



Cooling Tower Identification 101:

How to Use Satellite Imagery to Identify Cooling Towers

Jazmin Fontenot, MPH, Alexander Yu, MD, MPH, Sarah Rutschmann, MPH,
and Seema Jain, MD

**Disease Investigations Section, Infectious Diseases Branch,
Division of Communicable Disease Control California Department of Public Health**

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DEFINITIONS

ArcMap/ArcGIS Desktop: A geospatial desktop application licensed and developed by ESRI software. Used to examine, edit, create, and analyze spatial data. As of 2019, is being replaced by ArcGIS Pro. Not compatible with Macintosh operating systems.

ArcGIS Pro: Similar to ArcMap, ArcGIS Pro is a newer geospatial processing program licensed and developed by ESRI with 64-bit architecture and some additional built-in analysis features and increased compatibility with ArcGIS online services. ArcGIS Pro is the newer version of ArcMap and will replace it over time. Not compatible with Macintosh operating systems.

Cooling Tower: A heat removal device that uses water to transfer waste heat into the atmosphere. Cooling towers are typically used to provide heating and air conditioning. They are very diverse among models, shapes, sizes, and heights and serve multiple building types and uses.

Geodatabase: A collection of files in a folder that can store, query and manage both spatial and non-spatial data.

Google Earth Pro: A free geospatial application displaying a combination of satellite and aerial images of the earth as a three-dimensional globe at different catalogued time points. Google Earth superimposes satellite imagery with aerial imagery. Google Earth is compatible with most GIS products and can be used for importing global positioning system (GPS) data, finding geographical features, and exporting locational data.

KML File: Keyhole Markup Language (KML) is a file format used for Google Earth. It is an extensible markup language (XML) notation for geographical and visualization data with internet-based maps and 2D/3D Earth browsers. This is the default file type for spatial data in Google Earth.

KMZ File: A file format used for Google Earth placemark files. Stands for Keyhole Markup Language Zipped. Similar to a KML file, the KMZ file is a compressed (zipped) version that can be used to transfer large Google Earth locational data to other programs.

Legionnaires' Disease: A severe pneumonia caused by inhalation or aspiration of *Legionella* bacteria.

Shapefile: A file format used for storing geometric location and attribute information that is compatible between most GIS programs. Shapefiles will end with .shp after the file name, but for a shapefile to work properly, additional associated files (i.e., ending in .dbf and .shx) that contain critical information are stored in the same workspace as the shapefile.

ABBREVIATIONS

CDC	U.S. Centers for Disease Control and Prevention
CDPH	California Department of Public Health
CT	Cooling Tower
DIS	Disease Investigations Section
ESRI	Environmental Systems Research Institute
GE	Google Earth
GIS	Geographic Information System
GRASP	Geospatial Research, Analysis, and Services Program
IDB	Infectious Diseases Branch
KML	Keyhole Markup Language
KMZ	Keyhole Markup Language Zipped
LD	Legionnaires' Disease
OC	Orange County
OCHCA	Orange County Health Care Agency
PDPH	Philadelphia Department of Public Health

BACKGROUND

INTRODUCTION

Legionnaires' disease (LD) is a severe, potentially life-threatening pneumonia with an associated fatality rate of close to ten percent. Pontiac fever (PF) is a milder, self-limiting influenza like illness. LD and PF are collectively known as legionellosis and can be caused by over 50 different species of *Legionella* bacteria, most commonly *L. pneumophila* and *L. longbeachae*.^{1, 2} *Legionella* bacteria live in natural freshwater bodies as well as in soil environments, and most commonly cause human disease when inhaled in contaminated, aerosolized water droplets. The annual incidence of legionellosis in the United States has been increasing, with a rate of 2.29 per 100,000 population in 2017.^{3, 4}

Cooling towers (CTs) are units commonly used to cool large spaces and disperse large volumes of hot water into the air in the process. They are also prone to *Legionella* bacteria colonization, and have been extensively linked to outbreaks and sporadic, community-acquired cases of LD.⁵ Investigations of CTs are an important component of LD outbreak management. However, identifying and distinguishing CTs from other cooling units and structures can be difficult and time-consuming. For more details on CTs, see [B. INTRODUCTION TO COOLING TOWERS](#). This document describes a protocol for using satellite imagery as a tool for the identification CTs.

For illustrative purposes throughout this document, we will reference a CT mapping project conducted as a collaborative effort between the California Department of Public Health (CDPH) and the Orange County Health Care Agency. The goal of this project was to map all CT locations in Orange County (OC) in order to examine the relationship between CTs and sporadic cases of LD among residents living in OC from January 1, 2014 to December 31, 2018.

GOALS

This guide is meant to (1) provide background knowledge of CT systems and model types, (2) describe the steps to identify CTs using satellite imagery, and (3) describe methods used to prepare spatial data of CTs for use in spatial analysis.

Identifying CTs on digital maps (mapping of CTs) requires a basic understanding of CT models and mechanics, as well as a basic knowledge of Geographic Information Systems (GIS) products and satellite and aerial imagery. With guidance from the U.S. Centers for Disease Control and Prevention (CDC) Agency for Toxic Substances and Disease Registry, Geospatial Research, Analysis, and Services Program (GRASP), CDPH has created this protocol for internal use to identify and/or map the location of CTs in California.

The purpose of the “Cooling Tower 101: How to use Satellite Imagery to Identify Cooling Towers” protocol is to provide a step-by-step guide on CT identification by scanning regional satellite/aerial imagery. This protocol includes example images, reference diagrams, and a list of resources for understanding CT identification to support future satellite imagery projects. This guide presumes minimal pre-existing knowledge of either GIS or CTs.

IMAGES AND PRODUCTS DISCLAIMER

Unless otherwise noted, the images of CTs or CT mechanisms included in this document are for example only, intended to familiarize users with the variety of structures that may be found while conducting searches for CTs. Any mentions of brand-name products are for informational purposes only; use of product names or images in this document does not imply commercial endorsement by CDPH, nor does CDPH take credit for the images included in this document. Images are used in accordance with fair use, as they are provided for teaching and research purposes only.

STRUCTURE OF THIS DOCUMENT

The following document is organized into three main sections: (1) Pre-scan (pre-requisites before scanning for CTs), (2) Scan (process used to scan for, identify and label CTs), and (3) Post-scan (data processing and analysis). Each section should be used in order and, if possible, iteratively to fully understand CT models and methods for identification. At the end of the document, we have included additional resources including presentations, videos, guides, and GIS maps to help structure CT identification. Resources from various partners at state and local health departments that offered assistance in developing this protocol are embedded in the final sections of the document. We have also included recommendations for starting a CT scan, and lessons learned to help streamline CT identification.

Lastly, a separate [Cooling Tower Identification Guide supplement](#) is provided, which includes specific details, images, and examples to help distinguish and identify CTs from non-CTs.

OVERVIEW OF THE COOLING TOWER IDENTIFICATION PROCESS

The three main steps to identify CTs using satellite images are highlighted in [Figure 1](#) below.

Step 1: Pre-Scan – *Understanding CTs and other pre-requisites before scanning*

Step one discusses the mechanics of CTs and common model types; this is crucial to understanding how CTs may differ in appearance from other

mechanical devices on buildings. Software used for the project and options for alternative satellite imagery are also discussed.

Step 2: Scan – Using satellite imagery to find CTs

This section includes step-by-step methods that can be used for CT identification, including creating strategies to systematically evaluate geographic regions for CTs.

Step 3: Post-Scan – Processing of data for analysis

The post-scan section documents how to convert and analyze data products with GIS, including components of saving a Google Earth (GE) file in the correct file format and converting it to a file format compatible for GIS. The last chapter includes recommendations, lessons learned, and limitations of using satellite imagery for CT identification.

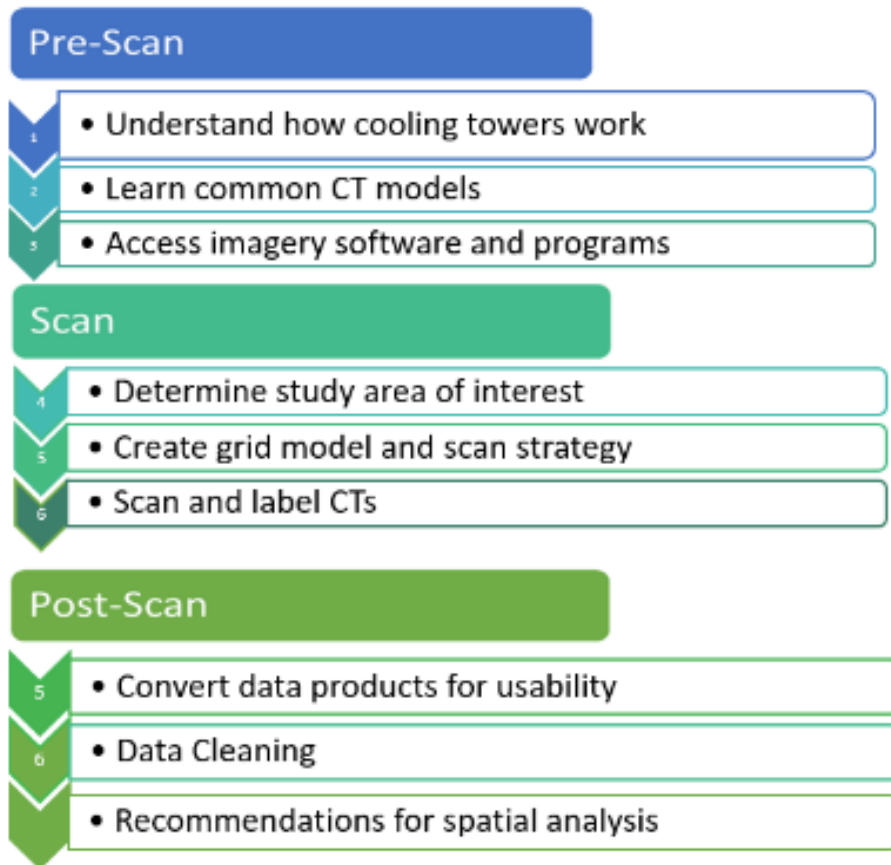


Figure 1 : Overview of CT Identification.

Pre-Scan



1. PRE-SCAN

A. SOFTWARE REQUIREMENTS

The software needed to follow this guide and conduct a CT scan include:

1. Satellite imagery streaming service
 - a. [Google Earth Pro](#), or
 - b. See the alternative section in [High Resolution Imagery](#) options below
2. GIS spatial mapping program
 - a. ArcMap version 10.5+, or
 - b. ArcGIS Pro version 2.1+, or
 - c. ArcGIS Online, or
 - d. QGIS
3. Microsoft Excel

Install each program as a desktop application directly to the computer being used for the analysis.

I. GOOGLE EARTH

Google Earth Pro (GE) was chosen for the CT-identification portion of this project because:

- a) The combined satellite and aerial imagery allow for 6-inch resolution.
- b) Some 3D reconstructions of buildings are available, providing orthogonal views.
- c) It is freely available.
- d) It provides easily accessible, catalogued, time-stamped imagery from prior years.

It is not recommended to use GE launched from a web browser. For PCs, Macintosh, or Linux, GE can be directly downloaded as a free application to computer desktops. It is recommended to use GE on desktop as it is easier to store files than the web application. For those unable to access GE, please see the section below for alternate resources for High Resolution Imagery.

HIGH RESOLUTION IMAGERY

Different images are needed for different parts of this protocol. The most image-intensive task is CT identification, as CTs can be small and the identifying features on them even smaller. To reliably identify CTs, it is best to use a service that provides resolution of at least 6 inches per pixel.

Currently available satellite images have a resolution limit of greater than 12 inches. Thus, a combination of satellite and aerial (i.e., drone, plane, helicopter) imagery is

necessary. Additionally, orthogonal views are extremely helpful as many CTs are on the sides of buildings or otherwise obscured. Imagery services that provide updated, time-stamped and current images or catalogued images from prior years is helpful, though not mandatory, for examining CTs.

There are a number of publicly and privately available high-resolution satellite imagery resources. In our exploration of different image sources, we were unable to find a readily available free resource with high enough resolution that allowed for CT identification, with the exception of GE. This is likely because most publicly available imagery is from satellites and limited in resolution to 12 inches, whereas GE combines satellite imagery with higher-resolution aerial imagery. However, it is possible that such resources exist or that investment in private satellite imagery can be necessary depending on the planned use. As a streaming web-service, reliance on GE images can be limiting for certain types of spatial analyses that require downloadable image data.

Below is a non-exhaustive list with a few comments on each source.

- **DigitalGlobe**: Private. High-resolution satellite images, now with some partnerships with ESRI to provide their basemaps. Includes QuickBird satellites and GeoEye. Available at <https://www.maxar.com/>.
- **US Geological Survey**: Public. Collects Landsat data, Aster, NASA (MODIS, AVHRR) and other publicly available aerial and satellite imagery, digital elevation models, topography maps; this a great place to start looking for resources. Available at <https://www.usgs.gov/>.
- **National Oceanic and Atmospheric Administration (NOAA)**: Public. Jason-2, GOES, and high-quality atmospheric data, also good for remote sensing. Available at <https://www.nesdis.noaa.gov/OPPA/jason2.php>.
- **European Space Agency (ESA)**: Public. Sentinel data, which gives more bands (useful for remote sensing) and has resolution equal to Landsat. Available at <http://www.esa.int/>.
- **State, county, or city GIS clearinghouse**: These may be the best repositories for high-resolution imagery as they are often used for fine-resolution work (i.e., public planning, business, utilities groups). Availability and access will depend on the state or county.
- **EagleView/Pictometry**: Private. Both high-resolution satellite and aerial imagery, and oblique images. Likely most suitable dataset for CT identification (though we were unable to obtain any images to trial). Available at <https://www.eagleview.com/product/eagleview-reveal/>.

- **Other:** A summary of other private imagery services, including those that offer aerial imagery, is available on the [AppGeo imagery comparison webpage](https://www.appgeo.com/imagery-comparison-satellite-aerial) at <https://www.appgeo.com/imagery-comparison-satellite-aerial>.

*Protocols for this document use GE and may not apply to other imagery sources.

II. GIS SPATIAL MAPPING PROGRAMS

Most available GIS software are suitable (i.e., ArcMap, ArcGIS Pro, ArcGIS online, or QGIS). All processes included in this protocol can be done with any of these programs, though this protocol is written with demonstrations from ArcMap. However, there are important distinctions between these programs:

- There is minimal functional difference between ArcMap and ArcGIS Pro:
 - ArcGIS Pro is the newer, 64-bit version of ArcMap. ESRI will likely phase out support for ArcMap over the next few years.
 - The computing resource intensity of ArcGIS Pro is higher and thus it may not run as smoothly on certain desktops or with certain versions of Windows OS.
- ArcGIS Online is a web-browser and does not require a link to either desktop versions of ArcMap or ArcGIS Pro, however its GIS capabilities are more limited.
- Licensing for ArcGIS online varies, and many analyses done using ArcGIS online may cost ESRI 'credits' whereas the same function on the desktop ESRI platform does not cost 'credits.'
- QGIS is a free, open-source GIS software that works well on Macintosh as well as PCs; it has the same general functionality as ArcMap or ArcPro, though many of these are through open-source plug-ins rather than built-in functionality.

Choice of software will likely depend on what is being licensed and available.

B. INTRODUCTION TO COOLING TOWERS

A CT is a heat rejection device that sends waste heat into the atmosphere. The purpose of a CT is to take in hot water that has been heated by an industrial system, process, building or space, effectively lower the temperature, and send cool water back to once again fulfill cooling needs.

Nearly all CTs run on the same overall mechanical design. Inside a CT, water and air mix to lower the temperature of outgoing water. [Figure 2](#) shows a simplified version of how water moves through a CT.

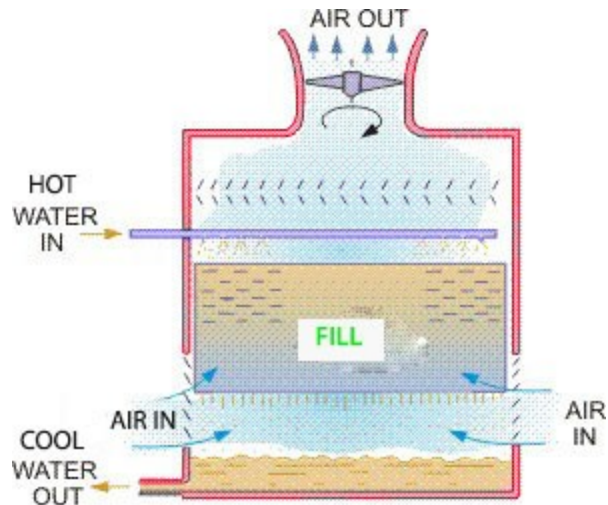


Figure 2: CT cooling process.

Hot water typically enters a CT through piping connected to air conditioning units, condensers, and other industrial machinery from a building.⁶ After hot water is pumped into the CT structure, it moves through nozzles that spray incoming water onto a CT fill ([Figure 2](#), [Figure 3](#)). Fill is a type of medium used to increase the surface area of water.⁷ At the same time, outside, ambient air is pulled in from openings in the CT sides and/or bottom and circulates through the fill, allowing hot water and air to mix and decrease the overall water temperature. This air is pulled through the CT by a motor-driven, electrical fan(s), on the top or side of the CT. As the water temperature lowers, some amount of hot water rises (evaporative mist) and is ejected by the CT fan (CT drift). Cooled water moves down the CT structure and empties into a bottom basin. If the water is not effectively cooled, it will recirculate in the CT until it reaches the ideal temperature.

Given this mechanism of cooling hot water, CTs share similar traits with each other regardless of their overall design or appearance. These traits can be advantageous for identification (see [Cooling Tower Identification Guide supplement](#) for additional CT appearance notes):

- Presence of a fan to draw air in and circulate it through the fill
 - Fan usually is on top of the unit or on the side
 - Fan is usually large, both in absolute size and also relative to the CT unit to move large amounts of air slowly through the unit
 - Air does not need to circulate quickly in CTs; thus, the fans tend to be slower moving (and blades often can be seen visibly on still satellite images, rather than as a blur of fans)
- Often with open sides and visible fill ([Figure 3](#): left image)

- Many water lines running to and from the CT, to move hot and cooled water (Figure 10)



Figure 3: Examples of CT fill (Left: worker spraying fill on side of CT; Middle: fill removed from CT; Right: image of fill showing movement of water and air).

I. COOLING TOWER DRIFT

Water that is ejected from a CT fan with evaporative mist is called CT drift (Figure 4). Many of the newer CT models have CT drift eliminators to prevent excess water loss. However, CT drift can occur regardless of model type or drift eliminator. In comparison to water vapor that will naturally escape a CT fan and is thought to be harmless to the environment, CT drift consists of small water droplets that can contain chemicals, minerals, and bacteria harmful to the environment.⁸

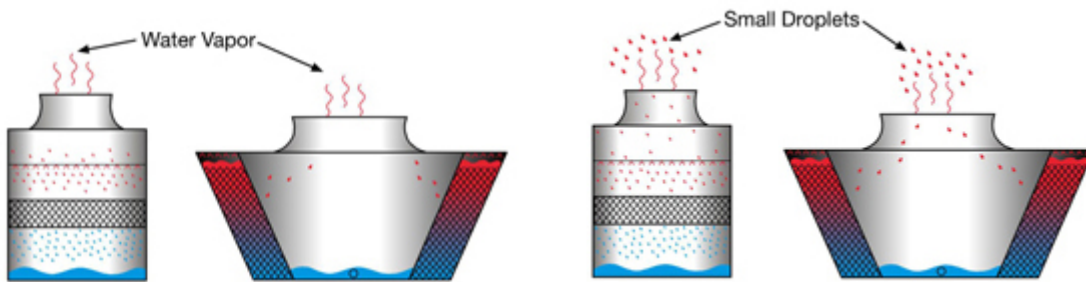


Figure 4: CT evaporative mist (left) showing small amounts of water lost by evaporation versus CT drift (right) showing small droplets of water ejected from CT by a fan.

II. COOLING TOWERS AND LEGIONNAIRES' DISEASE

Legionella bacteria are naturally occurring in freshwater environments and can proliferate in stagnant and hot water. CTs are of special interest for LD control because they circulate massive volumes of hot water (1,000-6,000 gallons/minute) and provide favorable conditions for *Legionella* growth, including optimal growing temperatures and

recirculated water.² If CTs are not maintained and properly disinfected, *Legionella* can become aerosolized through CT fans and expose individuals to infection. The distance that the subsequent *Legionella*-contaminated, aerosolized water can travel varies with CT height, fan size, relative atmospheric humidity, temperature, and wind speed and direction.⁹

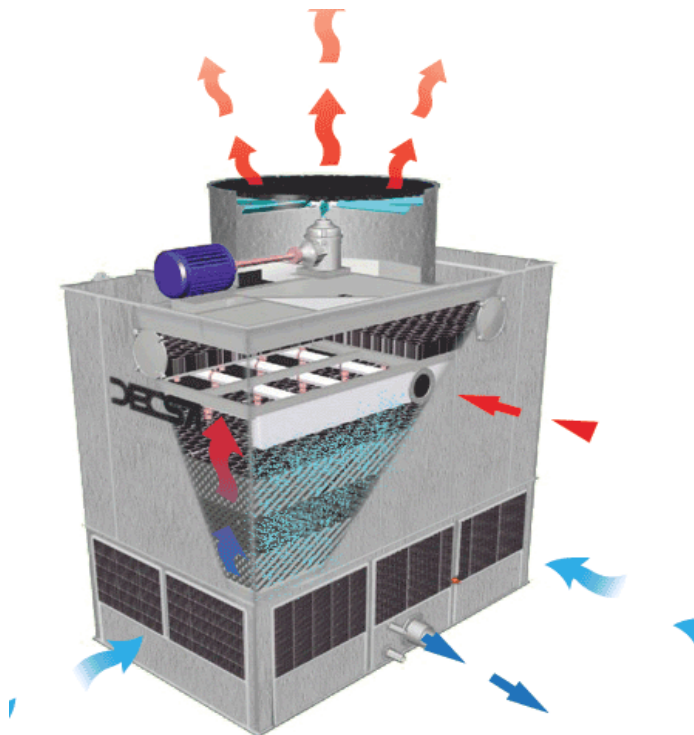
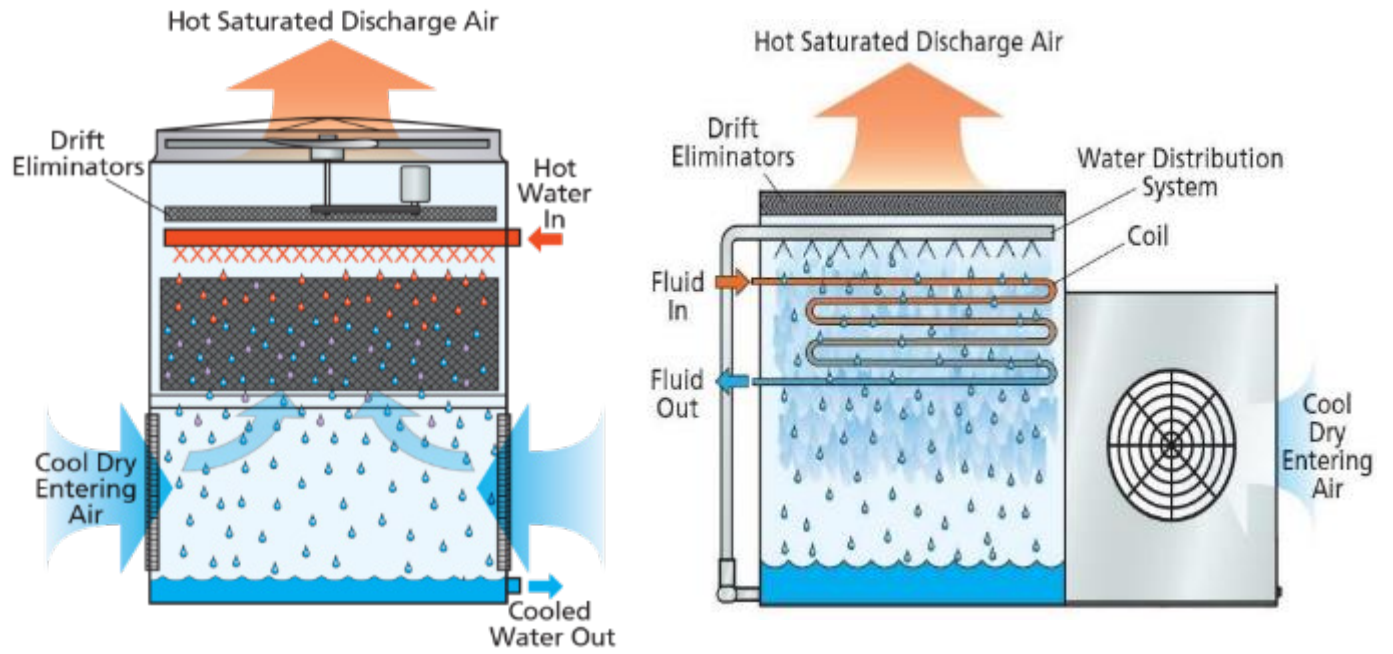
This ability for CTs to serve as amplifiers for *Legionella* growth and to also aerosolize large volumes of water over long distances explains why CTs are the most extensively implicated cause of large LD outbreaks.⁵ Smaller evaporative coolers have less commonly been linked to outbreaks due to the much lower volumes of aerosolized water. Closed-circuit coolers and air conditioners are not designed to generate any type of aerosol, and while they have been linked to cases, are not thought to be high risk for causing LD.⁵

III. TYPES OF CTS

There are two different types of CT structures that are necessary to delineate for purposes of looking at exposure to CT drift: open circuit CTs and closed circuit CTs. A closed-circuit CT does not have an opening fan blade that allows water or air to escape the structure. Open-circuit CTs are those with exposed fans and fills. For identifying CTs that may expose individuals to CT drift and *Legionella*, we focused on scanning for open-circuit CTs.

While open-circuit CTs also come in numerous shapes and sizes, they all follow similar general mechanics. Some examples of common, open-circuit models are shown in the following pages, grouped by shape and size: Rectangular and Square CTs, Round Shape CTs, and Large Hyperboloid Forced Draft and Induced Draft CTs. Also included are images of CTs with fans on their sides, and CTs of different colors and with attached water pipes.

RECTANGULAR AND SQUARE CTS



RECTANGULAR AND SQUARE CTS, CONT.

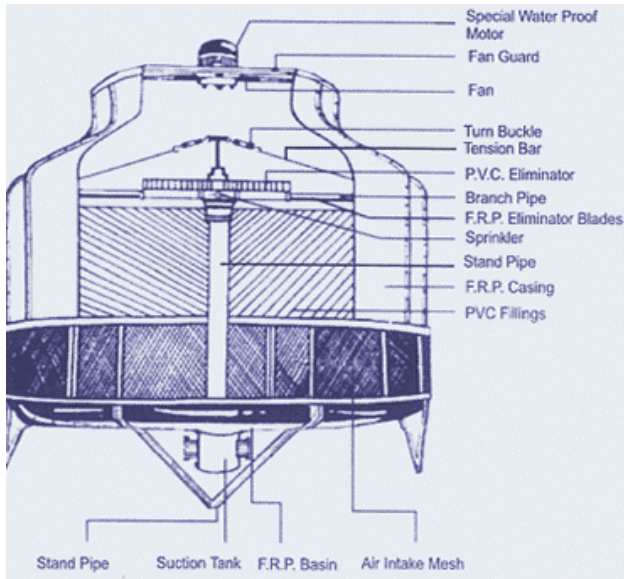
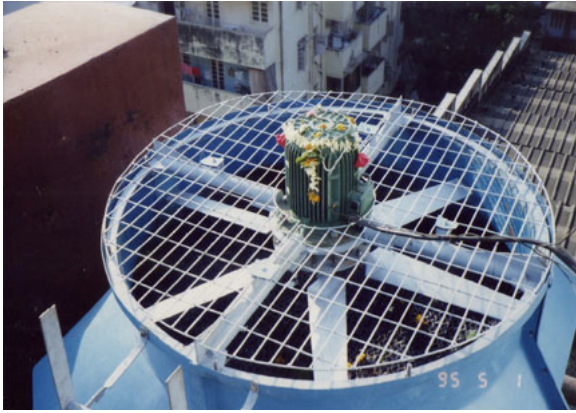


RECTANGULAR AND SQUARE CTS, CONT.



Figure 5: Rectangular and square CTs, the most common types of CT. (Images of branded CTs courtesy of [Delta Cooling Towers](#) and [SPX Cooling Technologies](#).)

ROUND SHAPE CTS



ROUND SHAPE CTS, CONT.



Figure 6: Round designs of open CTs, often substantially smaller than other CTs and more commonly on the ground. (Images of branded CTs courtesy of [Delta Cooling Towers](#) and [Cooling Tower Systems](#).)

LARGE HYPERBOLOID FORCED DRAFT AND INDUCED DRAFT CTS

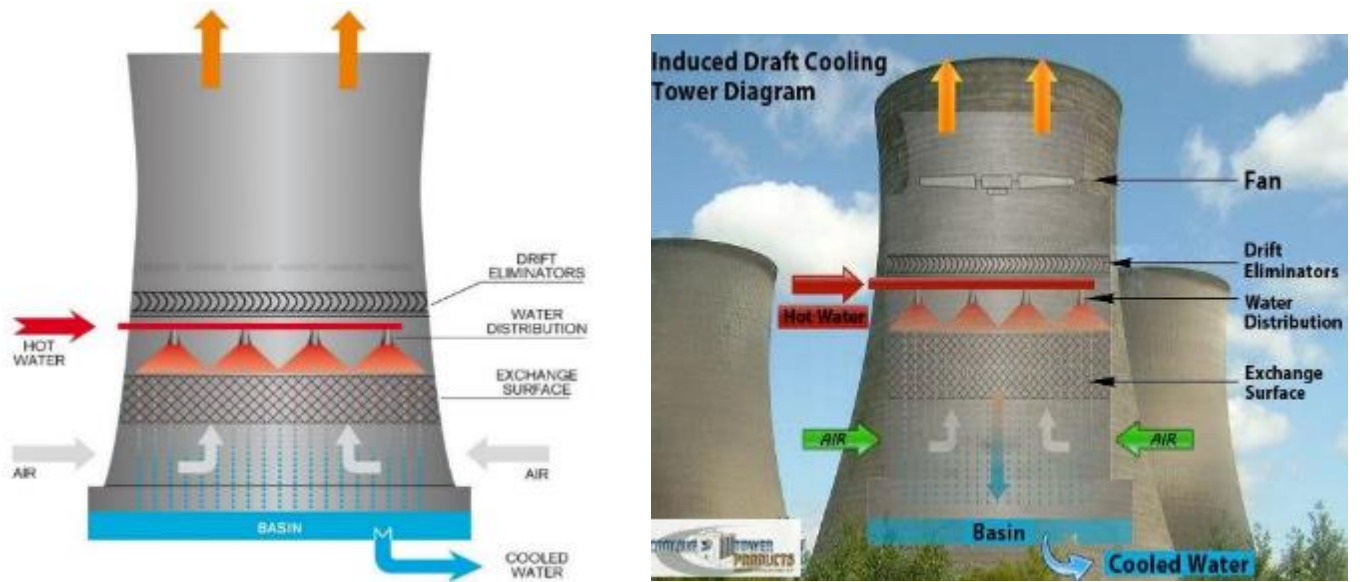


Figure 7: Large hyperboloid shaped CTs are typically easy to find on a satellite images but are much less common; these models are used for very large industrial plants.

CTS WITH SIDE FANS



Figure 8: CTs with side fans or other less common fan configurations.

COLORED CTS AND WATER PIPES

Aside from silver/metallic CTs, other common colors for CTs are blue and green ([Figure 9](#)). These colors can also often be seen on pipes to represent the presence of a water source or water supply ([Figure 10](#)). Other companies have used blue and green to represent newer models that have shells with resins that are “anti-microbial.” For more information on types of anti-microbial CTs, visit the [Delta Cooling Towers, Inc. Anti-Microbial Cooling Towers information webpage](https://deltacooling.com/products/cooling-towers/anti-microbial-cooling-towers) (<https://deltacooling.com/products/cooling-towers/anti-microbial-cooling-towers>) (for informational purposes only; CDPH does not endorse these products).



Figure 9: Colored CTs.



Figure 10: Colored water pipes.

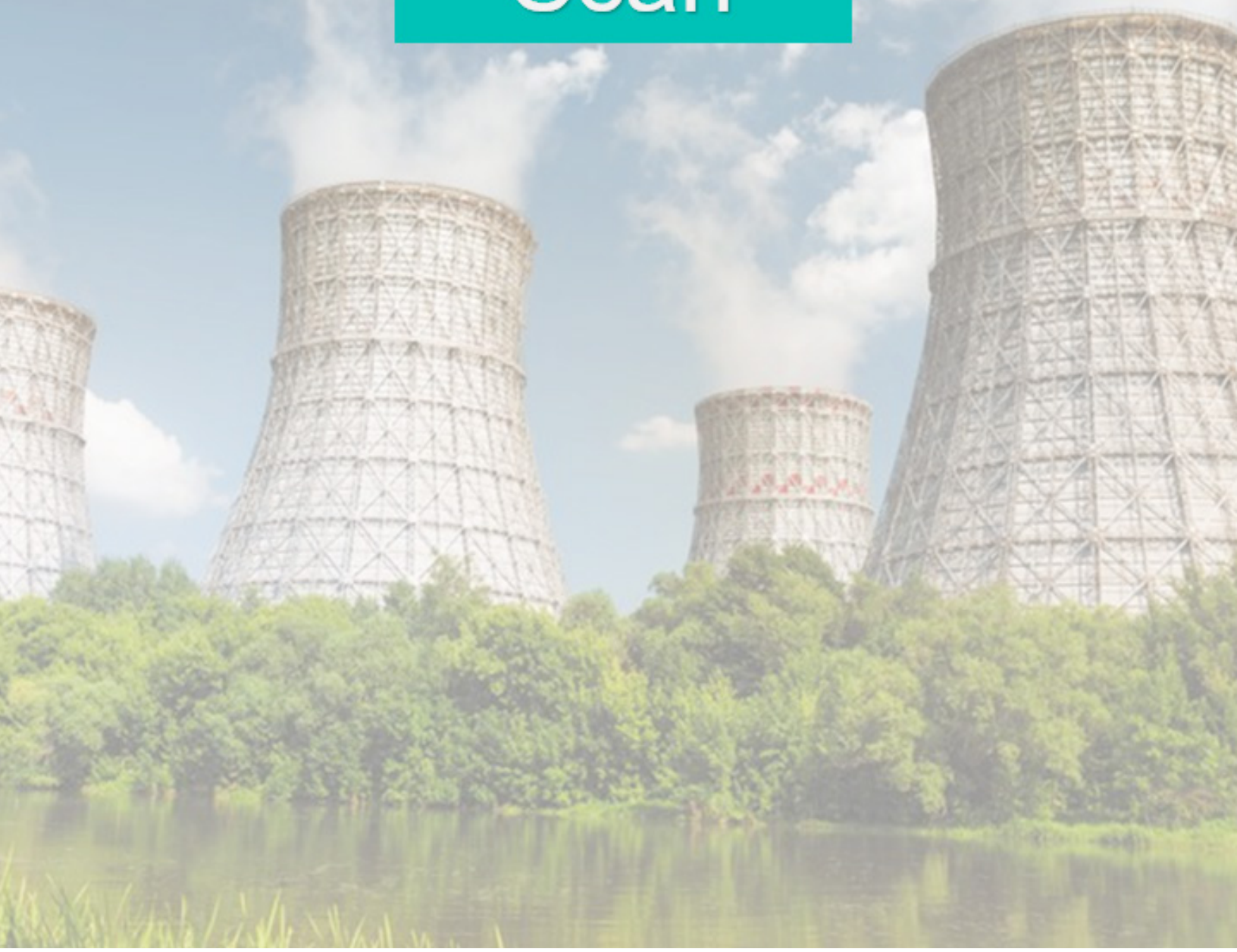
The following are additional references on CTs:

- [“Buildings Cooling System”](https://www1.nyc.gov/assets/buildings/pdf/evaporative_cooling.pdf)
(https://www1.nyc.gov/assets/buildings/pdf/evaporative_cooling.pdf)
- [“What is a Cooling Tower”](https://www.cti.org/whatis/coolingtowerdetail.shtml) (<https://www.cti.org/whatis/coolingtowerdetail.shtml>)

More information and videos that explain CT mechanics and structure are available online.

For a list of CT manufactures please visit the [Cooling Tower Institute webpage](https://www.cti.org/directories/manufacturers.php) (<https://www.cti.org/directories/manufacturers.php>).

Scan



2. SCAN

After becoming familiar with CT models and shapes, the following section lists the methods for using GE to conduct and set up a systematic CT scan, identify CTs, and label CTs for later use.

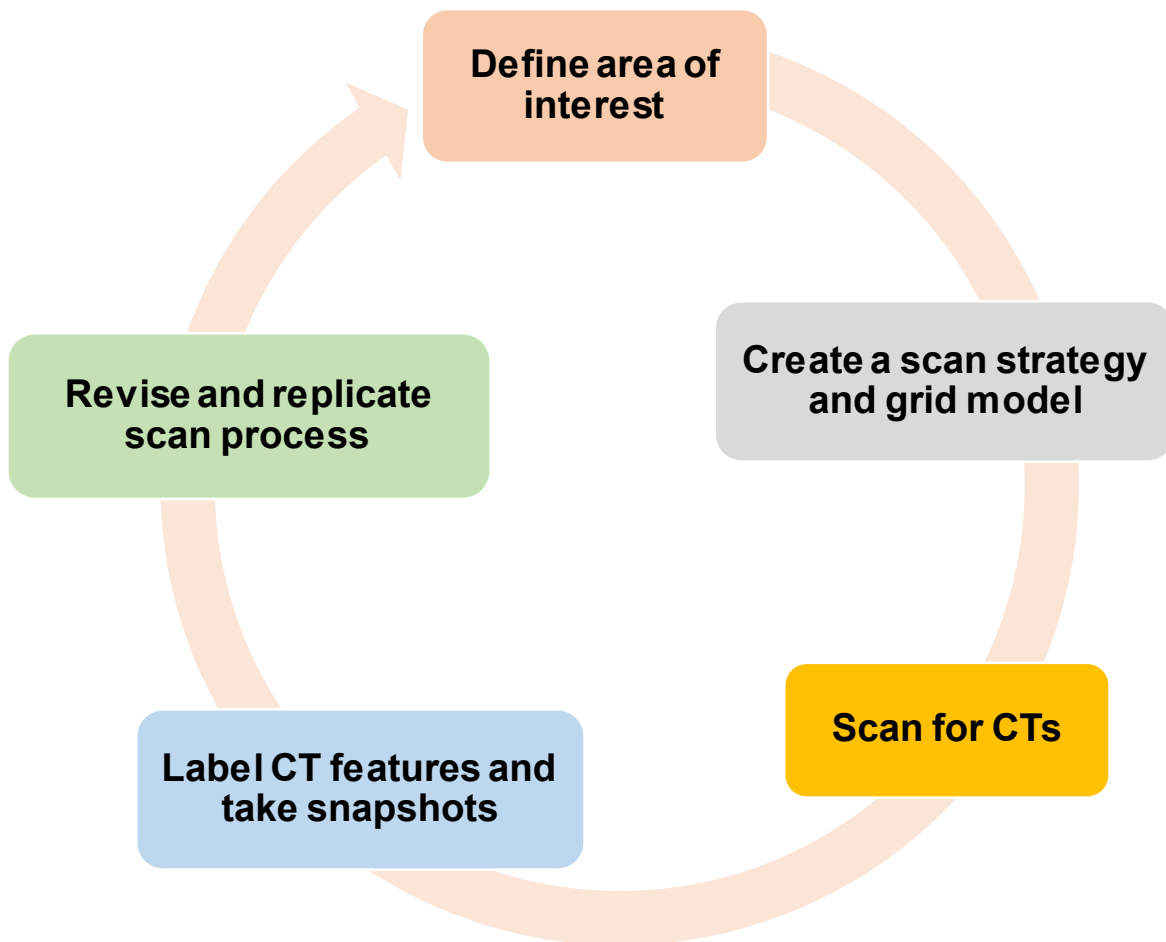


Figure 11: A CT scan starts with defining a study area of interest. The second step is creating a strategy to help track progress during the scanning process. The next steps, the bulk of the scanning process, include learning how to scan/ identify CTs structures, and label CTs to track progress. The final step is to refine methods used and review CTs identified. The scan process is iterative and can be repeated to increase accuracy of results and identify changes to maps of CT locations as time passes.

A. DEFINE AN AREA OF INTEREST

Before beginning the scan, define the area of interest that will be examined for CTs. This could be defined by administrative or other boundaries (i.e., a county, city, neighborhood, street block, or the perimeter of an outbreak area). A consideration when defining an area of interest is whether a shapefile already exists to help delineate borders within GE ([Figure 12](#)); presence of a pre-existing shapefile will make the GIS workspace easier to establish.

There are no limits on the geographical boundaries for an area of interest, but it will be easier to learn the process by starting with a smaller area of interest, such as a neighborhood or a small block, and then revising the scan strategy for a larger area. The larger the study area, the more time it will take to identify CTs. For reference, below we estimate the amount of time it will take one experienced person to identify CTs based on common area geographies.



Figure 12: Common types of geometries for shapefiles are neighborhoods, cities, and census tracts.

Geographical Area	Approximate Time to Complete a CT Scan
Small block or census tract	2-3 hours
Small, non-dense city	1 month
Large city (over 1 million people)	2-4 months
Small county	2-5 months
State	12-48 months

OPTION 1: DESIGNATING AN AREA OF INTEREST IN GOOGLE EARTH

* For all demo protocols, Orange County, California was used as the area of interest.

- Download and open [Google Earth Pro](#)
- Zoom to the area of interest
 - In the top left search bar type the area of interest and click 'Search'
 - If the study area is not available from the search bar or the study area is unconventional, then use available zoom tools:
 - Zoom using computer mouse scroll and mouse pointer
 - Zoom using the slider icon at the top right corner of the screen
- If able, zoom to the study area on the map, then right click the location and select 'Save to My Places'
 - The name of the study area should now be seen in the contents bar on the left side, under 'My Places'

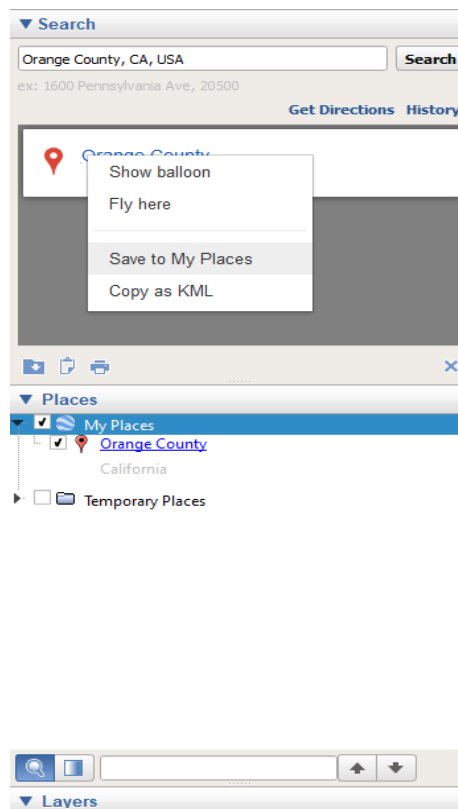





Figure 13: Study area saved under 'My Places' in GE.

- If the defined study area was not available in the search bar, the drawing tools can be used instead to outline the study boundaries or drop a pin.
 - To drop a pin for the study boundary, click the 'Placemark' icon  on the top menu bar. Drag the placemark to the study area of interest. A small box should pop-up. Under name, label the placemark with the name of the study area.
 - To outline the study boundary, click 'New Polygon' icon  at the top menu bar
 - If the study area does not fit the shape for drawing a polygon, use the free hand 'New Path' tool icon  and draw the study boundaries.
 - Alternatively, any of the three options can be selected using the 'My Places' tab.
 - Under 'My Places' > right click > select 'Add' > and choose to add 'New Polygon', 'New Path' or 'Placemark.'

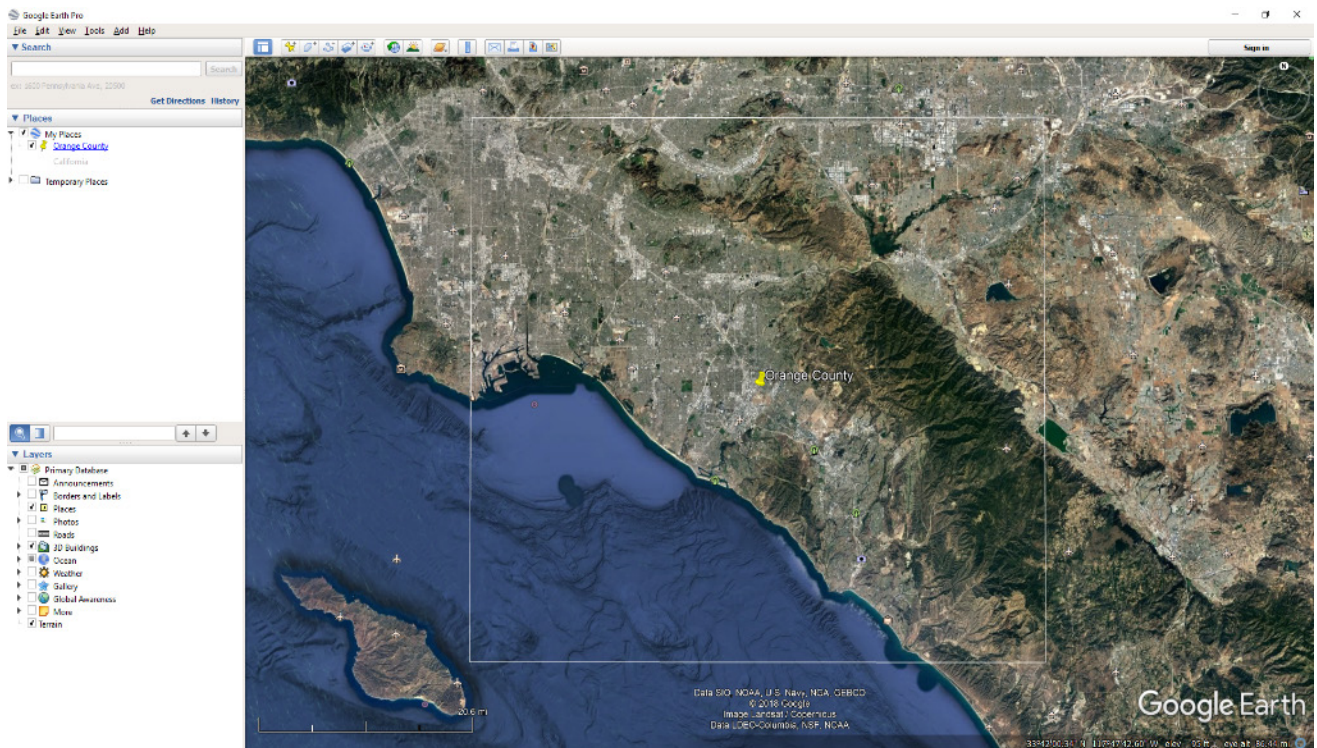


Figure 14: 'Placemark' added to indicate a study area in GE.

- Save area boundaries.
 - Once the study area has been designated, save the location so that the point can be referenced every time GE is reopened.

- To save > right click 'My Places' > Select 'Save Place As.'

Each time the GE file is opened, the study area should be labeled under 'My Places,' and the file should be saved. If the file is opened from a saved place, it typically opens under the 'Temporary Places' tab, and from there can be moved and dragged to 'My Places.' Having the file under 'My Places' allows for the file to be immediately moved to the location where the user left off each time the program is opened.

OPTION 2: IMPORT THE AREA OF INTEREST DIRECTLY USING A SHAPEFILE

- If the study area boundaries have already been established, or if the user has a shapefile, they can be imported directly into GE. For example, if the study area is counties in the San Francisco Bay Area, then the shapefile can be downloaded online from the United States Census Bureau.
 - Once the shapefile has been downloaded and saved, open the shapefile in GE and move it from the 'Temporary' folder to 'My Places.'

*For additional info on databases of available shapefiles, see **Analysis Resources** under [Additional Resources](#).

B. CREATE A GRID MODEL FOR SCANNING

The purpose of a grid model is to help track progress of each CT scan. Grid models are most useful for larger study areas and may not be necessary if scanning smaller regions (i.e., one census block). We recommend using a grid model if: (1) the scan is estimated to take more than 30 minutes, (2) if more than one user will be scanning the same area, or (3) if the study boundaries are not a typical geometric shape. If the study area is small and a grid model is not needed, then skip to [Strategy to Organize Scanning](#).

There are several ways to create a grid model that will be compatible with GE, and additional links are provided at the end of this section. The following steps describe how to create one type of grid using ArcMap (the methods in ArcPro should be similar).

1. Download and open ArcMap 10.5.
2. Import downloaded shapefile for the study area of interest.

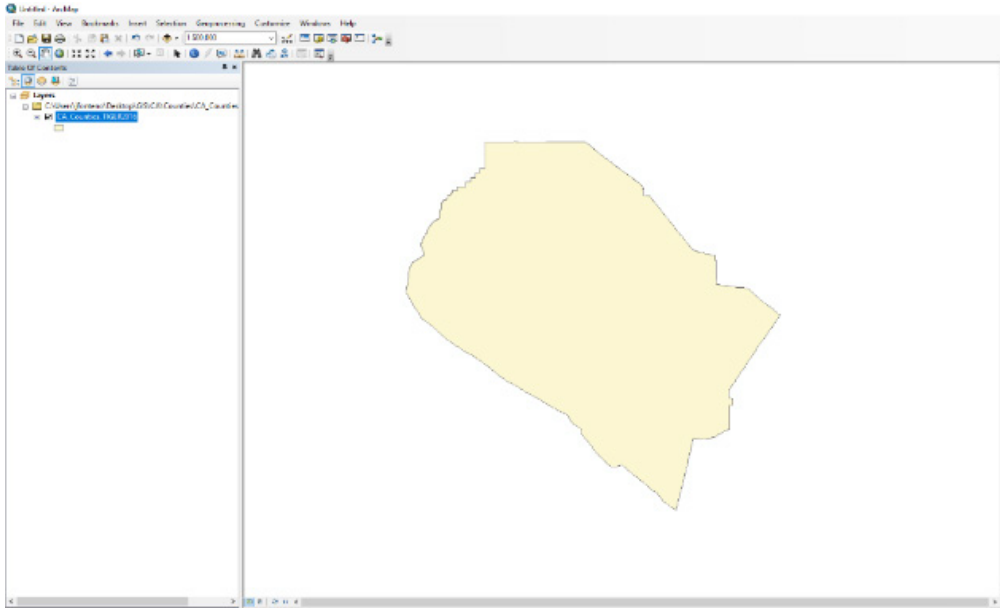


Figure 15: A study area boundary created by importing a shapefile directly into ArcGIS.

- a. If the study area is the boundary of a state, county, or a city, then shapefiles should be available from [the United States Census Bureau TIGER database](https://www.census.gov/geographies/mapping-files/time-series/geo/tiger-line-file.html) (https://www.census.gov/geographies/mapping-files/time-series/geo/tiger-line-file.html).
3. Open the 'ArcToolbox' > 'Data Management Tools' > 'Create Fishnet.'
 - a. Note: Organizational licenses for ArcMap vary, and some of the features needed for this step might be locked. If this occurs, users should contact their organization to have fields enabled.
4. In the 'Create Fishnet' tool, users can customize the grid layer to the size that they want (for OC, we used a grid size of 200 meters x 200 meters). See [Grid Model Scanning](#) for more details on choosing an appropriate grid size.
 - a. For example:
 - i. Output feature class: Grid_'name of area'
 - ii. Template Extent: Same as layer 'name of your shapefile layer'
 - iii. Cell size height: 5
 - iv. Cell size width: 5
 - v. Number of rows: 0 (zero is a default setting which automatically creates rows)
 - vi. Number of columns: 0
 - vii. Check create label points
 - viii. Geometry type: Polygon

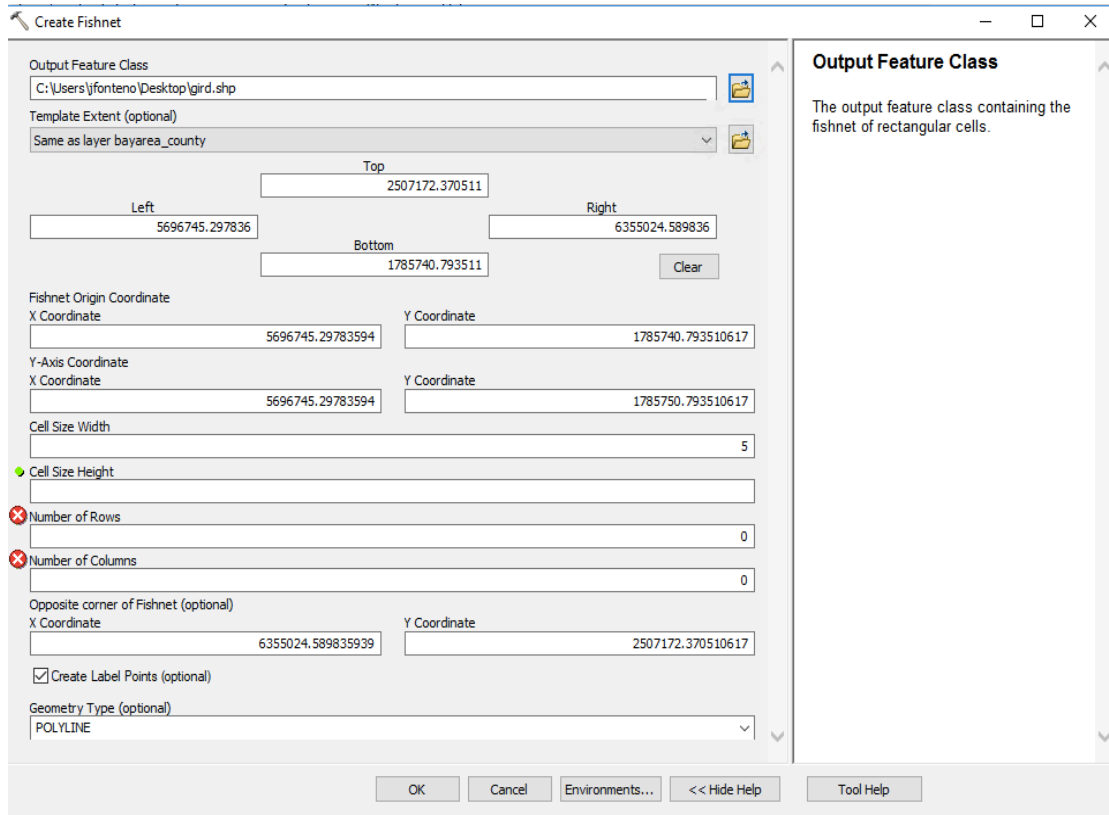


Figure 16: 'Create Fishnet' window in ArcGIS.

5. After running the grid model, convert it to a KML file, and import the grid into GE.
 - a. In 'ArcToolbox' > 'Conversion Tools' > To KML > input the grid layer and pathway to where the file will be stored.
6. In GE > 'File' > 'Open' > navigate to the saved KML grid layer.
7. If using ArcGIS Pro, use the 'Generate Tessellation' tool. Under 'Extent,' choose a layer with whatever area boundary is being used, or just zoom into the area of interest and use the screen extent. For shape type, choose square.

For additional reference on grid models use the following videos and guides:

[“How to Create Grid in ArcGIS with Required Dimension”](#):

<https://www.youtube.com/watch?v=7o01Y9bWwFw>

[“ArcGIS Creating Polygon Grid - Create Fishnet”](#):

<https://www.youtube.com/watch?v=v3U3DJ2JZXg>

[“ArcGIS Desktop: Creating a Polygon Grid with Specified Coordinates”](#):

<http://desktop.arcgis.com/en/arcmap/latest/extensions/data-reviewer/creating-a-polygon-grid-with-specified-coordinates.htm>

[“Work with a Grid in ArcGIS Pro”](#): <https://www.youtube.com/watch?v=Tm-k5d3Ar54>

[“Michigan Technological University: Creating a Regular Grid for Point Sampling”](#):

http://gis.mtu.edu/wp-content/uploads/2012/06/Regular_Sampling_Tutorial.pdf

ArcPro Guides:

[“ArcGIS Pro - Grid Index Features”](#): <https://pro.arcgis.com/en/pro-app/tool-reference/cartography/grid-index-features.htm>

[“ArcGIS Pro - Add a Grid”](#): <https://pro.arcgis.com/en/pro-app/help/layouts/add-a-grid.htm>

C. STRATEGY TO ORGANIZE SCANNING

A scan strategy is the process used to track progress and easily identify which areas have already been scanned for CTs and which areas still need to be scanned. Forming a scan strategy is simple and based on what will best help to track the overall scanning process. Two model suggestions are provided below: a scan strategy using census tracts and one using grid models. Building parcel data (i.e., Landvision) can also be incorporated to help prioritize scan areas, described in [Parcel Data / Landvision](#).

I. CENSUS TRACT SCAN STRATEGY

This strategy uses the census tract boundaries to help define the scanning ‘work space.’ This is often used in combination with the grid model approach (see [Create a Grid Model for Scanning](#)). By itself, a census tract approach is less systematic than a grid strategy. However, if the work area is small (i.e., a few census tracts), then this method can be used on its own.

Some additional pros and cons of this method:

- Pros:
 - Census tract boundaries are readily available online.
 - The overall scan area may fall more neatly into census tract boundaries rather than county or ZIP code.
- Cons:
 - Census tracts are quite varied in size and keeping track of progress within each census tract can quickly become difficult (it is easy to miss areas or repeat work).

The following steps describe how to use census tract borders to organize scanning and track progress:

1. Open the previous GE file with the area of interest saved. Be sure to also download and open the shapefile that has the study area with census tracts.
2. Move the file from ‘Temporary Places’ to ‘My Places’ to permanently save within the project.
3. Right click the ‘Census’ layer > ‘Properties’ > ‘Style and Color’ > Change fill color to ‘no fill’ > Change outline color to be more visible and increase the outline width.

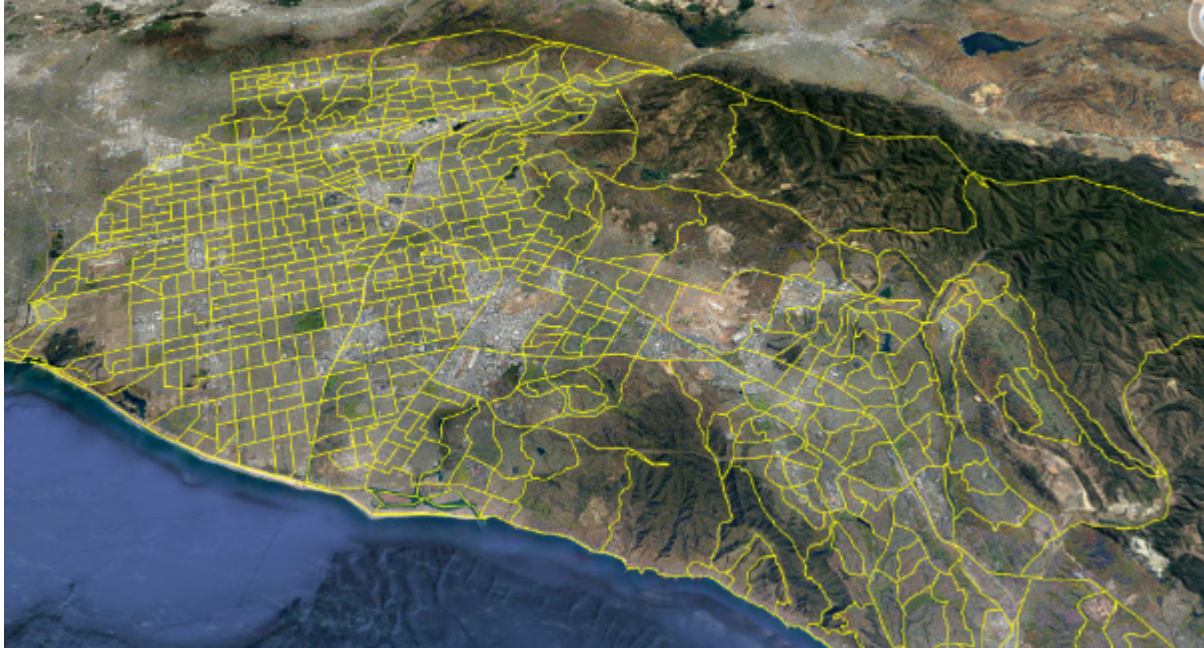


Figure 17: Study area with census tract borders added.

- 4. Next, zoom into one of the census tracts (this is one scanning strategy, using census tracks as boundaries).
- 5. Within each census tract, start by filling each screen to scan right to left. Then, scan down, and lastly scan again left to right. This process of moving across the screen continues until the entire census tract has been scanned.



Figure 18: Zoomed-in view of a study area census tract, with arrows indicating the recommended scan path.

After each census tract is completed, mark the center of the census tract with a pin to easily keep track of areas that have been scanned.



Figure 19: Census tract for which scanning is complete, as indicated by a pin.

II. GRID MODEL SCANNING

Using a grid model for scanning may be easier and more systematic, as grids will have a set shape. An effective strategy for larger areas is to use a combined grid and census tract strategy; within census tracts, a grid is used to track scanning progress while overall progress towards completion of a county is tracked by completion of census tracts. Grids can be modified to different sizes with the main purpose being to prevent losing track of which buildings have already been scanned and which have not. This means grid sizes can vary depending on user preference. One strategy might be to zoom into a high enough resolution sufficient to identify CTs. Using that screen size as reference, a single grid square would be the same size as the screen. Thus, once a single screen is finished, the user can pan to the next grid square without duplicating work or missing buildings ([Figure 20](#)).



Figure 20: Sample grid/fishnet over OC.

Practically speaking, users will zoom in and out multiple times depending on what types of buildings are being scanned. Additionally, a single-screen grid size can be impractical as the number of grids needed to cover an area can be quite large. A compromise then might be a grid size that covers four screens (i.e., two vertical screens and two horizontal screens; [Figure 21](#)).

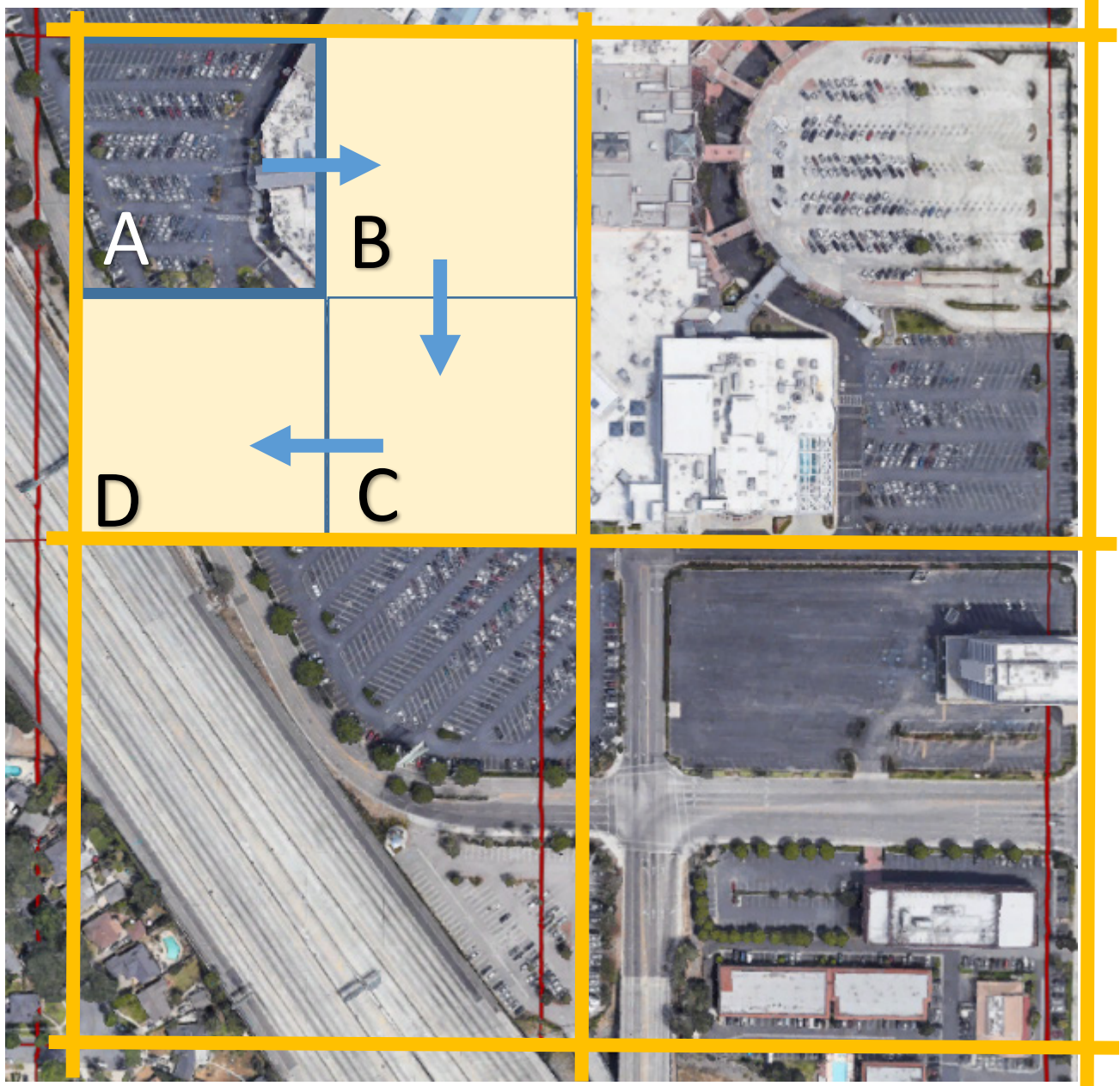


Figure 21: Each grid square (yellow squares) can be divided into four zoomed-in images. Starting in the top left corner of the grid square, the first entire zoomed-in image (A) can be scanned without moving the map around the screen. Once that zoomed-in image is completed, the map is panned to the right and the second zoomed-in image is completed (B). In this manner, the grid square can be systematically completed while only moving the map 4 times (A > B > C > D).

For the OC CT project, a grid size of 200 meters x 200 meters (40,000 square meters) was used. At this size, one grid square could be completed by panning the monitor only 4-8 times, with variation depending on what resolution was being used ([Figure 21](#)).

Experiment with larger or smaller grid sizes to see what works best; the trade-off is between load times in GE and grids being small enough to help divide up work efficiently.

III. CREATING A GRID

See [Create a Grid Model for Scanning](#) for details on creating a grid.

IV. PARCEL DATA / LANDVISION

Parcel data from Landvision (Digimap Lightbox) can be used to reduce workload. Landvision parcel data provide information on the zoning details for parcels. CTs are generally not found in areas zoned for single family homes (in our OC CT mapping project, no CTs were found in areas zoned for single family homes). So, one use of Landvision parcel data could be to select all parcel zone types *except* those for single family homes. By identifying parcels not zoned for single family homes, efforts can be focused on areas of higher yield, and the risk of missing retail or other establishments hidden in residential areas can be decreased. Whether CTs could exist on single family homes in areas outside of OC is unknown and use of parcel data should be tailored to the region of interest after an initial pilot scan. Additional filters could be used as well and should be explored.

USING LANDVISION

Landvision data are not freely available, but some government agencies pay for ongoing access. Users may have to work with their information technology (IT) teams to arrange access to Landvision data.

After launching the Landvision web application, first choose the property types on which CTs are more likely to be used. For our purposes, we chose all zone types except for those containing single family homes. Since Landvision highlights building types selected (rather than buildings that are excluded), we chose to exclude single family homes (rather than to include single family homes and exclude all other building types) so that we would focus on visually highlighted areas ([Figure 23](#)). The following steps describe how to use Landvision data to prioritize scan areas.

1. First, choose the area of interest. Landvision will automatically show all parcels meeting the search criteria on the screen, and it is best to minimize the number of results to reduce processing time. Additionally, the maximum number of results that can be exported to a shapefile is 500, which is a very small number. One way to address this is to reduce the size of the area of interest (and repeat this process numerous times). Alternatively, keep the area the same, and instead group the types of property (i.e., only show industrial buildings and then, only hospitals and hotels).

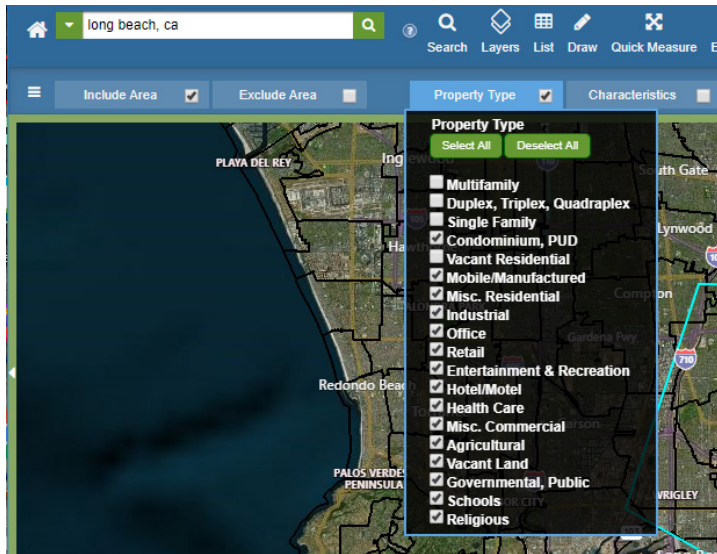


Figure 22: List of property types as shown in Landvision.

2. Once there are fewer than 500 'visible search results,' export to a shapefile using the 'Copy to Markup' option that is within the icon of an arrow pointing down next to the 'Add to List' button. As long as there are fewer than 500 results, they can be copied to a markup layer, and then extracted as a shapefile in the layer options.
3. The copied layer will appear on the layers menu as 'Search Results: Property Search' and in the icon next to that layer, choose 'Extract' and the shapefile download will begin in the browser.
4. Once downloaded the shapefile(s) has been downloaded, import this file into GE. Once loaded, change the borders of the parcel data into a color that is easy to see (e.g., bright green) with transparent filling. Then, when scanning, users will be able to quickly focus only on areas that light up, potentially saving time and reducing fatigue.



Figure 23: Example of highlighted Landvision parcel data (bright green polygons) showing areas that are zoned for retail or public use. CT scanning can focus on these areas and ignore other areas, including those zoned for single family homes.

V. TRACKING EACH SCAN

Within each grid/census tract, be systematic about the buildings being scanned. As many as 5-10% of CTs can be hidden in parking lots, on the sides of buildings, under trees, and in other hard-to-see places. **It is very easy to miss even a large CT if a systematic scan method is not being used.** A system that was used for the OC project (and can be adapted for different users) was to divide up the common objects making up the screen (i.e., building rooftops, roads/parking areas, green areas, etc.). For each object type, we scanned the screen, moving from left to right in an ordered fashion. Once the scan was completed for each object type, we repeated the process for the next object type until all objects in the screen were scanned.

Example of scanning a school area:

1. Scan the rooftop(s): Start by looking specifically at the rooftop(s) in the image/area. In the below example ([Figure 24](#)), the school campus has multiple buildings. Look at each rooftop in order (A, B, C, D, etc.) before looking at other things (trees, ground, etc.). Note that a closer zoom than the zoom level of the picture below will be needed in order to spot CTs.



Figure 24: Scanning rooftops.

2. After finishing looking at the rooftops, circle the perimeter of each building from an oblique view to look for CTs hidden on the sides of buildings.



Figure 25: Example of oblique images showing sides of buildings, where CTs can sometimes be located.

3. Look at all asphalt/parking areas/dumpsters/small ground buildings (everything gray or on the ground that is not grass/green), outlined by the red line in [Figure 26](#).



Figure 26: School buildings, with the path eyes should follow to look for asphalt/parking/small ground buildings marked in red.

- Next, look at all the green areas (i.e., grass, trees, etc.), with the path outlined in red below ([Figure 27](#)).



Figure 27: School buildings with the path eyes should follow to look for CTs hidden under trees or on lawns marked in red.

VI. MARKING PROGRESS

Regardless of the scan strategy being used (grid or census tract, with or without using Landvision data), it is important to mark when each grid cell or census tract cell is finished. One way of doing this is to shade in each layer that has been completed ([Figure 28](#)). Another option is to add pins to grid cells or census tracts after scanning is complete ([Figure 29](#)).

Marking each grid or census tract will help to track progress until the entire area of interest has been scanned, ensuring that work is not repeated, or areas missed.

- Color coding: On the current grid or census tract, right click > 'Properties' > 'Style and Color' > 'Area' > 'Filled and Outlined' > to change the fill color and differentiate between cells that have not been scanned.

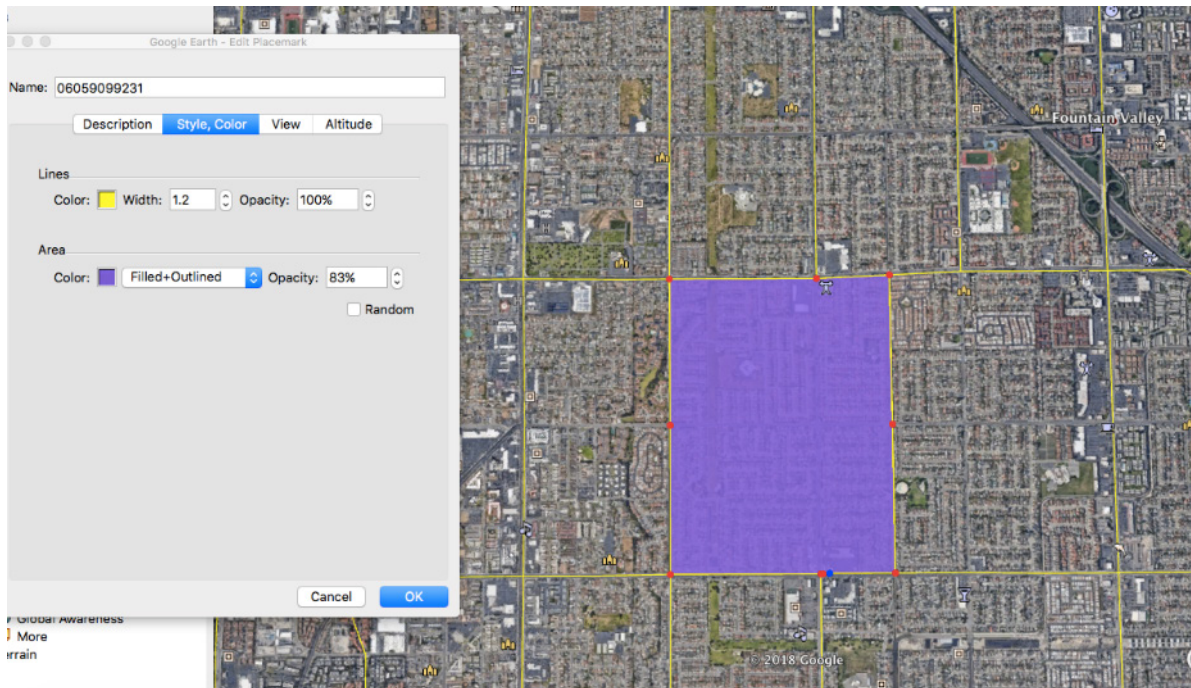


Figure 28: Example of using color coding to shade in scan progress.

- Adding a pin:



Figure 29: Yellow pins in each grid square indicate which grid squares have been completed.

D. SCANNING FOR CTS

After accessing imagery, defining the area of interest, creating a grid model and/or a scan strategy, scanning can begin! The following is a general protocol with parameters to use when scanning for CTS.

I. SCAN PARAMETERS

1. Open the GE project with the area of interest and grid model and zoom to the first scan cell. With the scan strategy in mind, start to look at building structures for CTS.
2. Use the following parameters to ensure scanning is occurring at the proper distance:
 - i. Set eye altitude (GE term for zoom resolution) and zoom at a minimum distance of 600 feet (about 200 meters).
 - i. Click 'Google Earth Pro' in the menu bar > 'Preferences' > '3D View Tab' > and set the unit of measure to feet, miles (or meters, kilometers).
 - ii. Under the 'View' tab > check the box for 'Status Bar.'
 1. Elevation and coordinates will appear on bottom right of the screen.
 2. Zoom into the first grid and scan for CTS with an eye altitude of about 600 feet ([Figure 30](#)).




Figure 30: CT from about 600 feet eye altitude in GE.

- ii. Adjust tilt view to look directly parallel to ground surface. (Quickly do this by hitting Control + R or Shift + Up arrow on keyboard.)
 - a. Use the keyboard arrows to move left and right as you scan.
 - b. Examine the sides of buildings by titling the view up or down. This will help to identify potential side fans on CTs ([Figure 31](#)).



Figure 31: CT found using tilt view in GE for a side view.

- iii. Under 'Layers' > select the checkbox for '3D Buildings.' Turn off all other layers except 'Terrain' and '3D Buildings.'
- iv. Ensure the time slider displays the most current satellite image.
- v. In the top menu bar, make sure that the 'Show Historical Imagery'  tool is not selected.

II. COOLING TOWER IDENTIFICATION GUIDE

A question that should be asked repeatedly and often is, “Is that fan unit actually a cooling tower?” Identifying whether a structure is a CT or not is one of the most difficult and important tasks in the entire CT-identification process.

As such, please now see the [Cooling Tower Identification Guide supplement](#) for tips, suggestions, and examples on distinguishing between CTs and non-CTs on satellite and aerial imagery. This section is an adjunct but is an important and useful section that was extracted to a supplemental document due to the number of photos included and potential usefulness as a standalone document.

After reviewing the supplemental document, return to this document and proceed for additional steps in the CT-identification process.

III. EXAMINE OLDER SATELLITE IMAGES FOR COOLING TOWERS

Historical imagery can be helpful for a few reasons: by providing additional imagery with which to confirm that a structure is a CT, and by helping gauge the age of the CT/when a CT may have been built. The following are steps for viewing older images in GE.

1. At the top toolbar click ‘View’ and check the box for ‘Historical Imagery.’
 - a. A slider should appear in the top left corner with the current year. Use the tool to slide to historical images, labeled by date of the satellite image.
 - b. To exit, uncheck the ‘Historical Imagery’ box in the ‘View’ toolbar options or close the box.
 - c. The image below ([Figure 32](#)) shows the same CT with imagery from March of 2015. Use the slider to see how buildings and CTs have changed over time.

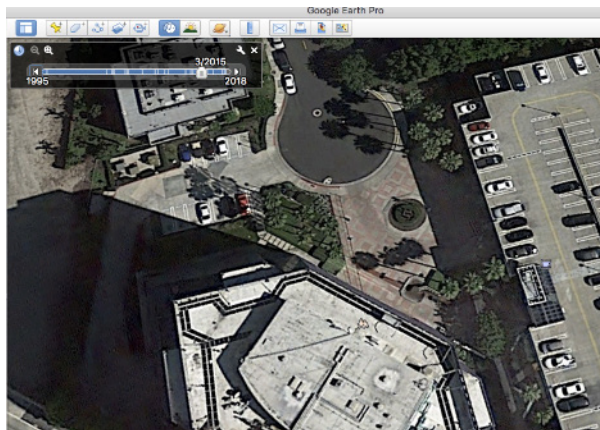


Figure 32: Historical images toolbar in top left of GE.

E. LABELING COOLING TOWERS

When scanning and identifying CTs, applying labels and descriptions can later help with analyzing project data. The type of labels to add depend on the intended use of the data. For the OC project we used:

- Object Identification Number (OID)
 - Can label sequentially or define a scheme for naming/numbering CTs identified
- Location
 - Ground
 - Roof
- Number of fan blades
- Year CT appeared in satellite images between 2014 to 2018
- Confidence score
 - Low
 - Medium
 - High
- Size
 - Diameter in meters
- Building type

I. LABEL DESCRIPTIONS

OID is the numerical order for CTs identified. For example, the first CT found from a scan was given the ID number 1 and then labeled numerically. This also helped track the total number of CTs found in the study area. Different schemas can be designed for different needs. For the OC project, we labeled each structure that appeared to be independent (i.e., we imagined that an independent CT could be removed, without rendering an adjacent CT inoperable) as an individual CT. Another method might be to label each cluster of CTs as one CT, regardless of how many independent CT structures may be there. It is important to decide on a method of determining an independent CT *before* scanning begins and maintain the same scheme throughout the scan process for consistency ([Figure 33](#)).



Figure 33: Cluster of CTs on a rooftop. This could be considered one CT cluster, three CT groups, or six independent CTs. Numbering schema should be consistent throughout your identification process.

- **Location** is the physical location of a CT (whether on top or side of a building, or on the ground). This was included since the distance that CT drift can reach may vary if a CT is on the ground or on top of a building. Consideration could be given to approximate height (i.e., 50 story building versus two story building).
- **Number of fan blades** can be determined by counting the number of circular fans on each CT base. Most round CTs have only 1 CT fan, while square and rectangular CTs often have sets of two, four or six fans. This is also important, as it is sometimes difficult to determine what constitutes a single CT unit. Some units may have six very large fans, while others may only have one small fan.
- **Year CT appears** included the earliest year a CT was found present in CT images, using the time slider option on GE. For the initial study we viewed images from 2014 to 2019. If the CT was present before the study period, it was given the earliest study date of 2014.
- **Confidence score** was used as a measure for rating the scanner's overall confidence that a CT was actually present at a location marked. We used scores of low, medium, and high. These categories were subjective, and a means to mark CTs for later discussion or review with another scanner. CTs marked with a confidence score of 'High' were those for which the scanner was highly confident, and thus did not need review by another scanner. 'Low' confidence CTs were those that were not clearly CTs and were all reviewed by another scanner for a second opinion. 'Medium' confidence CTs were thought to likely represent a CT but were still reviewed by another scanner after all 'Low' confidence CTs were first reviewed.
- **Size** was recorded as both diameter of fan in meters and a qualitative size category (i.e., small, medium, large). Qualitative categories can be adjusted based on distribution of diameters of CT fans found within each project.

II. ADDING LABEL DESCRIPTIONS

When a structure that appears to be a CT is found, drop a pin to mark the location and add a label description.

1. Right click on the folder name under 'My Places' > 'Add' > 'Placemark'
 - a. A text box and a yellow box will appear.
 - b. Move the yellow box on the map to the location of the identified CT.
 - c. Under the 'New Placemark Name,' label the object ID for the CT.
 - d. To change the placemark symbol or color, click the 'Placemark' symbol next to the name
2. Under the description box, add more specific labels.
 - a. When adding descriptions, we separated values with a comma for future data cleaning. There is no need to add label headers, only the values for each label.
 - b. [Figure 34](#) shows the OID for CT number 7 from the OC project, and descriptions as: Location=roof, Number of fans= 2, Confidence= high, Year available= 2014.

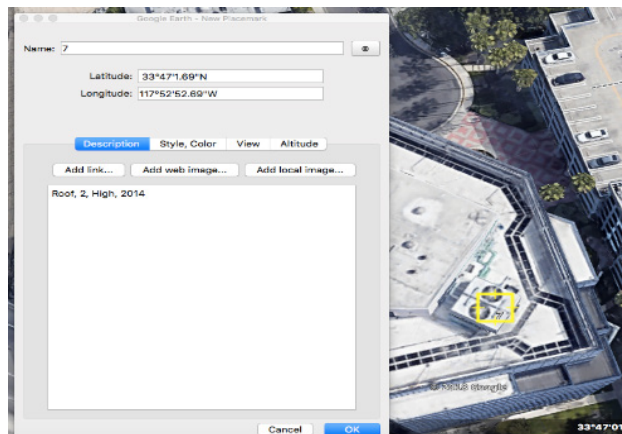


Figure 34: Adding a placemark and label descriptions.

III. TAKING SNAPSHOTS (OPTIONAL)

Adding pictures of each CT as an additional label may be useful to create a repository of CT images found. Note however that this may consume a lot of memory / disk space and may not be necessary for many projects. The below steps outline how to take and label snapshots.

1. After adding a placemark label, take a screenshot of the CT in GE.
2. Select the label for a CT for which an image has been identified > 'Get Info' > 'Add' > 'Local Image' > navigate to the screenshot.
3. Whenever the CT is selected, the image and label descriptions will appear ([Figure 35](#)).

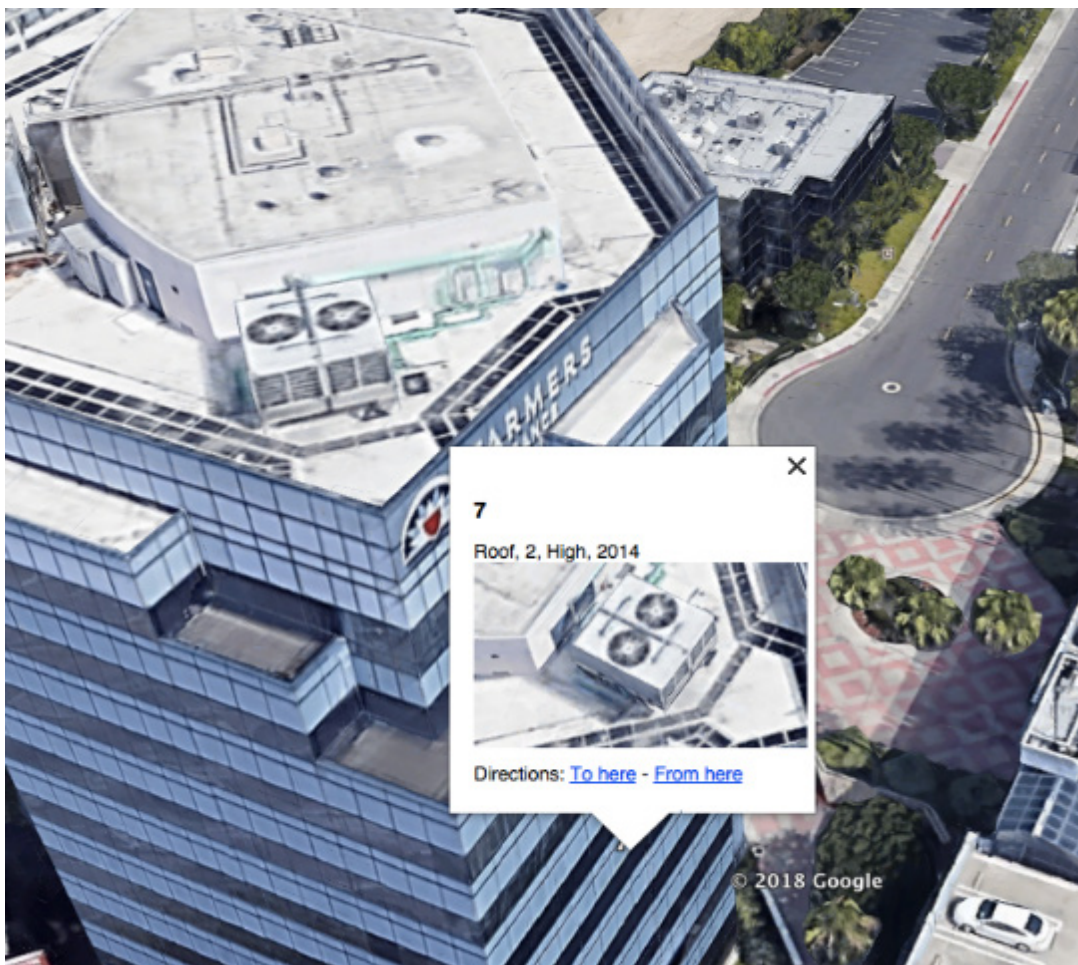


Figure 35: Example taking screenshots for additional label descriptions.

Post-Scan



3.POST-SCAN

A. CONVERTING DATA PRODUCTS

I. CONVERTING GOOGLE EARTH FILES FOR GIS ANALYSIS IN ARCMAP

While GE is an excellent GIS program, it is less ideal for analysis. Thus, users may want to export GE files into another GIS program (e.g., ArcGIS) for analysis.

1. In GE, first save the CT layer as a KMZ file. In GIS programs, layers are generally a distinct set of data (either a raster/picture, points or polygons) that is 'layered' over a base map (i.e., the satellite image of an area). For this project, the CT pins are a point layer.
 - a. Each folder under 'My Places' in GE can be considered one layer. The CTs towers should be individual pins, but all organized under a folder within 'My Places.' If the CTs are not within a folder, then each CT is considered an individual layer.
 - i. To organize CTs into a folder, first create a folder.
 1. Right click 'My Places' > 'Add' > 'Folder'
 - a. Name the folder 'Cooling Towers'
 - ii. Drag all CT pins into the 'Cooling Towers' folder.
 - b. Right click on the folder containing the CTs > 'Save Place As', and choose the .kmz file extension to save in.
 2. Open ArcMap
 - a. Use 'Toolbox' > 'Conversion Tools' > 'Convert from KML to Layer.'

Refer to the [Tufts GIS Center resource for detailed instructions on Google Earth file conversion](http://sites.tufts.edu/gis/files/2013/11/GoogleEarthTutorial_kml-shp_conversion1.pdf) (http://sites.tufts.edu/gis/files/2013/11/GoogleEarthTutorial_kml-shp_conversion1.pdf).

II. GEOCODING COOLING TOWER POINTS

If the KML file is not already georeferenced, or additional data needs to be geocoded (i.e., legionellosis cases) with known latitude / longitude coordinates, then start by geocoding the points for it to be spatially recognized in ArcGIS.

1. Geocode the X,Y,Z coordinates for the attribute table.
 - a. 'Toolbox' > 'Data Management Tools' > 'Features' > 'Add XY Coordinates' > Select the current table in ArcMap from the KML conversion.
 - b. Exit the toolbox.

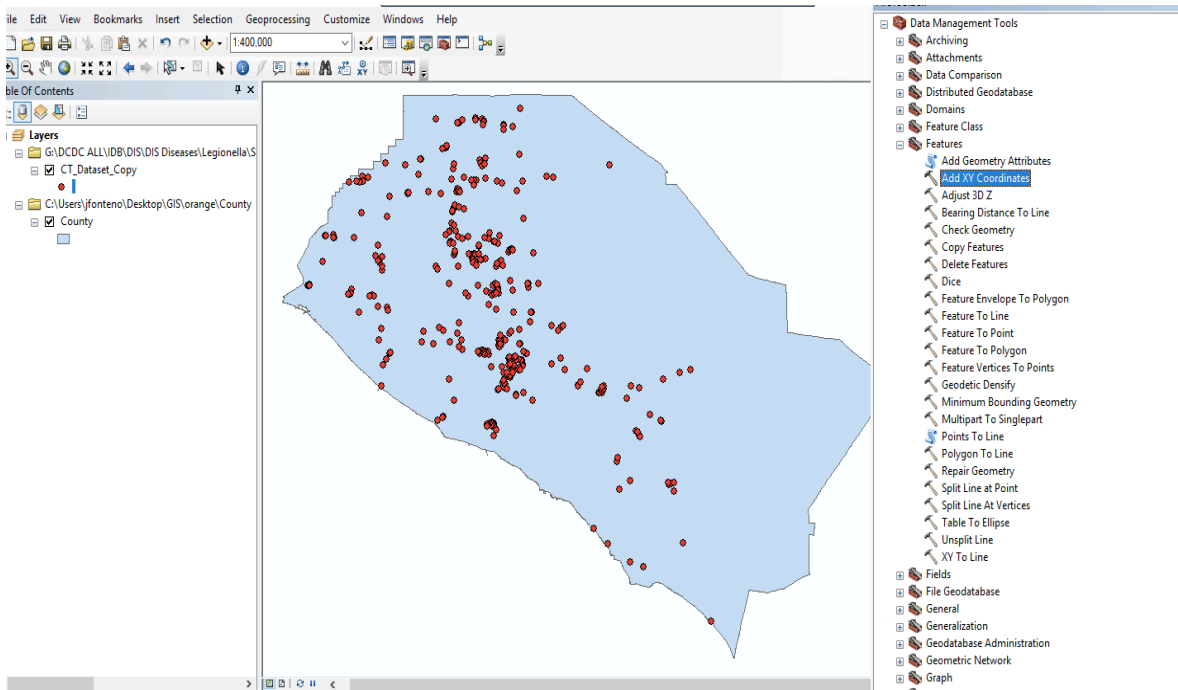


Figure 36: Example showing the 'Add XY Coordinates' function in the ArcGIS 'Toolbox.'

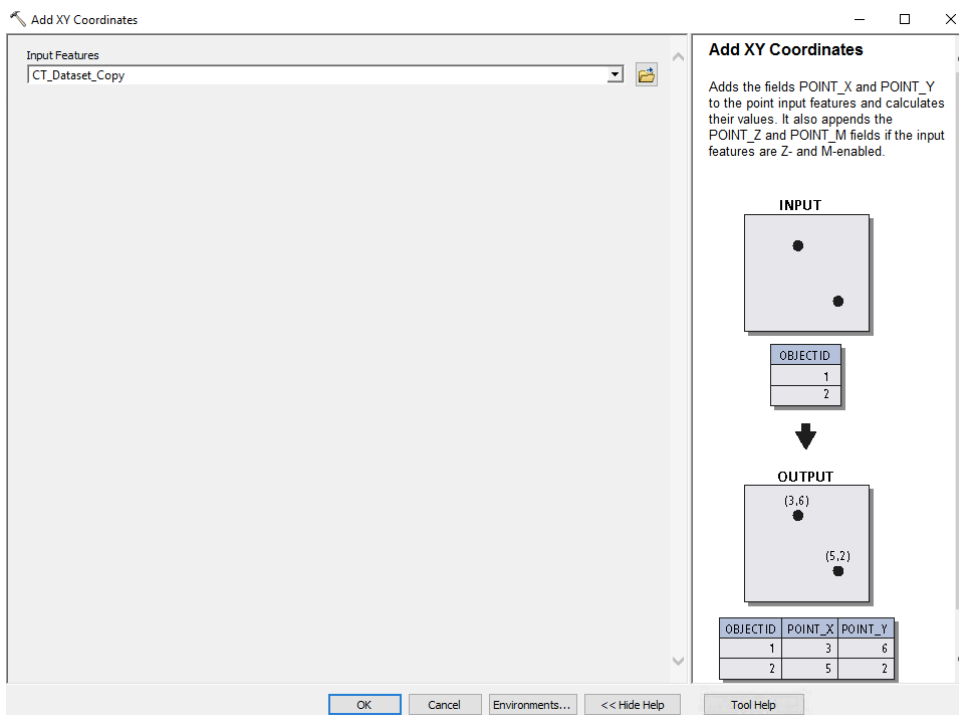


Figure 37: Window in which to select table for the 'Add XY Coordinates' function.

III. EXPORTING TO MICROSOFT EXCEL FOR DATA CLEANING (RECOMMENDED)

While data in ArcGIS can be viewed and edited by using the attribute table (a spreadsheet attached to each layer), it is best to do non-spatial data cleaning and manipulation in a separate program and then re-import into ArcGIS (using the steps from [II. GEOCODING COOLING TOWER POINTS](#) above).

1. Navigate to the 'Toolbox' > 'Conversion Tools' > 'Excel' > 'Table to Excel.'
2. 'Input Table' = the labeled file in ArcMap (which should now include X and Y coordinates for all CT points).
3. 'Output Excel File' = Name the file.

CONVERTING DATA IN MICROSOFT EXCEL

When cleaning data, be sure to properly label each column, convert the CT labels created in GE, and ensure that erroneous data are removed or corrected.

1. Open Excel and navigate to the Excel file exported from ArcPro or ArcMap.
 - a. Remove columns that are not needed (i.e., Folder Path Column, Symbol ID, AltMode, Base, Snippet, HasLabel, LabelID).
 - b. Convert the CT label data into different columns.
 - i. Move 'PopupInfo' Column to be the last column in the dataset.
 - ii. Select the entire column > 'Data' > 'Text to Columns' > Choose 'Delimited' and click 'Next.'
 - iii. Under 'Delimiters' select the check boxes for 'Tab' and 'Comma' then click 'Next.'
 - iv. Select 'General' and click 'Finish.' *Column labels separated out should now be visible
 - c. Relabel columns, if desired.
2. Data cleaning and quality checks can now be done to look for missing or erroneous data. The specific steps needed for this are similar to other data cleaning.

B. ITERATIVE PROCESS

Quality assurance is an important part of the CT identification process. Depending on the goals of the CT project, differing levels of quality assurance can be taken. While specific steps taken for quality assurance may vary depending on size and goals of the project as well as available staff, they should generally target the following areas:

- 1) Re-scanning areas to ensure no CTs are missed
- 2) Ensuring that CTs identified are actually CTs
- 3) Data validity

I. RE-SCANNING AREAS TO ENSURE NO COOLING TOWERS ARE MISSED

The goal of re-scanning is to make sure CTs are not missed. CTs are easily missed, especially if scanning areas that are large, or early on in the scanning process, while building experience identifying CTs. If multiple people are available, re-scanning can involve randomly selecting areas for multiple people to re-scan without knowing where CTs have already been identified by others. If multiple scanners are not available, then blinding earlier results and re-scanning random grids/census tracks at the end of the projects might be a reasonable approach.

For the OC project, a second scanner independently reviewed ten percent of census tracts, which were randomly selected.

II. ENSURING THAT OBJECTS IDENTIFIED ARE ACTUALLY COOLING TOWERS

One of the most difficult parts of the CT scanning process is identifying what constitutes a CT. At the very least, for quality assurance purposes, all CTs labeled as 'Low' confidence should be reviewed with another scanner. If another scanner is not available, then other experts (i.e., environmental health specialists familiar with CTs) can be recruited, with images reviewed together. If time permits, all, or a subset of 'Medium' confidence CTs should also be reviewed.

Depending on project goals, ground truth verification can also be very important as the presence of a CT on a satellite does not guarantee it is truly a CT or that it is operational/being used. Verification can take the form of physically visiting CTs to verify or calling buildings to ask about the presence of CTs. Both are time-intensive processes with their own limitations. Physically visiting structures may be fruitless as CTs may be behind locked doors or on top of high-rise buildings or otherwise obscured. Calling buildings may also be misleading as some building personnel may not know what a CT is or may not want to share that information. However, ground truth verification can be very important to verifying the presence or absence of CTs and validate scanning techniques.

III. DATA VALIDITY

Data validity is an important quality control measure for any dataset; cross-checking labels during the quality assurance and re-scanning processes and ensuring that identified objects are actually CTs are important ways to validate data. Other standard procedures for reviewing data should also be established and used.

C. LIMITATIONS OF SATELLITE IDENTIFICATION

Satellite imagery is not a perfect method for finding all CTs in a geographical area. Using aerial and satellite images disregards CTs that can be inside or within buildings. This method is biased towards larger CT structures that can be seen on satellite images rather than smaller CTs that may require greater spatial resolution to find. Additionally, if satellite images for CTs are covered by other building structures or vegetation, such as large trees masking a building, it will be harder to find a CT using this method. We are unaware of any other identification process to identify closed-circuit CTs using satellite imagery and are therefore limited to scanning for open-circuit CTs with fans. Satellite images are also dated; new CTs may not appear and older CTs may have been removed by the time the image was acquired. In addition, presence of a CT on an image does not indicate whether the CT is operational. For the OC project, we assumed that anywhere from 5-30% of CTs could be missed during the scanning process.

4. GENERAL RECOMMENDATIONS

- 1. Start with a pilot study area:** Refining and replicating a CT scan can be very time consuming and is much easier if scanners start with a small region within the study area for a practice or pilot scan. Starting with a pilot area allows scanners to refine methods before spending a lot of time learning to scan and label.
- 2. Reduce the area that needs to be scanned:**
Methods that help to reduce the area that needs to be scanned (i.e., using Landvision building parcel data) can substantially reduce the amount of time needed as well as reduce fatigue and thus errors. Spend time focused on higher risk areas (i.e., hospitals, identified by appearance on satellite imagery or by building parcel data) but be careful not to ignore other areas.
- 3. Save the GE file:** Do not try to save the GE file by clicking > 'File' > 'Save As.' This will not store the locational data and layers. Instead, save the data specifically:
 - Keep the data (pins) organized in layers (folders) in GE. For instance, for CT data (pins):
 - i. Create a folder by right clicking 'My Places' > 'Add' > 'Folder,' and name the folder 'Cooling Towers.'
 - ii. Drag all CT pins into the 'Cooling Towers' folder.
 - Save the data within layers (folders) as a KMZ. Whenever there are data within 'Layers' (folders), Navigate to 'My Places' > right click the layer > 'Save As' > name of file.
- 4. Use multiple CT scanners:** Have more than one individual scan the same area of interest to compare findings and consolidate datasets. This helps with limiting bias for only one scan. Further, we used confidence scores to prioritize which CTs should

be re-validated/cross-checked. For instance, all CTs with 'Low' confidence scores were re-validated first, and then all 'CTs with 'Medium' confidence scores were re-validated. 'High' confidence CTs were not re-validated.

5. ADDITIONAL RESOURCES

CT-related Articles

- [“Back to Basics: Cooling Tower 101”](https://blog.senseware.co/2018/02/06/back-basics-cooling-towers-101) <https://blog.senseware.co/2018/02/06/back-basics-cooling-towers-101>
- [“How Cooling Towers Work: W/Diagram, Pictures, & Principles\) 2018”](https://www.coolingtowerproducts.com/blog/how-cooling-towers-work-diagram-pictures-2015.htm#7) <https://www.coolingtowerproducts.com/blog/how-cooling-towers-work-diagram-pictures-2015.htm#7>
- [“Buildings Cooling System”](https://www1.nyc.gov/assets/buildings/pdf/evaporative-_cooling.pdf) https://www1.nyc.gov/assets/buildings/pdf/evaporative-_cooling.pdf
- [“What is a cooling tower?”](https://www.cti.org/whatis/coolingtowerdetail.shtml) <https://www.cti.org/whatis/coolingtowerdetail.shtml>
- [“CTI Journal: Official Publication of the Cooling Technology Institute”](https://www.cti.org/downloads/win10journal.pdf) <https://www.cti.org/downloads/win10journal.pdf>

Analysis Resources

- [“Prioritizing Cooling Towers Testing Using Routes Walked by Legionellosis Patients”](https://www.cti.org/whatis/coolingtowerdetail.shtml) <https://www.cti.org/whatis/coolingtowerdetail.shtml>
- Databases for shapefiles:
 - [Berkeley Library Geodata](https://geodata.lib.berkeley.edu/): <https://geodata.lib.berkeley.edu/>
 - [Data.gov Data Catalog](https://catalog.data.gov/dataset/tiger-line-shapefile-2017-county-orange-county-ca-all-roads-county-based-shapefile): <https://catalog.data.gov/dataset/tiger-line-shapefile-2017-county-orange-county-ca-all-roads-county-based-shapefile>

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