Long Term Ecological Monitoring and Data Management using ArcGIS

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Abstract

Capturing, analyzing, and retrieving ecological field data presents ongoing challenges of data management for the employees of the Watershed Management Division in Seattle's Cedar River Watershed. The use of mobile computing devices, SDE and ArcGIS facilitate the entry, maintenance and analysis of these valuable data. A database design that leverages the capabilities of relational databases and integrates vegetation plots, transects and forest plots will be presented. The primary goals of the database are to support long-term monitoring and ecological research as well as providing an organizational framework for all field data.

Introduction

The Habitat Conservation Plan (HCP) adopted by the City of Seattle in 2001 mandates a 'no timber harvest' policy for the 141 square mile Cedar River Watershed which provides drinking water to over 1.3 million people in the Puget Sound region. The HCP also requires that a series of commitments be met relative to habitat restoration. These commitments fall into categories that include: site prioritization, restoration prescriptions, restoration action (or inaction), and long term monitoring. Each of these has significant information needs. These needs include habitat mapping, forest modeling, query, storage, retrieval, and data management. ArcGIS and ArcSDE provide a foundation for meeting these needs and commitments.

The design and establishment of a long term ecological sampling program and related databases is necessary to fulfill many of these commitments. Such a program presents unique challenges to information management and system design. The specification of sampling design and sampling protocols provide a tangible basis for the design and specification of the database. A database model to support long term monitoring is presented and its potential to support other types of activities is explored. Scientists are in the field daily, recording observations, measurements and events. The design of a database to support long term monitoring can be leveraged to support a wide range of field observations from wildlife sightings to incidents of trespass.

HCP Commitments

The Habitat Conservation Plan is a legally binding agreement between multiple parties to facilitate habitat restoration while recognizing the need to operate the watershed as a public water supply. The HCP commits the City to a variety of actions and outcomes. These include but are not limited to:

- Characterizing terrestrial, aquatic and riparian habitats
- Tracking long-term trends in habitat
- Monitoring

- Use of the best available science

One component of fulfilling these commitments is the establishment of a long term ecological monitoring program. Significant effort was devoted to the establishment of a sampling design and related sampling protocols. The goals for the sampling design and long term data collection include:

- Use of a systematic random sampling design that is statistically representative of the watershed.
- Establishment of monumented plot locations that can be revisited over multiple decades.
- Creation of a long-term data set to monitor the trajectory of forest condition and processes through time.
- Providing watershed-wide data compatible with, and complementary to, monitoring strategies for site specific restoration projects.
- Provision of ground truth data for use in image classification and analysis.
- Establishment of baseline characterization.
- Determination of the current and future range of variation in habitat conditions.
- Documentation of trends in habitat condition, composition, complexity, and structure.

Sampling Design

It was decided to use a systematic random sampling design based on a desire for statistical validity, dispersion throughout the watershed, and sampling across a range of elevations and habitats. Based on the experience of a consultant, the total area of the watershed, and an estimate of available resources it was determined that approximately 300 sample plots would:

- be representative of the range of habitats
- be within the range of available funding
- capture habitats occupying as little as 2% of the watershed.

Based on this estimate of desired sample size it was determined that a spacing of 3600 feet would approximate the desired number of points. A random origin was generated that fell within the ownership boundary of the watershed.

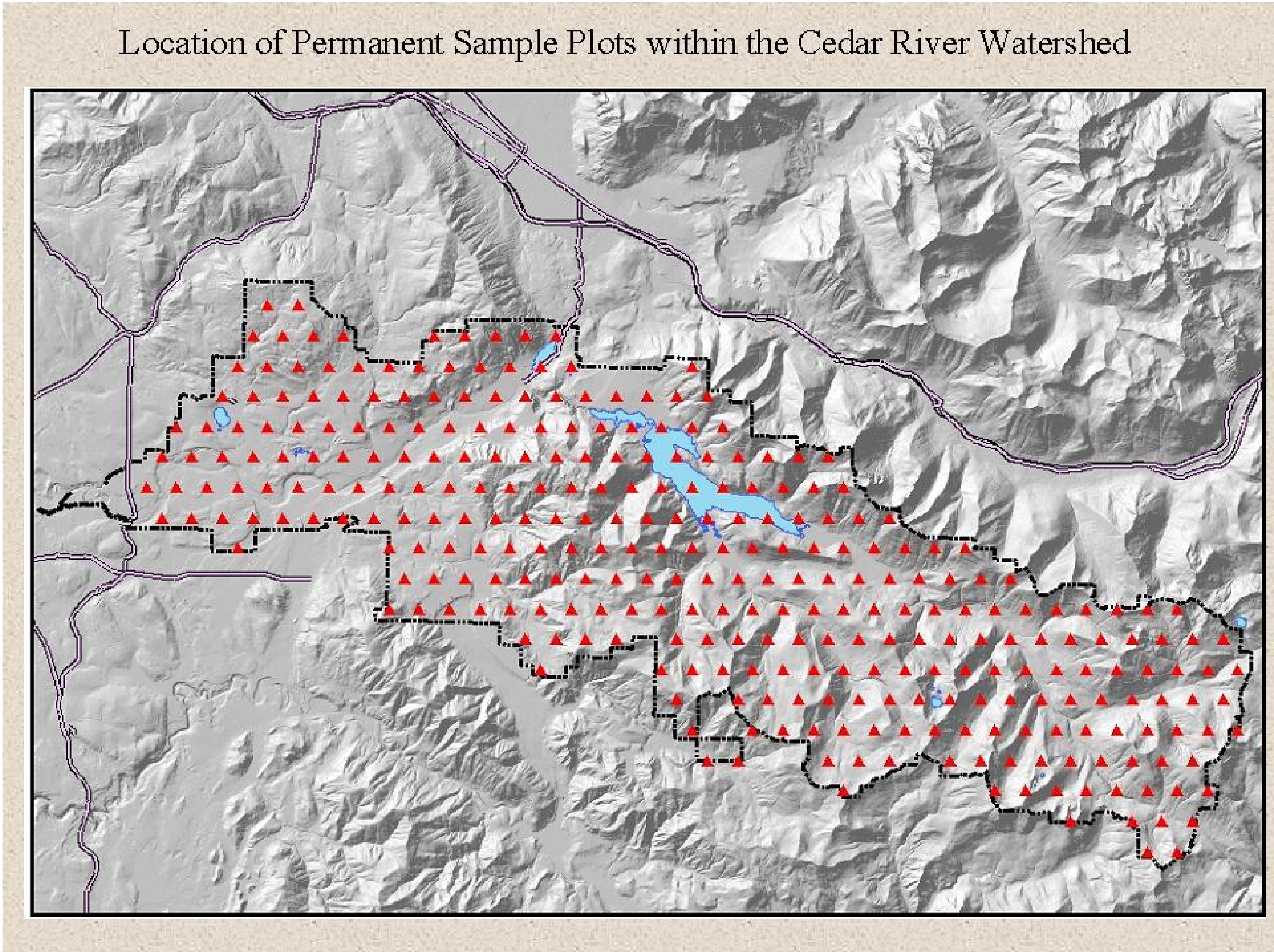

Figure 1. Distribution of Permanent Sample Plots in the Cedar River Watershed.

An extensive sampling protocol was developed. Data is collected at a variety of levels. Trees are sampled at the plot level and tagged for revisit. Shrub plots and herbaceous plots are established as are transects for sampling down, dead, woody debris (Figure 2). This information, what data would be gathered and in what spatial units, provided invaluable guidance in the definition and design of the underlying data structure.

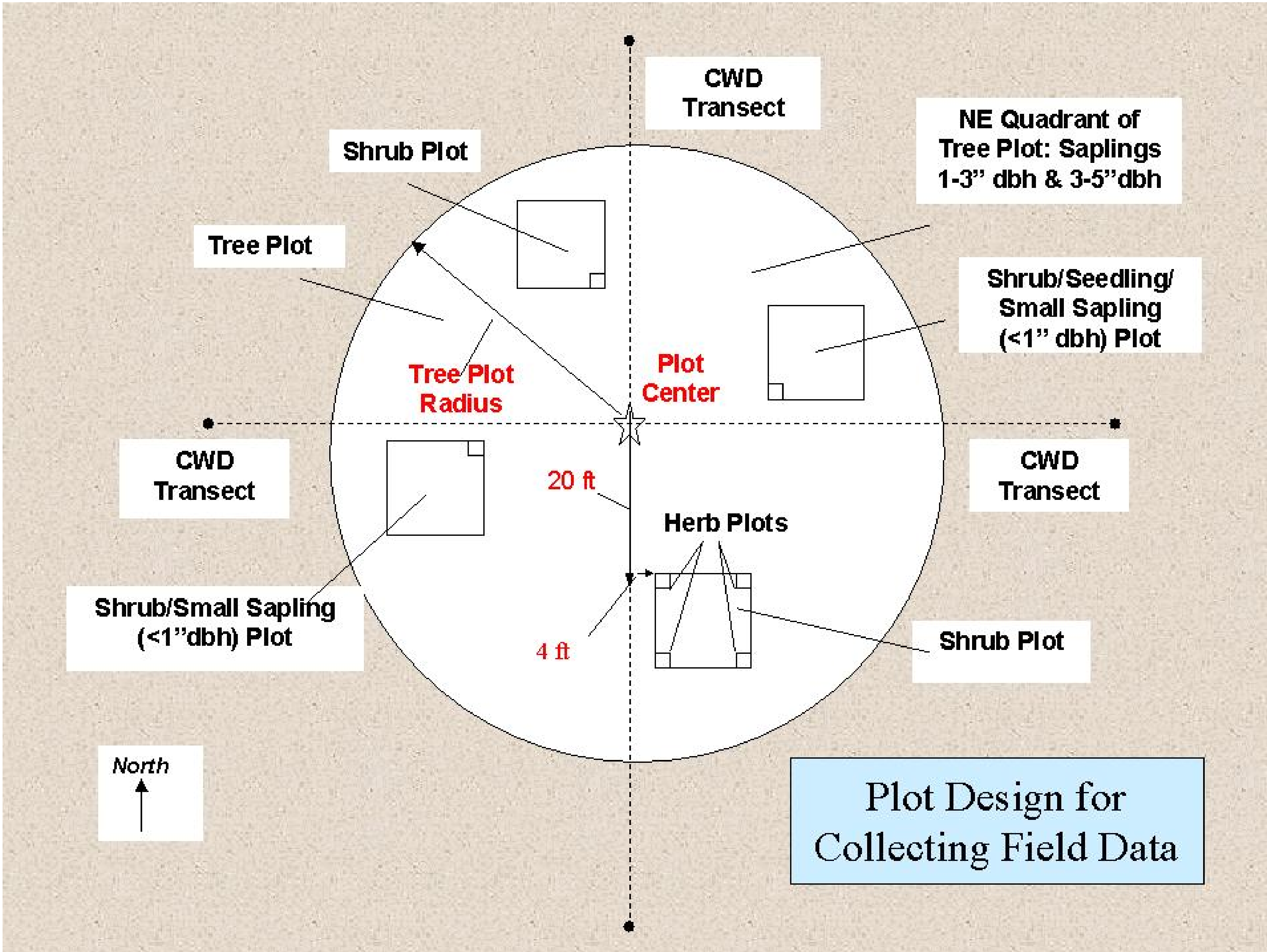

Figure 2. Sample Plot Design.

Stands versus Plots

Characterizing forest is a challenging proposition. Based on observations of individual trees assessments are made that characterize broad areas, or stands. Often these areas exhibit some homogeniety, or they may simply be based on uniform ownership. A stand, even though it may vary widely in size, is the frequently the focus of silvicultural planning or activity.

Traditionally this is driven by ownership. A land owner managing a land parcel, for example, will treat, manipulate, or harvest based on those ownership boundaries. The Forestry Data model developed by ESRI recognizes 'stand' as a spatial feature. What defines this stand boundary if not ownership?

In fact the entire Cedar River Watershed can be considered a stand. As stated previously this definition is driven by ownership. Obviously however it is not a meaningful unit of analysis for prioritizing or monitoring site specific actions or trends.

One method of obtaining aggregate measures, or characterizing forest stands, is via timber cruises. Various cruise methods can be used and it is its own highly developed field of study and application. However, all are based on taking measures at specific locations, or plots, and deriving stand level characteristics. The stand boundary is determined by ownership or interpretation of remotely sensed data, either aerial photographs or digital imagery. However little attention is paid to the specific location of each plot. This is because it is assumed that the goal is to assess the stand as a unit, deriving aggregate measure for the stand as a unit. The unit of interest is the stand, not the plot.

Such was the case with an extensive timber cruise completed in the early 1990's within the Cedar River Municipal Watershed. The scope of work was very clear that what was desired was an assessment of the value of timber within the City's ownership boundary. Systematic cruises were done and every plot was assigned to a stand based on boundaries that had been derived from classified Landsat Imagery obtained in 1988.

Now, imagine one wished to derive stand boundaries based not on ownership or timber value but rather own ecological variation. In essence this is the focus of this discussion. How to develop field methods and a data model that captures cruise data, or field measures, at the plot level. Given that field measures are regularly taken within the CRW the goal of the data model is to capture plot level information and to tie it to an explicit location.

GPS receivers are used to navigate to known plot locations. When plot records are entered they are tied directly to previously determined locations.

Integrating multiple sampling units within each plot and multiple measures through time is handled with multiple composite relationships. The spatial feature class aspect is very simple. It consists of individual points that denote known locations. These are tied to hexagons that associate each point to the area closest to it. This facilitates thematic mapping of individual or summary measures about each location.

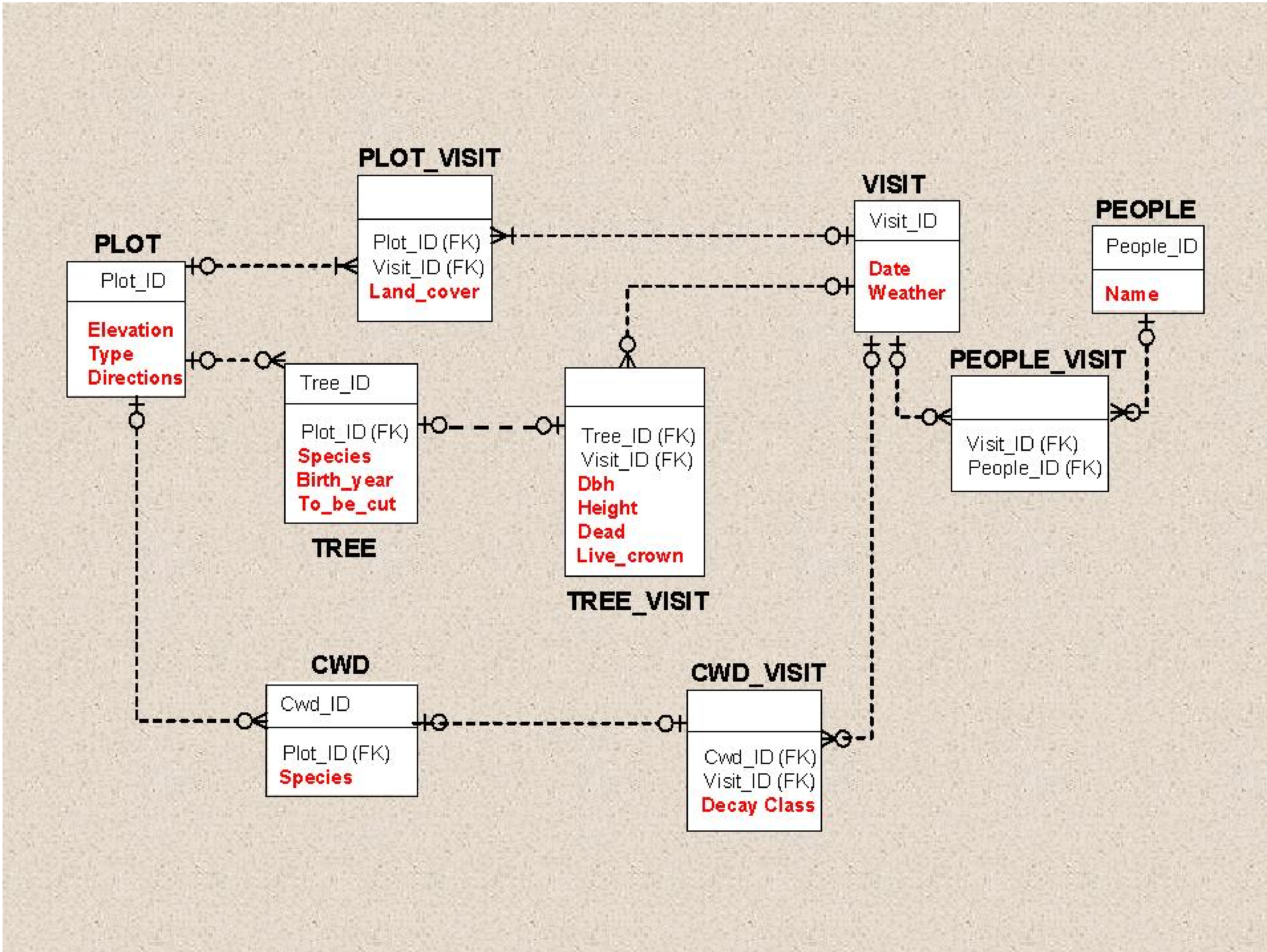

Figure 3. Partial Data Model of plot level data.

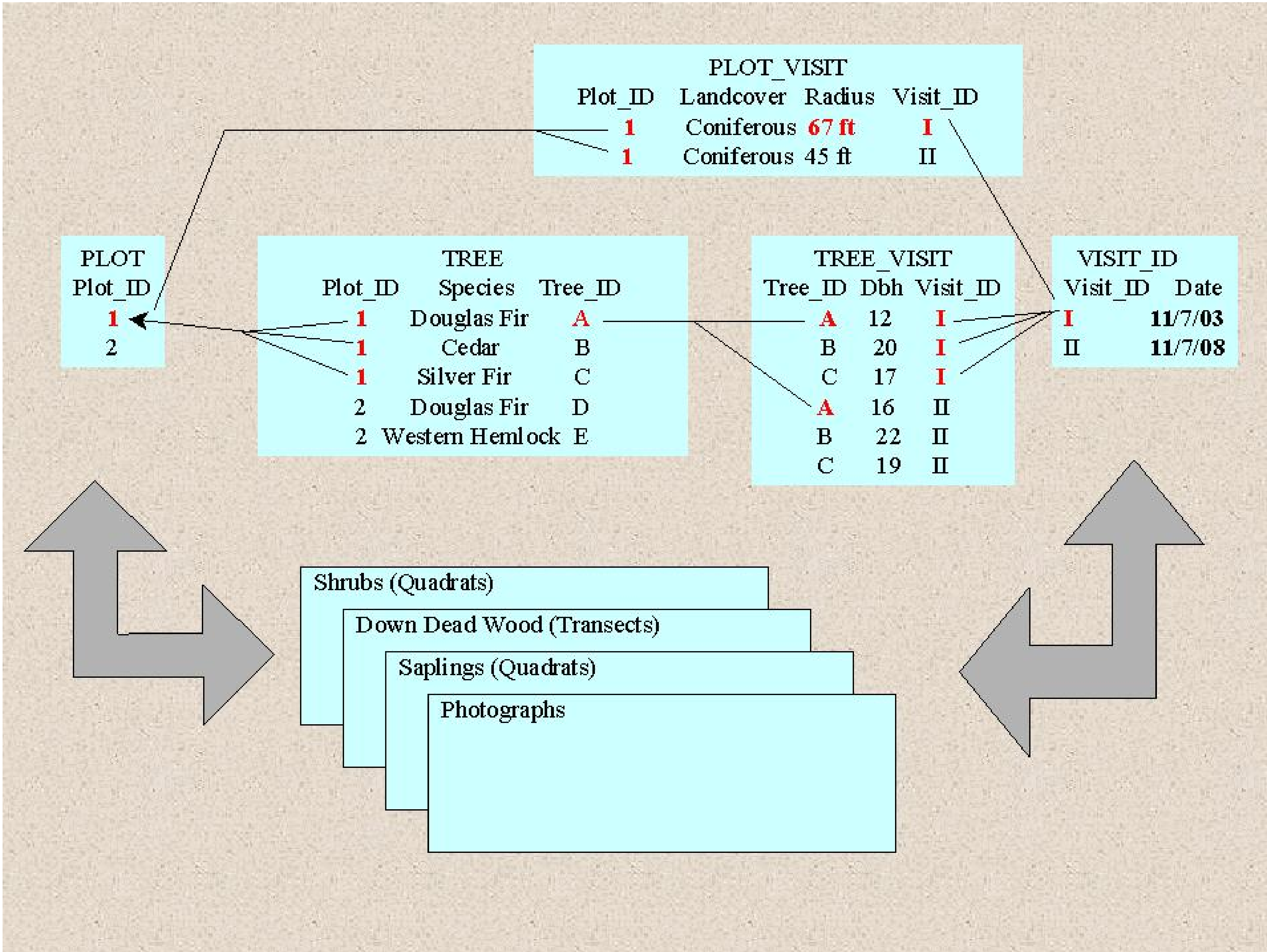

Figure 4. Example of entity relationships.

Answering the questions

The focus of this brief paper is on the development of a data model that deals with observations repeatedly collected at known locations in the field. Particular facets of this challenge include temporal issues, spatial resolution issues, and spatial aggregation.

The intent is to develop a data model that allows questions such as the following to be answered:

- What is the density of trees at a site?
- Where is species diversity the highest?
- What is the rate of growth for Douglas Fir and how does it vary across the watershed?

There is an advantage to the trees growing slowly but data are being collected while prototypes are developed to assure that the questions of interest can be addressed, both now and in the future.

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