to the furthest point within the **feature** (Figure 5A).

Property **extent** not evident - once the outer **boundaries** are determined, use them to find **coordinates** as for <<1.1 Feature - with an obvious spatial extent>>, namely find the center of the smallest circle containing the outer, uncertain boundary. If that center falls within the inner, confident boundary, use it to determine the **geographic radial** by finding the distance from that point to the furthest point on the uncertain **boundary** (Figure 5B). If the center does not fall in or on the confident inner **boundary**, let the **corrected center** be a point on the inner confident **boundary** that minimizes the **geographic radial** to the outer uncertain **boundary** (Figure 5C).

Additional parameters: Coordinate Source, Coordinate Format, Datum, Coordinate Precision, Radial of Feature, GPS Accuracy/Measurement Error, Distance Units (see <<1.6 Georeferencing Concepts>>).

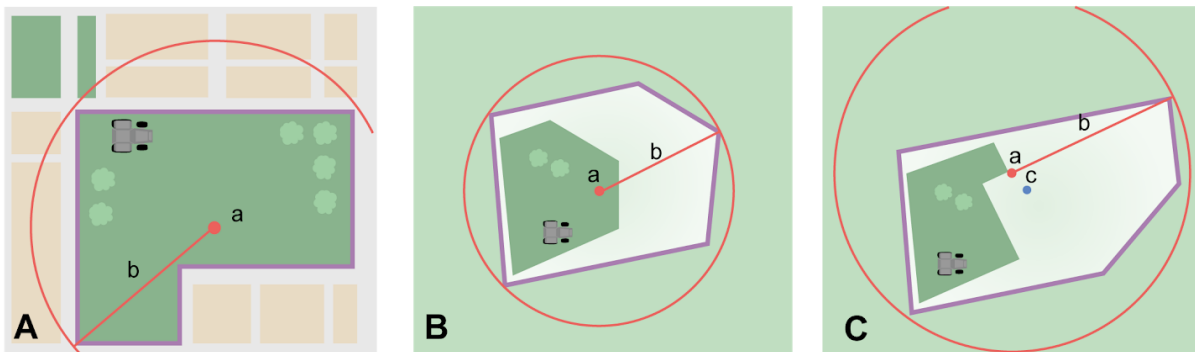


Figure 5. Boundary, corrected center (a) and geographic radial (b) of a property. A: with evident extent; B: with a rough outer boundary and an evident inner boundary, where the center of the outer boundary falls within the evident boundary; C: with a rough outer boundary and an evident inner boundary, where the center of the outer boundary (c) does not fall within the evident boundary.

iii. Feature - Path

A **path** is a linear **feature** such as a road, trail, river, stream, contour line, **boundary**, **transect**, track of an animal's movements, marine **transect**, tow, trawl, etc. The **locality** may also refer to part (or subdivision) of a bigger **path**. Note: a **path** may cross over itself, such as the track of an animal's movements.

Examples: see Table 1

Feature boundary: As a linear **feature**, a **path** is often represented as a series of line segments (*i.e.*, a polyline), with or without a buffer. When viewed on satellite imagery these **features** (especially rivers) can be quite complex, so a constant buffer around the midline is not always a good representation in these cases. When possible, determine the **boundary** as for any other shape using <<1.1 Feature - with an obvious spatial extent>>) (Figure 6A). Otherwise, treat the **boundary** as a polyline (Figure 6B) and determine the **corrected center** and **geographic radial** as explained below.

Note: **Paths** are susceptible to change over time, so it may be best to find a map source from the period during which the **event** occurred. The scale is important when looking at a **path** on a map, as smaller scale maps reduce the complexity shown, with corners cut off, and with loops (oxbows, billabongs), etc. often not shown.

Contour Lines — these are linear features defined by **elevation** or **depth**. The horizontal width of the buffer around the contour line depends on the **uncertainty** in **elevation** due either to an elevational range, or due to the imprecision in the **elevation** recorded. For example, if the elevational range is given as 100-200 m, then the **boundary** of the

feature defined by the contours would contain the horizontal area between the contours at 100 m and 200 m.

The determination of the **boundary** would be similar for an elevational buffer defined by the **uncertainty in elevation**. For example, if the **elevation** is given as 220 m, the elevational precision would be to the nearest 10 m and the **boundary** would be defined by the contours 210 m and 230 m. Note: Buffers might require interpolation on a topographic map if they do not correspond with the printed contour lines (Figure 6C).

These considerations apply equally to **depth** and bathymetry.

Coordinates and geographic radial: If the **extent** and **boundary** as a shape can be determined, treat as for <<1.1 Feature - with an obvious spatial extent>> and measure the distance from the **coordinates** of the **corrected center** to the furthest point within the **feature** (Figure 6A). If the **feature** must be treated as a polyline, draw a straight line connecting the ends of the polyline and determine its midpoint. If the midpoint falls on the polyline, that will be the center (no need for correction), and the **geographic radial** will just be the distance from that point to either of the endpoints of the polyline. If the midpoint does not fall on the polyline, move it to the point on the polyline that minimizes the distance to both endpoints. This is the **corrected center** and the distance to the endpoints is the **geographic radial** (Figure 6B).

Additional parameters: Coordinate Source, Coordinate Format, Datum, Coordinate Precision, Radial of Feature, GPS Accuracy/Measurement Error, Distance Units (see <<1.6 Georeferencing Concepts>>).

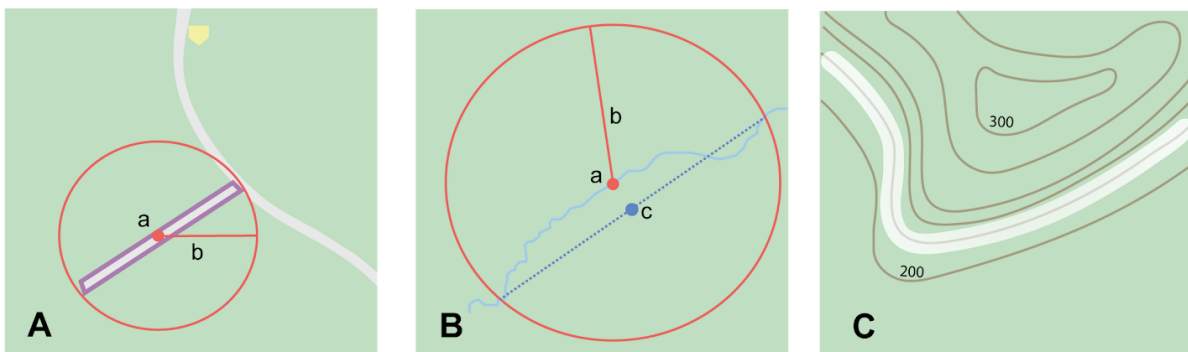


Figure 6. Corrected center (a) and geographic radial for a path: A. treated as a shape, showing its **boundary**; **B.** treated as a polyline, showing the midpoint (c) between the ends of the **path**. **C.** a section of a contour line, in this case an isohypse of 220 m with an elevational uncertainty of 10 m.

iv. Feature - Junction, Intersection, Crossing, Confluence

The **locality** is the junction of two or more **paths** - roads, a road and a river, the mouth

of a river (*i.e.*, where it meets a larger water body), a road or river and an administrative boundary (*e.g.*, of a park), a road and a contour line, etc.

Examples: see Table 1

Feature boundary: Determine the boundary of the junction to find the names and routes of highways, roads, and rivers using resources such as [Google Maps™](#), [Mapquest®](#) or [OpenStreetMap](#), road atlases, GPS Navigators, satellite or aerial images (Figure 7A). Most modern spatial data can be used to determine the actual boundaries. If the only available representation of the junction shows the adjoining paths as lines, then the **boundary** must be determined as for <<1.2 Feature - without an obvious spatial extent>>.

Coordinates and geographic radial: Once the **boundary** has been determined, use the same method to determine the **coordinates** and **geographic radial** as for <<1.1 Feature - with an obvious spatial extent>> and measure the distance from the **coordinates** of the **corrected center** to the furthest point within the **feature** (Figure 7B).

Additional parameters: Coordinate Source, Coordinate Format, Datum, Coordinate Precision, Radial of Feature, GPS Accuracy/Measurement Error, Distance Units (see <<1.6 Georeferencing Concepts>>).



Figure 7. A. Intersection of a road and a stream with details of **boundary**, **corrected center** (a) (with no need for correction) and **geographic radial** (b) of the intersection. **B.** River mouth, *i.e.*, where it meets a larger water body, its **boundary**, **corrected center** (a) and **geographic radial** (b).

v. Feature - Cave

The **locality** is a cave, an underground mine, a tunnel, etc. For details of how to record a **locality** within a cave, see the section on <<2.12 Recording Data in Caves>> in *Georeferencing Best Practices*.

Examples: see Table 1

Feature boundary: Locate the cave and/or its main entrance.

Cave **extent** evident - if a map of all the interior of the cave with measurements and orientation to the surface is available, or if a position can be determined directly above the **location** inside the cave using a **ground zero** concept (see *Georeferencing Best Practices* Chapman & Wieczorek 2020), determine the **boundary** as if it is a **feature** with an obvious spatial **extent** (Figure 8A; see <<1.1 Feature - with an obvious spatial extent>>).

Cave **extent** not evident - if the limits of the cave are not evident: a) use the nearest identifiable feature to determine the **extent** and **boundary** of the cave, as for <<1.2 Feature - without an obvious spatial extent>> (Figure 8B); or b) determine the **coordinates** of the cave entrance and use any evidence of the size of the cave to circumscribe the **boundary** as a circle around the entrance with a radius commensurate with its size (Figure 8C). Document accordingly.

Coordinates and geographic radial: Once the **boundary** has been determined, use the same method to determine the **coordinates** and **geographic radial** as for <<1.1 Feature - with an obvious spatial extent>> and measure the distance from the **coordinates** of the **corrected center** to the furthest point within the **feature**.

Additional parameters: Coordinate Source, Coordinate Format, Datum, Coordinate Precision, Radial of Feature, GPS Accuracy/Measurement Error, Distance Units (see <<1.6 Georeferencing Concepts>>).

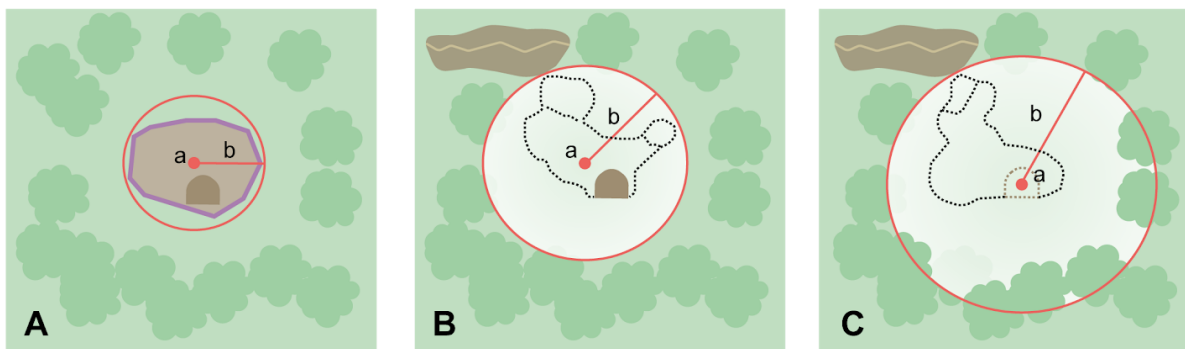


Figure 8. Boundary, corrected center (a) and geographic radial (b) of a cave. A: cave **extent** known and projected onto the surface. **B:** cave **extent** not known, but inferred from other evidence. **C:** cave **extent** not known, but maximum horizontal length known and measured from the entrance.

vi. Feature - Dive location

The **locality** is a diving site (marine or freshwater). Commonly recorded using the

geographic coordinates of the point on the surface where the diver entered the water (*i.e.*, **entry point**).

Examples: see Table 1

Feature boundary: Locate the **extent** of the dive as a 3D-shape, which should be projected perpendicularly onto the water surface. Determine the **boundary** of that projection in the horizontal plane (*i.e.*, the **geographic boundary**). See Figure 9.

Dive **extent** evident - underwater **locations** are often recorded as a distance, direction and water **depth** from the **entry point**. Below the surface there may be a “trajectory” with a three dimensional aspect that includes a horizontal component and a minimum and maximum water **depth**. Use these to circumscribe the **boundary** on the surface (Figure 9A). See <<*e. Three Dimensional Shapes*>> in *Georeferencing Best Practices*.

Dive **extent** not evident - if the limits of the dive are not evident, there is no trajectory, and no distance or direction from the entry point, use a reasonable upper limit for the distance the diver might have been able to cover in a straight line from and back to the **entry point**. This could vary greatly depending on the diver, the equipment, the depth reached, etc. Use any evidence of the length of the dive to circumscribe the **boundary** as a circle around the **entry point** with a radius commensurate with that length (Figure 9B).

Coordinates and geographic radial: Treat as for <<*1.1 Feature - with an obvious spatial extent*>> and measure the distance from the **coordinates** of the **corrected center** to the furthest point within the **feature**.

Additional parameters: Coordinate Source, Coordinate Format, Datum, Coordinate Precision, Radial of Feature, GPS Accuracy/Masurement Error, Distance Units (see <<*1.6 Georeferencing Concepts*>>).

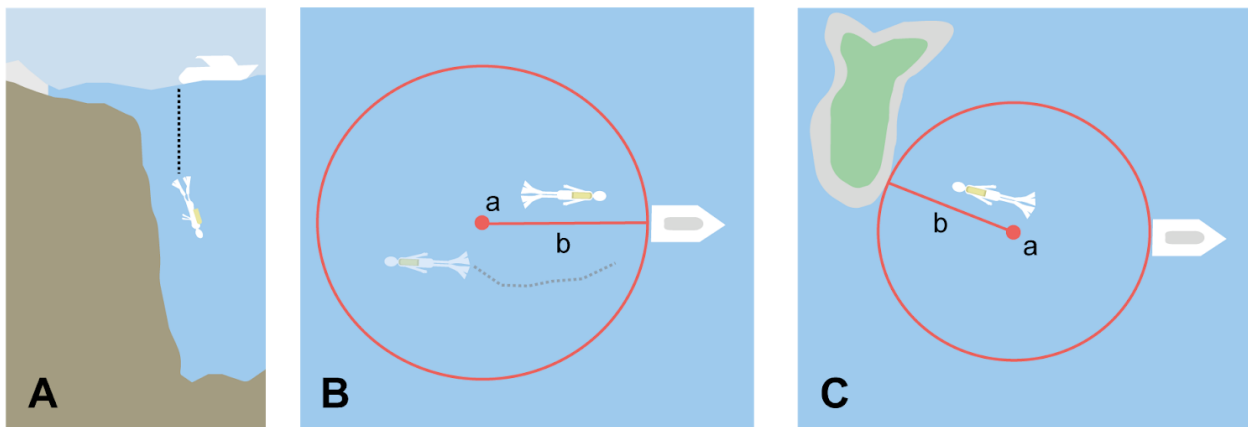


Figure 9. Boundary, corrected center (a) and geographic radial (b) of a dive

location. A: side view of a dive with **extent** evident **B:** top view of a dive **location** with evident **extent**, projected onto the surface. **C:** top view of a dive location with **extent** not evident, but inferred from other evidence.

vii. Feature - Headwaters of a waterway

The headwater of a waterway is the farthest place upstream in a drainage basin from the mouth (also called "the source") from which water flows. The location of the source may not be evident because the source is a small stream not indicated on a map. In these cases it may be possible to find the headwater of a river by using a published watershed map. If not, then follow the waterway upstream on a terrain map for as long as the map indicates that there is water flow to find the source.

Examples: see Table 1

Feature boundary: When the position of a headwater is well known, the feature is essentially just a point. If the position is not well known, then treat as <<1.1 Feature - with an obvious spatial extent>>. If the headwater issues from a stationary waterbody such as a spring or lake, the feature is a line segment or polyline across the area where the water flows out of the stationary waterbody. In the latter case, treat the boundary as for a path (see <<1.3f Feature - Path>>), albeit a short one, as it is transverse to the flow of the waterway (Figure 10).

Coordinates and geographic radial: If the headwaters is known, use the coordinates of that point and use a minimal value (*e.g.*, "determine the smallest area around where the stream arises - if the headwater is where the stream is 1 meter wide, then use 1 meter") for the geographic radial. If it is not well known, use the criteria for <<1.1 Feature - with an obvious spatial extent>>. If the headwater issues from a stationary waterbody, use the **boundary that was** determined and treat as for <<1.1 Feature - with an obvious spatial extent>> and measure the distance from the **coordinates** of the **corrected center** to the furthest point within the **boundary**.

Additional parameters: Coordinate Source, Coordinate Format, Datum, Coordinate Precision, Radial of Feature, GPS Accuracy/Measurement Error, Distance Units (see <<1.6 Georeferencing Concepts>>).

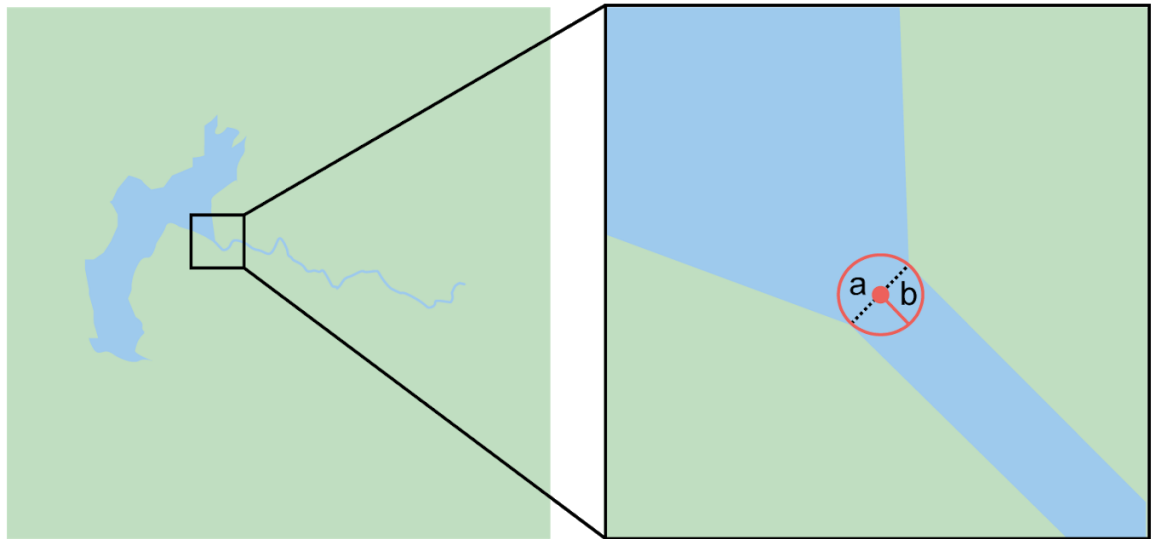


Figure 10. Overview of a headwater issuing from a stationary waterbody (in this case a lake). Detail of **corrected center** (a) and **geographic radial** (b).

viii. Feature - Near a Feature

The **locality** is given with a proximity to a **feature**, usually written as “near”, “in the vicinity of”, or “adjacent to” in relation to a cited **feature**, without any particular **heading** or distance from the feature. “Off” of a locality, often seen in marine locations, is included here, but in this case there is at least one constraint imposed by the shore.

Examples: see Table 1

Feature boundary: First determine the **boundary** of the feature itself based on whatever the feature type is, either as <<1.1 Feature - with an obvious spatial extent>>, or as <<1.2 Feature - without an obvious spatial extent>>. Then, to account for the proximity indicator, extend that **boundary** outward for a fixed distance in all directions (Figure 11A). Call this the “extended feature”. If the extension overlaps any similar extension of other similar **feature** modify the **boundary** in the shared space to be half the distance between the nearest boundaries between the two features (Figure 11 B).

Note: Neighboring features were not necessarily there at the time the locality was recorded, nor were they necessarily the same size. The feature of interest may have changed size in the time between the recording of the locality and the time when the map you use was made. These considerations add to the vagaries associated with this type of **locality** and underline the importance to never describe localities in this way.

Note: The buffer distance for the extension is arbitrary - it is hard to defend any given value as a default. Make a judgement and imagine what the person who recorded the locality meant. Always document the rationale and decisions made. Remember, one

goal of a georeference is that it is repeatable.

Coordinates and geographic radial: Once the **boundary** of the “extended” feature has been determined, treat as for <<1.1 Feature - with an obvious spatial extent>> and measure the distance from the **coordinates** of the **corrected center** to the furthest point within the extended **feature**.

Additional parameters: Coordinate Source, Coordinate Format, Datum, Coordinate Precision, Radial of Feature, GPS Accuracy/Measurement Error, Distance Units (see <<1.6 Georeferencing Concepts>>).

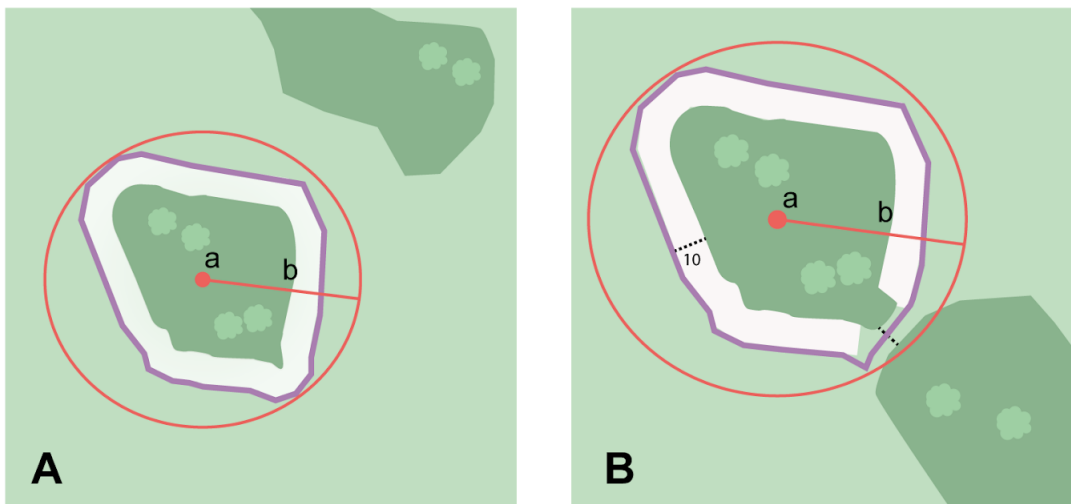


Figure 11. Boundary, corrected center (a) and geographic radial (b) of an interpretation of "Near a feature" with a boundary extended a fixed distance in all directions, in this case 10 km (a). A: Boundary extended a fixed distance in all directions with no neighboring conflicts. B: Boundary extended a fixed distance in all directions except in the area overlapping a similar feature, where it extends half the distance to the neighboring feature.

ix. Feature - Between two Features

The **locality** description uses the pattern “between A and B”, where A and B are two distinct **features**.

Examples: see Table 1

Feature boundaries: Determine the **boundaries** of each **feature** as <<1.1 Feature - with an obvious spatial extent>> or <<1.2 Feature - without an obvious spatial extent>> (Figure 12 A).

Coordinates: Once you have determined the **boundaries** of the two **features**, find their **corrected centers**, as for <<1.1 Feature - with an obvious spatial extent>>. Use the midpoint between the **corrected centers** of the two **features** (Figure 12B) to determine

the **coordinates** of the **location** between the **features**.

Geographic radial: The **geographic radial** of the **location** between the two **features** is half the distance between the **corrected centers** of the **features** (Figure 12B).

Additional parameters: Coordinate Source, Coordinate Format, Datum, Coordinate Precision, Radial of Feature, GPS Accuracy/Measurement Error, Distance Units (see <<1.6 Georeferencing Concepts>>).

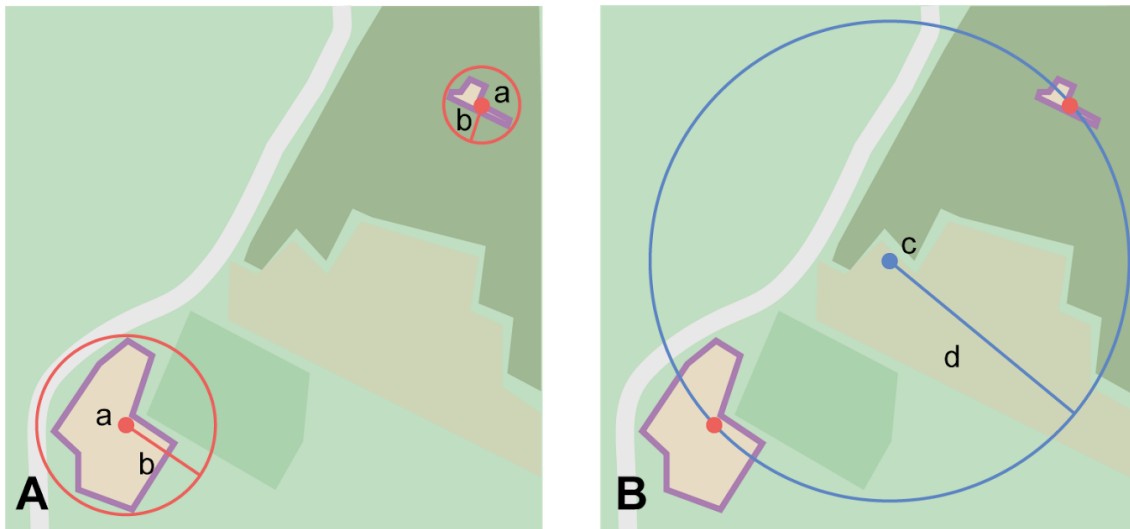


Figure 12. A. Boundary, corrected center (a) and geographic radial (b) of two features. B. Coordinates (c) and geographic radial (d) of the interpretation of "between two features".

x. Feature - Between two Paths

The **locality** describes a **location** between two **paths** (two roads, two rivers, a road and a river, etc.).

Examples: see Table 1

Locality Type: "Geographic feature only"

Feature boundary: Create a **boundary** that includes the two **paths** and any other boundaries that terminate those paths (*e.g.*, the location is known to be within a given administrative division) (see Figure 13A). Note: **Paths** may cross each other one or more times, with the area between switching from one side of each **path** to the other, resulting in a **boundary** consisting of multiple polygons (Figure 13B).

Coordinates and geographic radial: Once the boundary has been determined, obtain the **coordinates** and the **geographic radial** as for <<1.1 Feature - with an obvious spatial extent>> and measure the distance from the **coordinates** of the **corrected center** to the furthest point within the **feature**.

Additional parameters: Coordinate Source, Coordinate Format, Datum, Coordinate Precision, Radial of Feature, GPS Accuracy/Measurement Error, Distance Units (see <<1.6 Georeferencing Concepts>>).



Figure 13. Boundary, corrected center (a) and geographic radial (b) for a location between two paths (i and ii), that A: do not cross; B: cross each other multiple times, with location restricted by an administrative boundary (dashed line).

2.2 Offsets

Definition: An **offset** is a displacement from a reference **location**. Usually used in conjunction with **heading** to give a distance and direction from a **feature** (see <<2.9 Offsets>> and <<3.4g Uncertainty Due to Offset Precision>> in *Georeferencing Best Practices*). There are a variety of ways in which offsets interact with **features** and **headings** in **locality** descriptions, each with its own methods of spatial interpretation.

In all cases, the **coordinates** and **geographic radial** of the reference **feature** are needed for the **point-radius georeferencing** using the *Georeferencing Calculator*, so this section on **Offsets** will refer repeatedly to **features** as determined by the methods presented in the various sections of <<1. Geographic feature only>>.

The **locality types** that involve **offsets**, in addition to the one we have already seen above (<<1.3h Feature - Near a Feature>>), are:

- distance only (e.g., "5 mi from Bakersfield")
- **heading** only (e.g., "North of Bakersfield")
- distance along a **path** (e.g., "13 miles east (by road) from Bakersfield")
- distance along orthogonal directions (e.g., "2 miles east and 3 miles north of Bakersfield")
- distance at a **heading** (e.g., "10 miles east (by air) from Bakersfield")

- distances from two distinct **paths** (e.g., "1.5 mile east of Louisiana State Highway 1026 and 2 miles south of U.S. Highway 190")

a. *Offset - Distance only*

Locality consists of an offset from a **feature** without any direction specified.

Examples: see Table 1

Locality Type: "Distance only"

Feature boundary: Determine the **boundary** of the feature as you would for <<2.1c.viii *Feature - Near a Feature*>>, except that the distance to use for the buffer is the distance given in the **locality** description, and there is no need to account for the proximity of other **features**.

Coordinates and geographic radial: Once the boundary has been determined, obtain the **coordinates** and the **geographic radial** as for <<1.1 *Feature - with an obvious spatial extent*>>, namely, measure the distance from the **coordinates** of the **corrected center** to the furthest point within the **feature**.

Offset Distance: Set to 0. The distance has already been incorporated in the determination of the boundary. Use the distance and units given in the locality description to georeference using the *Georeferencing Calculator*.

Distance Precision: Though the Offset distance is set to zero, the Distance Precision should still be set (see <<1.6m *Distance Precision*>>) to account for this source of uncertainty.

Additional parameters: Coordinate source, Coordinate format, Datum, Coordinate Precision, Measurement error, Distance Units (see <<1.6 *Georeferencing Concepts*>>).

b. *Offset - Heading only*

The **locality** consists of a direction from a **feature** without any distance specified. Note that seldom is such information given alone; there is usually some supporting information. For example, the **locality** may have higher-level geographic information such as 'East of Albuquerque, Bernalillo County, New Mexico'. This provides a stopping point (the county border), and should allow you to **georeference** the **locality**. Alternatively, there might be another similar **feature** in the **heading** given that can constrain the **offset**.

Examples: see Table 1

Locality Type: "Geographic feature only"

Feature boundary: First determine the **boundary** of the **feature** itself based on whatever the **feature** type is, either as for <<1.1 *Feature - with an obvious spatial extent*>>, or as

for <<1.2 Feature - without an obvious spatial extent>>. Then, to account for the **offset** at a **heading**, extend that **boundary** outward in a cone defined by the **heading uncertainty** (see <<3.4f Uncertainty Related to Heading>> in *Georeferencing Best Practices*) until reaching a constraining **boundary** imposed by other information in the **locality** record, or until reaching the proximity of another similar **feature**, whichever is nearer the original **feature** (Figure 14A). Call this the "extended **feature**". If the extension impinges on any similar extension of another similar **feature** in cone of the specified **heading**, modify the **boundary** in the shared space to be half the distance between the nearest **boundaries** between the two **features** (Figure 14B). For example, "N Palmetto" could mean "northern part of Palmetto" or "North of Palmetto". Since we have no way of knowing which was intended, we choose the latter interpretation, which is more inclusive and will entirely contain the less inclusive interpretation. Use the rules for **heading uncertainty** to determine angle within which to find the nearest similar **feature**. For example, for "N Palmetto" look for a named place somewhere between NE and NW of Palmetto. For more details and options for **georeferencing** such **locations**, see the Section on <<2.9.b Offset Direction Only>> in *Georeferencing Best Practices*.

Coordinates and geographic radial: Once you have determined the **boundary** of the "extended" **feature**, treat as for <<1.1 Feature - with an obvious spatial extent>>, namely, measure the distance from the **coordinates** of the **corrected center** to the furthest point within the extended **feature**.

Additional parameters: Coordinate Source, Coordinate Format, Datum, Coordinate Precision, Radial of Feature, GPS Accuracy/Measurement Error, Distance Units (see <<1.6 Georeferencing Concepts>>).

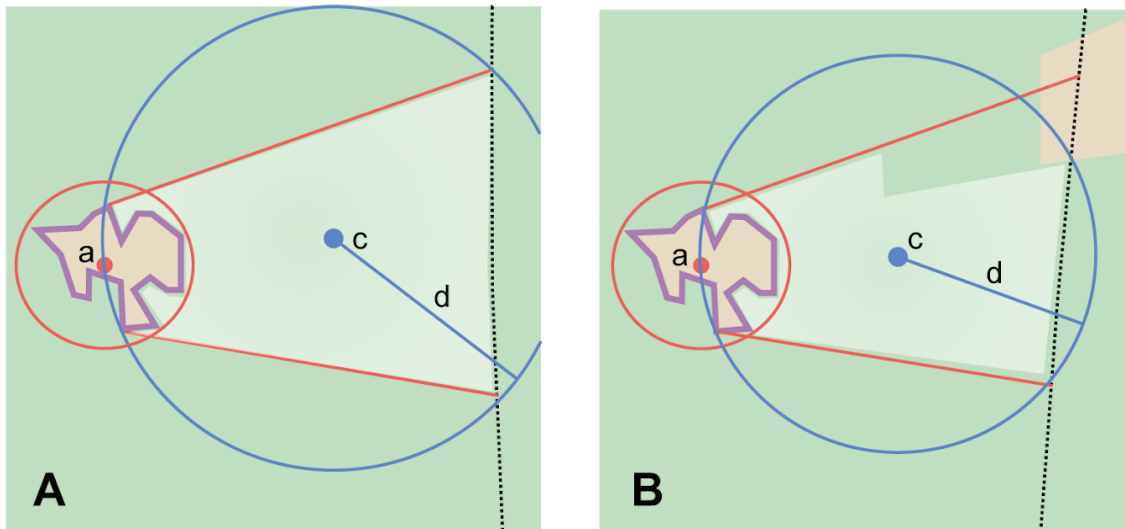


Figure 14. A locality "East of" a feature, but bound by an administrative border (dotted line). **A: Boundary** and **corrected center** (a) of starting feature. Cone to the east forms part of the new boundary with center (c) and **geographic radial** (d). **B:** Similar to A, but with an intervening feature to the northeast before the border.

c. *Offset - Distance along a Path*

The **locality** consists of a reference **feature** to start from and a distance to travel along a **path** from there. Most of the time there will be just one **path** that matches the description and it will not be very wide compared to the reference feature, such as a highway out of a town. In these cases the georeferencing method is relatively simple (see <<2.2c.i *Offset along a narrow path*>>). On occasion a path might be comparable in width to the reference feature, or there might be multiple possible paths matching the locality description. The method for dealing with these scenarios is much more complicated (see <<2.2c.ii *Offset along a wide or multiple possible paths*>>). Either way, the end product will cover a segment of the path or possible **paths** that includes all the sources of **uncertainty**. See also the discussion of special concerns about **paths** in the "Feature boundary" entry in <<2.1c.iii *Feature - Path*>>. Though there might be a **heading** mentioned in the **locality** description, it serves only to constrain which **path** or **paths** are possible, and does not contribute **uncertainty** due to **heading precision**.

Note: The more accumulated curvature there is in the **path**, the more important it is to measure carefully (and therefore use a map of appropriate scale or zoom), otherwise there will be an accumulated **error** in the position of the **offset**.

i. Offset along a narrow path

Examples: see Table 1

Locality Type: "Distance along path"

Feature boundary: Find the **boundary** of the intersection of the reference **feature** with the **path** as you would for <<2.1c.iii *Feature - Junction, Intersection, Crossing, Confluence*>>.

Feature coordinates and geographic radial: Once the **boundary** of the starting **feature** has been determined, use the same method to determine the **corrected center** and **geographic radial** as for <<1.1 *Feature - with an obvious spatial extent*>>, namely, measure the distance from the **coordinates** of the **corrected center** to the furthest point within the starting **feature**. Enter the length of the **geographic radial** in "Radial of Feature" in the *Calculator*.

Input Latitude and Input Longitude: Enter the **coordinates** of the **offset** position, which can be determined by measuring the length along the midline of the **path** from the **corrected center** of the starting **feature** to the distance given in the **locality** description.

Additional parameters: Coordinate Source, Coordinate Format, Datum, Coordinate Precision, Radial of Feature, Measurement Error, Distance Units, Distance Precision (see <<1.6 *Georeferencing Concepts*>>).

ii. Offset along a wide or multiple paths

Examples: see Table 1

Locality Type: "Geographic feature only" (not "Distance along path")

Starting feature boundary: Find the center of the intersection of the reference **feature** with the **path** as you would for <<2.1c.iii *Feature - Junction, Intersection, Crossing, Confluence*>> (see Figure 15A).

Starting feature coordinates and geographic radial: Once the **boundary** of the starting **feature** has been determined, use the same method to determine the **corrected center** and **geographic radial** as for <<1.1 *Feature - with an obvious spatial extent*>>, namely, measure the distance from the **coordinates** of the **corrected center** to the furthest point within the starting **feature**.

Offset reference points: In order to determine the **boundary** of the segment of the **path** or possible paths that matches the **locality** description, four (two pairs of) reference points will need to be determined (Figure 15).

One pair of reference points are start and end points along one of the outer edges of the

path or possible **paths** and the other pair are start and end points along the opposite outer edge of the **path** or possible **paths**. To find the start point for a given outer edge, on a printed or digital map, measure the length along the outer edge of the **path** or possible **paths** from the **corrected center** of the starting **feature** to the distance given in the **locality** description minus half the **uncertainty** due to **distance precision** (see <<3.4f *Uncertainty Related to Offset Precision*>> in *Georeferencing Best Practices*), minus half the **geographic radial** of the starting **feature**. To find the end point for the same outer edge, measure along that outer edge from the start point on that edge for a distance equal to the **uncertainty** due to **offset precision** plus the **geographic radial** of the starting **feature**. Overall this should give you a boundary on the edge of the **path** with a length equal to the **geographic radial** of the starting feature plus the **uncertainty** due to **offset precision**, and centered on the **offset** along the same edge from the at a distance equal to the **offset** distance from the stating **feature**.

Do the same along the opposite outer edge to get the other two start and end points. If the starting feature does not intersect the opposite edge of the **path** (e.g., if the starting feature is on one bank of a large river), then use a starting point on the opposite edge of the path at the same **elevation** as the corrected center of the starting **feature**. The reason to use the same **elevation** is that, on a river, a higher or lower elevation is upstream or downstream, respectively.

Path segment boundary: Determine the end of **path** boundary by connecting the segment between the two starting points described above to the segments along the outer edges to the end points and to the segment between the two end points (Figure 15B).

Path segment coordinates and geographic radial: Once you have determined the **boundary** of the **path** segment, treat as for <<1.1 *Feature - with an obvious spatial extent*>>, namely, measure the distance from the **coordinates** of the **corrected center** to the furthest point within the **path** segment. Note that in the case of multiple possible **paths**, the **corrected center** must fall within or on the **boundary** of one of the possible **paths** (Figure 15B). The coordinates of the **corrected center** of the path segment are to be entered into the *Calculator* as the "**Input Latitude**" and "**Input Longitude**". Enter the length of the **geographic radial** of the **path** segment "**Radial of Feature**".

Additional parameters: Coordinate Source, Coordinate Format, Datum, Coordinate Precision, Measurement Error, Distance Units (see <<1.6 *Georeferencing Concepts*>>).

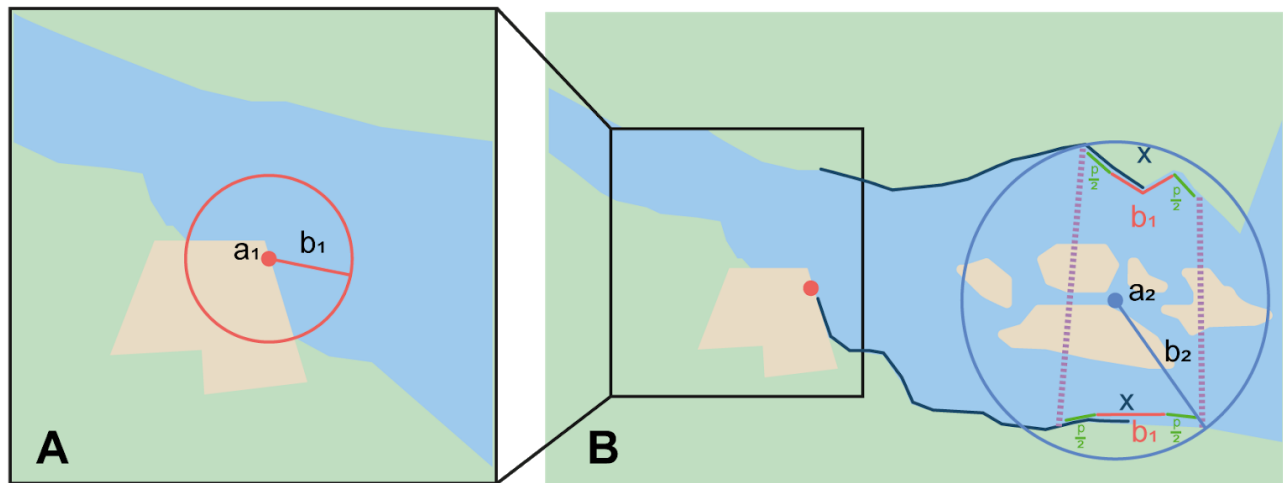


Figure 15. Determination of the input **coordinates** and **geographic radial** for a **locality** of the type **Offset along a path** where there are multiple possible **paths**. **A. Boundary, corrected center (a1) and geographic radial (b1)** for the starting feature along one edge of a river. **B. Boundary, corrected center (a2) and geographic radial (b2)** for the section of the river downstream of the starting feature by an offset X , plus or minus the length of the **geographic radial (b1)** of the starting feature plus the **uncertainty due to offset precision (p)** The position (c) is the center before correction.

d. *Offset - Distance along Orthogonal Directions*

Locality consists of a linear distance in each of two orthogonal directions from a **feature**. For more information and details see the section on <<2.9e. *Offset along Orthogonal Directions*>> in *Georeferencing Best Practices*. **Note:** Where localities have two orthogonal measurements in them, it should always be assumed that the measurements are 'by air' unless there is a reference that indicates otherwise.

Examples: see Table 1

Locality Type: "Distance along orthogonal directions"

Feature boundary: Determine the **boundary** of the **feature** based on whatever the **feature** type is, either as for <<1.1 *Feature - with an obvious spatial extent*>>, or as for <<1.2 *Feature - without an obvious spatial extent*>>.

Feature coordinates and geographic radial: Once the **boundary** of the starting **feature** has been determined, use the same method to determine the **corrected center** and **geographic radial** as for <<1.1 *Feature - with an obvious spatial extent*>>, namely, measure the distance from the **coordinates** of the **corrected center** to the furthest point

within the starting **feature**. Enter the length of the **geographic radial** in "**Radial of Feature**" in the *Calculator*.

Additional parameters: Coordinate Source, Coordinate Format, Datum, Coordinate Precision, North or South Offset Distance, East or West Offset Distance, Radial of Feature, GPS Accuracy/Measurement Error, Distance Units, Distance Precision (see <<1.6 Georeferencing Concepts>>).

e. *Offset - Distance at a Heading*

Locality consists of a distance in a given direction from a single **feature**. Such localities sometimes contain an explicit indicator of how the distance was measured, (e.g., "by air", "air miles W of", "due N of", "as the crow flies", "by road", "downstream from", etc.). Without such an indicator the interpretation is a matter of judgment, which should be documented in the georeference remarks.

NOTE: Since an **offset** at a heading "by air" will usually encompass the alternative by a path anyway, this is the recommended locality type to use. You can increase the **maximum uncertainty** to encompass the other option. This recommendation applies if you don't have a compelling reason to use <<2.2.c *Offset along a Path*>>).

The addition of an adverbial modifier to the distance part of a locality description (e.g., "about 25 km WNW Campinas"), while an honest observation, should not affect the determination of the **geographic coordinates** or the overall **uncertainty**.

Examples: see Table 1

Locality Type: "Distance at a heading"

Feature boundary: Determine the **boundary** of the **feature** based on whatever the **feature** type is, either as for <<1.1 *Feature - with an obvious spatial extent*>>, or as for <<1.2 *Feature - without an obvious spatial extent*>>.

Coordinates and geographic radial: Once the boundary has been determined, obtain the **coordinates** and the **geographic radial** as for <<1.1 *Feature - with an obvious spatial extent*>>, namely, measure the distance from the **coordinates** of the **corrected center** to the furthest point within the **feature**.

Additional parameters: Coordinate Source, Coordinate Format, Datum, Coordinate Precision, Direction, Offset Distance, Radial of Feature, GPS Accuracy/Measurement Error, Distance Units, Distance Precision (see <<1.6 Georeferencing Concepts>>).

f. *Offset - Distances from Two Distinct Paths*

Locality consists of orthogonal **offset** distances, one from each of two distinct **paths**.

Example

Locality Type: "Distance along path"

Although this is not technically a distance along a **path**, the choice of this **locality type** in the *Georeferencing Calculator* will allow all of the relevant parameters to be entered.

Feature boundary: Determine the **boundary** of the area matching the locality description by creating a copy of the paths, each offset by the distance and direction given. The overlap of these two copies defines the extent of the place described. Draw the boundary around the overlapping area.

Coordinates and geographic radial: Once the boundary has been determined, obtain the **coordinates** and the **geographic radial** as for <<1.1 Feature - with an obvious spatial extent>>, namely, measure the distance from the **coordinates** of the **corrected center** to the furthest point within the **feature**.

Additional parameters: Coordinate Source, Coordinate Format, Datum, Coordinate Precision, Radial of Feature, Measurement Error, Distance Units, Distance Precision (see <<1.6 Georeferencing Concepts>>).

2.3 Coordinates

Definition:

The **locality** consists of a point represented by coordinate information which may be in the form of **geographic coordinates (latitude and longitude)**, **Universal Transverse Mercator (UTM)**, Quarter Degree Squares (QDS) or any number of Cartesian reference systems including metric grids, map sheets, etc.

a. Coordinates - Geographic Coordinates

The **locality** consists of a point represented by **coordinate** information in the form of **latitude** and **longitude** in one of various **coordinate formats**:

- Degrees, Minutes and Seconds (DMS).
- Degrees and Decimal Minutes (DDM).
- **Decimal Degrees (DD)**.

Records should also contain a hemisphere indicator ('E' or 'W' and 'N' or 'S' for DMS and DDM formats; - for west or south in DD format).

Examples: see Table 1

Locality Type: "Coordinates only"

Coordinates: Enter the coordinates in the format they were captured from the **GPS** or from the verbatim **locality (decimal degrees, degrees decimal minutes, or degrees,**

minutes, seconds) with all of the given digits of **precision**.

Note: The *Georeferencing Calculator* preserves seven digits of precision in **decimal degrees** so that any transformation between **coordinate systems** is reversible without introducing rounding errors.

Additional parameters: Coordinate Source, Coordinate Format, Datum, Coordinate Precision, GPS Accuracy, Distance Units (see <<1.6 *Georeferencing Concepts*>>).

b. Coordinates - Universal Transverse Mercator (UTM)

The **locality** consists of a point represented by **coordinate** information in the form of Universal Transverse Mercator (**UTM**) or related **coordinate system** (see Note below). When databasing using **UTM** or equivalent coordinates, a Zone should ALWAYS be included; otherwise the data are of little value when used outside that zone, and certainly of little use when combined with data from other zones. Zones are often not reported where a region (*e.g.*, Tasmania) falls completely within one **UTM** zone. Be aware that **UTM** zones are valid only between 84°N and 80°S. For details on dealing with **UTM Coordinates** see <<2.4b. *Universal Transverse Mercator (UTM) Coordinates*>> *Georeferencing Best Practices*.

NOTE: There are many national and local **grids** derived from UTM and work in the same way – for example, the Australian Map Grid (AMG).

Examples: see Table 1

Locality Type: “Geographic feature only”

Although this is not technically a **feature**, this **locality** type will include all of the relevant parameters in the *Georeferencing Calculator*.

Coordinates: The **UTM** coordinates must be converted to decimal degrees using a **UTM** to Lat/Long conversion tool. If the Zone is not given with the **UTM coordinates**, try to determine it from other geographic information in the **locality** of geography fields combined with a **UTM** zone map. Use all of the digits of the converted **latitude** and **longitude** in the **coordinates** for the calculation.

NOTE: Where no zone is cited, first find the **UTM** zone by using [UTM Grid Zones of the World](#) (Morton 2006) using any additional information in the **locality** description, such as country, state/province, county, etc.

NOTE: **UTM coordinates** can sometimes be truncated to fewer digits, signifying a less precise **location**. To make the **coordinate** conversion, add zeros to the right of each **coordinate** to make 7 digits overall in the northing and 6 digits in the easting.

Coordinate Source: “locality description”

Geographic radial: If the **UTM** coordinates have 7 digits in **northing** and 6 digits in

eastings, the **geographic radial** is 0.707 m (because the **coordinates** distinguish to the nearest meter and the **geographic radial** is the diagonal of the 1 m by 1 m grid cell). For every digit less of **precision** in the **UTM coordinates**, multiply the **geographic radial** by 10. Note, however, that this based on **precision**, and the **accuracy** of the original recording may be greater than that worked out using just the **precision** - for example if the **location** was determined using a **GPS**, the **accuracy** of the **GPS** is most likely greater than 1 m, and if done prior to 2 May 2000 and the **datum** was recorded, then the **accuracy** is more in the order of 100 meters.

Additional parameters: Coordinate Source, Coordinate Format, Datum, Coordinate Precision, Radial of Feature, GPS Accuracy/Measurement Error, and Distance Units (see <<1.6 Georeferencing Concepts>>).

c. *Coordinates - Grid System*

Locality is a regular **grid**, such as the 100 m square grids extensively used in the UK and Europe, Quarter Degree Square Grids (QDS) as used in South Africa, and Township, Range and Section (TRS) or Public Land Survey System (PLSS) used in the mid- and western USA. For the TRS, Sections are usually one mile on each side. Similar subdivisions are used in other countries, and should be calculated in a similar way, once the sizes of the rectangles have been determined. Map sheets are sometimes used and can also be calculated in this way. Note that, unlike geographic grids, QDS grids are referenced from the top left corner.

A **grid** is essentially no different from that of any other **feature**. It is necessary to understand the **grid** descriptions and how they describe a place before trying to **georeference**. Note, that you may be able to refine the **georeference** and **uncertainty** by examining the textual locality data - this may restrict the location to just part of the **grid**. For more details see the section on <<2.3d. Grids>> in *Georeferencing Best Practices*.

Examples: see Table 1

Locality Type: "Geographic feature only"

Coordinates: Determined as for <<1.1 Feature - with an obvious spatial extent>>. Use the **coordinates** for the **corrected center** of the named **grid** area.

Note: Usually the **grid** is made up of bounding boxes, so determining the **geographic center** should be easy. For the PLSS system, large size grid cells (townships) tend to be areas of 6 by 6 miles, divided into 36 one by one mile sections, which can be further divided in half in each dimension. Be aware that not all townships are square, however, as some were adjusted to conform to natural boundaries (rivers, for example) or other surveying constraints. Numbered Townships are not unique descriptions without a **meridian**, which often is not given in a locality description. The meridian must be inferred from a Principal Meridian map using other information in the locality description to determine the rough location.

Coordinate Source: Coordinates could come from a map, in which case select the map type of the appropriate scale, otherwise select “**gazetteer**”.

Geographic radial: As for <<1.1 Feature - with an obvious spatial extent>>.

Note: For TRS sections, the **radial** is half of the hypotenuse of the section, or 0.707 mi (the square root of 2 divided by 2). For quarter sections, the extent is half of that, or 0.354 mi. (Table 2).

Additional parameters: (see <<1.6 Georeferencing Concepts>>).

2.4 Difficult Localities

Description:

At times, **locality** descriptions are fraught with vagueness. This may be due to any number of reasons, but in particular relates to historic collections in areas that at the time may have had no named **features** to reference. See the section <<3.5 Georeferencing Difficult Localities>> in *Georeferencing Best Practices*.

A cause of vagueness may be incorrect data entry and it is recommended that checking the original catalog books, field notes, specimen labels, etc. be the first step in removing the vagaries of a locality so that it can be georeferenced.

a. Dubious Locations

The most important type of vagueness in a **locality** description is one in which some or all of the **locality** is explicitly in question.

Examples: see Table 1

Georeferencing procedure: If some part of the locality description is in question, but aside from that there is location information that is not in question, use the unquestioned part of the locality to determine the **locality type** and **georeference** it normally following the appropriate method. Document in `georeferenceRemarks` what had to be disregarded in order to georeference the **locality** in question.

If the entire locality is in question, do not georeference it and document in `georeferenceRemarks` the reason for not **georeferencing** (e.g., “**locality** in question”).

b. Cannot be located

The cited **locality** cannot be located. This may be for any number of reasons, including:

- There is no **locality** information cited.
- The **locality** fields contain other than **locality** information.
- The **locality** cannot be distinguished from among multiple possible candidates.
- The **locality** cannot be found with available references.

At times more than one geographical **feature** fits a **feature** in a **locality** description.

These recommendations apply to all **locality** types.

Overlapping: If the possible **features** overlap at least in part, treat the combination of them as the **feature** and follow the procedure for the appropriate **locality** type. Make note of the multiple possibilities and the procedure used in **georeferenceRemarks**.

Non-overlapping, related: If two distinct places with the same name are related to each other (for example, “Battle Mountain” the town near “Battle Mountain” or the mountain), for the starting coordinates choose the point within or on the **boundary** of one of the **features** nearest to the midpoint between the centers of the places (**corrected center**). Measure from here to the point furthest from here on the **boundaries** of **features** to get the **geographic radial** and follow the procedure for the appropriate locality type. Make note of the multiple possibilities and the procedure used in **georeferenceRemarks**

Examples: see Table 1

Georeferencing procedure: Do not **georeference**, unless as noted above for non-overlapping and related **locations**.

Document in **georeferenceRemarks** the reason for not **georeferencing**, *e.g.*, “locality cannot be found with available references”, etc. Do still fill in the **georeferenceSources** field in your database so that the next researcher does not waste time using the same resources to track down the **locality**.

c. Demonstrably inconsistent

The **locality** description contains irreconcilable inconsistencies. Do not **georeference** these. It is difficult to know which part of the **locality** is the one in error and a risk to judge that one part of the description should take precedence over another. Rather than determine **coordinates** for such **localities**, annotate the **locality** with the nature of the inconsistency (*e.g.*, “Missoula County not in Idaho”) and refer the **locality** to the source institution for reconciliation.

One source of inconsistency in **locality** descriptions comes from trying to match **elevation** information with the rest of the **locality** description. In these cases, bear in mind that **elevation** data are notoriously inaccurate (see <<2.7 *Elevation*>> in *Georeferencing Best Practices*).

Another common source of inconsistency occurs when the **locality** description does not match the geopolitical subdivision of which it is supposed to be a part.

Often there is no way to know if the geopolitical subdivision or something in the **locality** description itself is at fault. The county may be wrong, the distance may be wrong, or the direction may be wrong. Such a **locality** cannot be disambiguated without going back to the originating institution, collection ledger, field notes, or by contacting the person who recorded the information, etc.

Examples: see Table 1

Georeferencing procedure: Do not **georeference**

Document in **georeferenceRemarks** the reason for not **georeferencing**, e.g., “locality contains irreconcilable inconsistencies”.

d. Cultivated or Captive

The **locality** refers to a captive animal or cultivated plant or from a non-natural occurrence. The **locality** cited is often that of a zoo, aquarium, botanical garden, etc. See <<2.13 Dealing with Non-natural Occurrences>> in *Georeferencing Best Practices*.

Examples: see Table 1

Georeferencing Procedure: **Georeference** the **locality** normally based on the **locality type** and **feature**. Retain the **location** (e.g., zoo) along with its **georeference**, as for other **localities** in this *Guide*, but be sure to record the nature of its provenance (cultivated, captive, washed ashore, etc.) in **georeferenceRemarks** or the Darwin Core term **establishmentMeans**.

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Table 1. Key to types of localities and examples of corresponding locality descriptions.

Location Type		Feature / subtypes	Locality description examples
Feature - with an obvious spatial extent	1.1	bounded/defined feature	
	1.1	town, suburb, populated place, or homestead	"Valdivia", "Puerto Madryn", "Verónica"
	1.1	spring, bore, tank, well, or waterhole	"Bennetts Waterhole", "Woodingdean Well"
	1.1	airport, buoy, dock, or jetty	"Gizo airport", "navigation buoy #14, San Diego harbor", "Jetty Swakopmund"
	1.1	trig point, spot height, or benchmark, trigonometric beacon, triangulation station, trig pillar	"Class 3 triangulation point in Shiroyama Park", "Trig beacon on the summit of Lion's Head"
Feature - without an obvious spatial extent	1.2	unbounded/undefined feature	
	1.2	area, region	"Pampa Grande"
	1.2	port, bay, gulf, or harbor	"Botany Bay", "Gulf of Tunis", "Capri harbor"
	1.2	hill, peak, pass, or mountain	"Mt Hypipamee", "Sani Pass"

Feature - Special cases	1.3	Depending on the information available, should be treated as 1.1 or 1.2.	
	1.3.a	street address	"Av. Angel Gallardo 470, Buenos Aires, Argentina", "1 Orchard Lane, Berkeley, CA", "21054 Baldersleigh Road, Guyra, NSW" (indicates that the locality is 21.054 km from the beginning of Baldersleigh Road).
	1.3.b	ranch, station, farm, finca, granja, estancia	"Victoria River Station", "Mathae Ranch", "Haskell Farm", "Estancia 9 de Julio"
	1.3.c	junction of two paths (roads, rivers, contour lines, boundaries, etc.)	"junction of Coora Rd. and E Siparia Rd", "Where Dalby Road crosses Bunya Mountains National Park Boundary", "confluence of Labarge Creek and South Labarge Creek", "junction of Rio Claro and Rio La Hondura", "bridge over the River Kwai", "At 100 m contour line on Black street"
	1.3.d	cave	"Carlsbad Caverns", "Cueva de Las Brujas"
	1.3.e	dive location	"Exploratory dive extending in a rough circle of 20 meters diameter between depths of 75 and 100 meters, beginning 100 meters south east of ground zero at a depth of 85 meters".

	1.3.f	river, stream, road, path	"Sacramento River", "Jones Road", "Río Paraná", "Arroyo Urugua-í", "Hwy 1", "along 100 m contour line", "N. Boulder Creek, 1.3 miles above Boulder Falls", "Eastern part of Logan Motorway",
	1.3.g	mouth or headwaters of a waterway	"headwaters of the Missouri River", "mouth of Goodpaster River"
	1.3.h	near a feature	"vicinity of General Conesa", "before Ceibas", "near Dina Huapi", "Big Bay vicinity", "near MS 117 on Dalton Hwy", "vicinity of bridge over Condamine River on Warrego Highway", "adjacent to the railway underpass on Smith Street"
	1.3.i	between two features	"between Missoula and Florence, Montana", "Entre Pampa Blanca y Pampa Vieja, Jujuy", "between Point Reyes and Inverness"
	1.3.j	between two paths	"between the Great Western Hwy and the railway line", "between Tanama R. and Clearwater Ck.", "between Aldersley and Bridge Streets" (<i>i.e.</i> , two streets that don't intersect), "on Hwy 14, between highway and adjacent fence"
	Other	point, cape, or peninsula	"Point Lookout", "Península San Pedro"
	Other	island, reef, or cay	"Isla Tiburón", "Lorne Reef"
	Other	park, reserve, or forestry zone	"Yosemite National Park", "State Forest Reserve 607"

Offset	2	Offset from a feature	
	2.1	direction only, no distance	"N Palmetto", "N of Berkeley", "Saladillo N", "Al N de Saladillo", "off Mar del Plata"
	2.2	offset only, no direction	"5 km outside Calgary", "12 km fuera de Purmamarca"
	2.3	offset at a heading	"50 miles W of Las Vegas", "10.2 km E de Amamá", "16 mi from St Louis on left bank of the Mississippi River – downstream", "about 25 km WNW of Campinas", "10 mi E (by air) Yerevan"
	2.4	offset along a path	"7.9 mi N Beatty, on US 95", "3 km en el Rio Jimenez arriba de Anita Grande", "left bank of the Mississippi River, 16 mi downstream from St. Louis", "Ruta Nacional 81, 8 km W de Ingeniero Guillermo Nicasio Juárez"
	2.5	offset in orthogonal directions	"6 km N and 4 km W of Welna", "2 mi E and 1.5 mi N of Kandy", "2 miles north, 1 mile east of Boulder Falls, Boulder County, Colorado"
	2.6	offsets from two distinct paths	"1.5 mi E LA Hwy. 1026 and 2 mi S U.S. 190"
Coordinates	3	point represented by coordinate information	
	3.1	coordinates from a Global Positioning System (GPS)	"36° 31' 21.4" N; 114° 09' 50.6" W" (DMS), "36° 31.4566'N; 114° 09.8433'W" (DDM), "36.524276° S; 114.164055° W" (DD), "-36.524276; -114.164055" (DD using minus signs to indicate southern and western hemispheres)

	3.2	Universal Transverse Mercator (UTM)	"N 4291492 E 456156", "N4291 E456", "UTM N 4291492; E 456156" (Note: no zone cited), "AMG Zone 56, x: 301545 y: 7011991", "30T 699582 m east 5709431 m north", "56: 301545.2; 7011991.4"
	3.3	grid system	"E of Bakersfield, T29S R29E Sec. 34 NE 1/4", "T3S, R42E, SEC.2", " QDS 3218CB"
Difficult localities	4		
	4.1	dubious	"possibly Isla Boca Brava", "presumably central Chile", "Bakersfield?"
	4.2	cannot be located	"locality not recorded", "Bob Jones", "summit", "San Jose, Mexico", "Battle Mountain" the town near "Battle Mountain" the mountain, "Junction of Hwy 50 and Stem Road" (where Hwy 50 and Stem Road intersect more than once)
	4.3	demonstrably inconsistent	"Sonoma County side of the Gualala River, Mendocino County", "10 mi W of Bakersfield, 6000 ft" (There is no place anywhere near 10 mi W of Bakersfield at an elevation of 6000 ft), "Delano, Tulare Co." (Delano is in Kern Co.), "5 mi N of Delano, Kern Co." (5 mi N would put the locality in Tulare Co.)
	4.4	cultivated or captive	"lab born", "bait shop", "Cultivated in Botanic Gardens from seed obtained from Bourke, NSW.", "San Diego Wild Animal Park"

Table 2. List of **feature** types and the default **geographic radial** to use. If the **feature** type you are looking for isn't on the list, use one that is most like the **feature** type you seek and be sure to document your choice in **georeferenceRemarks**.

Feature Type (list incomplete)	Default geographic radial
spring, bore, tank, well, or waterhole	10 m
small stream	1 m