RESEARCH

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RECOMMENDED PROTOCOL AND STANDARDS FOR UTILITY DATA SUBMITTALS

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16. Abstract

Study presents: 1) recommended standards for submitting digital data for utility infrastructure, and 2) prototype relational database architecture for utility data repository, including a draft Microsoft Access database. System function is to gather, manage, and disseminate data from newly permitted utility installations, UDOT construction projects, and existing utility data sets acquired through subsurface utility engineering (SUE) investigations. Goal direction is to supersede paper as-built plans and existing utility plans, and allow digital utility data to be integrated with UDOT's Enterprise GIS initiative. Study includes review of current practices, standards, latest technologies, and existing systems employed by state, federal, and private agencies. Recommended architecture features synthesis of coordinate, attribute, and metadata that accommodates characteristics unique to buried and aerial infrastructure. Recommended procedures coincide with current UDOT practices and requirements.

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TABLE OF CONTENTS

LIST OF FIGURES vi
EXECUTIVE SUMMARY 1
1 Introduction 5
1.1 Problem Statement 5
1.2 Scope of Project 6
2 Research Methods 8
3 Research Findings 10
3.1 Current UDOT GIS Initiatives 10
3.1.1 UDOT UGATE 10
3.1.2 UDOT uPlan 11
3.1.3 UDOT GIS Toolset Standards – July 2009 13
3.1.4 UDOT ATMS 13
3.2 Current UDOT Geo-Referencing Standards 14
3.2.1 UDOT Survey and Mapping Standards 14
3.2.2 UDOT Spatial Database Standards Draft – Jun '09, Rev. Mar '10 17
3.2.3 UDOT's Location Reference Task Force Standards Recommendations 17
3.2.4 Datum and Stored Coordinates 19
3.3 Current Utah State Geospatial Systems and Practices 20
3.3.1 The Utah Reference Network GPS (TURN GPS) 20
3.3.2 Utah Automated Geographic Reference Center (AGRC) 21
3.3.3 Utah State Statutes and NCEES Model Law for Surveying 22
3.4 Current Federal and National Geospatial Systems and Practices 23
3.4.1 MetroGIS 23
3.4.2 MetroGIS Metadata Standards 24
3.4.3 Open Geospatial Consortium, Inc. (OGC) 25
3.4.4 NCHRP Report 460 titled "Guidelines for the Implementation of Multimodal Transportation Location Referencing System" from NCHRP Project 20-27 26
3.4.5 NGS Guidelines for RTK GPS 27
3.4.6 ANSI INCITS 353-2006 Geographical Information Systems Spatial Data Standards for Facilities, Infrastructure, and Environment (SDSFIE) 29
3.4.7 Transportation Research Board (2011) SHRP 2 R01(A) Technologies to Support Storage, Retrieval, and Utilization of 3-D Utility Location Data 32

3.4.8 Table and Field Naming Conventions 33
3.5 Practices by Other Local Agencies and Private Enterprises 33
3.5.1 Practices by Others – Qwest, City of West Valley 33
3.5.2 Bentley MicroStation, Map, and Geospatial Server 34
3.6 TXDOT Prototype Utility Database 37
3.7 TXDOT Business Process with respect to Utilities and UDOT's Design Process 38
3.8 Current UDOT Utility Data Submittal Requirements 39
3.8.1 UDOT Construction Permits 39
3.8.2 UDOT Utility Permitting 40
3.8.3 UDOT Procedures for As-Built Construction Plans 41
3.8.4 UDOT Subsurface Utility Engineering 43
3.9 NAD-83 vs. WGS-84 45
3.10 Section Summary 46
4 Recommendations and Implementation 49
4.1 Database Schema 50
4.1.1 Surveys 51
4.1.2 Spatial Data 52
4.1.3 Features 54
4.1.4 Owners and Contacts 55
4.2 Coordinate Data 56
4.3 Attribute Data 57
4.4 Metadata 57
4.5 Implementation Plan 57
REFERENCES 59
APPENDIX A - ACRONYMS 63
APPENDIX B – DATABASE SAMPLE FORMS 65
APPENDIX C – UNIT CONVERSION 70

LIST OF FIGURES

Figure 1 uPlan display of Rocky Mountain Power infrastructure.....12
Figure 2 MetroGIS metadata guidelines derived from FGDC recommended standards.....25
Figure 3 Example of SDSFIE 3.0 Data Structure and Data Fields 31
Figure 4 Bentley Product Workflow Chart 35
Figure 5 Utility-Focused ROW Coordination in Project Development Process: Overview Diagram 39
Figure 6 Example of current UDOT standard for as-built plan submittal in PDF format.....42
Figure 7 Survey section of the database.....51
Figure 8 Detection Methods 52
Figure 9 Spatial Data linked to Survey Chains.....53
Figure 10 Feature Tables related to Survey Chains 54
Figure 11 Owners and Contacts related to Survey Chains 55
Figure 12 Application Screen - Project, Survey Campaign, Survey Chain.....68
Figure 13 Application Screen – Choosing a Survey Chain.....66
Figure 14 Application Screen – Survey Chain Details 66
Figure 15 Survey Chain Details - Feature Attributes.....67
Figure 16 Survey Chain - Add Survey Point Manually 68
Figure 17 Survey Chain - Bulk Uploading Survey Points 68
Figure 18 Survey Chain - Bulk Uploading Survey Points From Excel.....69

EXECUTIVE SUMMARY

The objective of this project was to develop a proposed standardized method for collecting and storing digital data of utility installations. Although the project focus is to facilitate management of installations within Utah Department of Transportation (UDOT) right-of-way (ROW), the proposed method can be used to collect and store information on infrastructure anywhere.

An exhaustive research of current practices, standards, latest technologies, and existing systems employed by state, federal, and private agencies across the country was performed, yielding an eloquent synthesis of coordinate, attribute, and metadata requirements which closely coincide with current UDOT practices and requirements.

Recommended standard data fields and procedures for collecting and submitting digital data for utility infrastructure were derived. A relational database architecture for a utility data repository was designed and a draft, prototype database was developed in Microsoft ACCESS as part of this project.

The recommended protocol is designed for capturing as-built data from newly permitted utility installations and UDOT construction projects, as well as from existing utility data sets acquired through subsurface utility engineering (SUE) investigations. This data, while currently generated for project use at significant cost, is useless for enterprise applications because UDOT lacks: 1) an appropriate digital repository and management system for utilities, and 2) procedures and standards for collecting and submitting digital utility data.

Better management of infrastructure asset data for facilities within UDOT right of way will: 1) immediately improve utility coordination efficiency between utility owners and UDOT (including UDOT's private consultants and contractors); 2) facilitate advanced planning practices which streamline construction and maintenance activities while including appropriate precautionary measures to safeguard existing utilities, workers, and the public; 3) promote value engineering within UDOT project development and delivery practices which reduce conflicts with existing and planned utility infrastructure; and 4) reduce utility relocations, utility related project delays, and utility damage claims, accordingly providing cost saving benefits to UDOT.

The new method is intended to do the following:

- supersede current Adobe Portable Document Format (PDF) and paper as-built plans and MicroStation existing utility plans;
- collect normalized standard data in digital format readily compatible for Geographic Information System (GIS), Computer Aided Drafting and Design (CADD), and numerous arising technologies and applications such as Global Positioning System (GPS), Google Earth, Building Information Modeling (BIM), Machine Control construction, etc.;
- accurately tie 3D positional coordinates to the National Spatial Referencing System (NSRS), which is established and maintained by the National Oceanic and Atmospheric Administration National Geodetic Survey;
- allow utility data to be integrated with UDOT's Enterprise GIS initiative; and
- become the nucleus for what will eventually become a computer aided utility management system.

Among other criteria, metadata recommendations are intended to satisfy:

- CI/ASCE 38-02 Standard Guidelines for the Collection and Depiction of Subsurface Utilities; and
- the 2002 GIS/LIS Addendum to the Report of the Task Force on the National Council of Examiners for Engineers and Land Surveyors (NCEES) "Model Law" for Surveying.

The 2002 GIS/LIS Model Law Addendum recommends: "GIS-based databases and maps intended to be used as the authoritative document for the location of … fixed works (e.g., utility infrastructure) must be compiled under the responsible charge of a Professional Surveyor or Land Surveyor." A recommendation is made herein that all newly permitted installations within UDOT ROW be surveyed and stored with Quality Level (QL) A designation in accordance with CI/ASCE 38-02 standard guidelines and that the QL A data be considered authoritative and compiled as recommended by the 2002 GIS/LIS Model Law Addendum. However, QL B, C, and D utility data may be compiled and submitted by a qualified SUE service provider and QL

B, C and D data is not to be considered “authoritative” (i.e., in which facilities are assigned coordinates with statistically based accuracy tolerances), but should be developed in accordance with accepted SUE practices and CI/ASCE 38-02 standard guidelines. GPS survey of QL A and B data should be performed in accordance with National Geodetic Survey (NGS) guidelines identified below.

Recommendations include all new infrastructure should be mapped to CI/ASCE 38-02 QL A standards with positional precisions typically 2 to 4 centimeters (0.8 to 1.6 inches) horizontal, 3 to 5 centimeters (1.2 to 2 inches) vertical (two sigma or 95 percent confidence). To coincide with NGS and existing UDOT guidelines, coordinates are recommended to be consistently tied to the National Spatial Reference System (NSRS i.e., North American Datum 1983 (NAD 83, 2007 adjustment) and North American Vertical Datum 1988 (NAVD88)), with:

- latitude and longitude digitally stored in decimal degrees (F12.8 format, negative longitude), and
- orthometric height (e.g., elevation) digitally stored in decimal meters (F7.2 format) and, per UDOT preference, U.S. Survey Feet.

(Note: Use of metric units for elevation is a trivial effort for the survey professional and would help avoid the pitfall of mixing U.S. Survey Feet with International Feet. See Section 3.2.1 below for details.)

The data schema is designed to accommodate metadata for documenting the responsible land surveyor’s certification of methods for establishing coordinate data to accuracies required for QL A designation. Methodologies recommended for achieving high accuracy global positioning system (GPS) coordinates include utilizing The Utah Reference Network GPS (TURN GPS) along with observation procedures provided by the U.S. Department of Commerce National Oceanic and Atmospheric Administration National Geodetic Survey (NOAA NGS) in the NATIONAL GEODETIC SURVEY USER GUIDELINES FOR SINGLE BASE REAL TIME GNSS POSITIONING (v. 1.0 January 2010 William Henning, lead author).

Utility attribute fields are based upon the Spatial Data Standards for Facilities, Infrastructure

and Environment (SDSFIE), recognized as an enterprise standard across the entire Department of Defense business mission area and managed by the Defense Installations Spatial Data Infrastructure (DISDI) Group. SDSFIE is now an American National Standard Institute (ANSI) standard.

The recommendations rendered from this project appear to be unique and groundbreaking for any agency in charge of managing public right of way, and to our knowledge the first of its kind to be published anywhere.

1 INTRODUCTION

This project focused on developing proposed data standards and protocol for collecting and storing utility data. The project team, consisting of Utility Mapping Services, Inc. (UMS) and the Texas Transportation Institute (TTI) of the Texas A&M University System, performed a combined technology transfer and research and development effort to devise a model utility data repository and corresponding standards for: 1) utility as-built data from newly permitted utility installations; 2) existing utility data submittals resulting from subsurface utility engineering (SUE) investigations; and 3) as-built data for utility work from UDOT construction projects. Recommendations for implementation were also developed. UMS served as the prime consultant to the Utah Department of Transportation (UDOT); work was performed under a UDOT research funding contract.

1.1 Problem Statement

Utility related problems in design and construction are nearly always the result of not having adequate (i.e., readily accessible, accurate, and complete) data on existing infrastructure. Without exception, belated, reactive measures executed during construction to deal with utility issues are more costly and disruptive than proactive, systematic activities executed during design development. There is a heightened need for systematic management of utility infrastructure data. Current UDOT business practices provide opportunities to capture and store data, and include: 1) subsurface utility engineering (SUE) for pre-construction design; 2) contractor construction as-built submittals for UDOT projects; and 3) utility permitting with required as-built submittals for new utility installations. Furthermore, UDOT is using the SUE process to identify and mitigate utility conflicts during project development, and pioneering innovative contracting practices to fully leverage utility data during project delivery. Unfortunately, UDOT lacks a digital utility management system, a tool that could greatly enhance utility related business practices and provide significant value for UDOT, the public, and all stakeholders.

Relational database, geographic information systems (GIS), global positioning system (GPS), and internet-based technologies can automate digital utility data handling, provide administrators with effective graphical and tabular analytical tools, and facilitate

communications and coordination with other departments and/or agencies. Emerging design and construction software technologies such as building information modeling (BIM, http://en.wikipedia.org/wiki/Building_Information_Modeling) and a variety of new 3D modeling and computer aided drafting and design (CADD) packages greatly empower transportation agents and designers to better leverage and utilize existing utility information. At the heart of every asset management system is a robust/legacy database, preferably designed in accordance with national and international standards set forth by organizations including the Federal Geographic Data Committee (FGDC), Open Geospatial Consortium (OGC), and adopted by American National Standards Institute (ANSI) and International Organization for Standardization (ISO).

This project addresses two fundamentals required for effective utility data capture and storage:

- standardized procedures and data submittal requirements for documenting permitted, pre-construction, and post-construction utility work; and
- a data repository architecture established for uploading, maintaining, and accessing acquired utility data.

The intent is to lay the foundation for a UDOT utility management system for collecting, storing, maintaining, analyzing and disseminating utility data in a manner that allows pro-active planning for permitting, design, maintenance, damage prevention, homeland security and emergency response tasks. This repository will also eliminate costs for rediscovery and survey for future projects, and shift costs for providing information on new infrastructure to facility owners.

1.2 Scope of Project

The project team developed proposed standard procedures, submittal formats, and architecture for a relational database that could serve as a utility repository. The effort included utilizing existing UDOT standards, regulations, and business procedures to develop a process to capture and accurately record all utility infrastructure installations within the UDOT ROW in a comprehensive, straight-forward manner. The data acquisition and submittal process is designed to be readily administered by UDOT and performed by utilities, SUE providers, and

UDOT contractors.

Standards for utility feature survey data were established to assure sufficient information is stored and maintained for accurate use on future design projects. The data schema allows the utility database to:

- Accept utility as-built data uploads that are in a straightforward, rudimentary format (e.g., comma delimited ASCII or MS Excel spreadsheet)
- Be compatible with current UDOT geographic information systems (GIS), computer aided drafting and design (CADD) systems, and survey systems;
- Output data in format readily acceptable for import into most CADD packages (especially MicroStation XM and AutoCAD)
- Be convenient for updating utility changes within UDOT right of way (ROW);
- Provide access to accurate survey data for future UDOT road designs and output data in format compatible for uploading into most data loggers for survey purposes;
- Be useable for utility firms and cities planning to install new utilities; and
- Aid UDOT Right of Way officials in their efforts to regulate utility easement permits.

UMS performed engineering services in accordance with generally accepted engineering principles and practices at this time and in accordance with applicable standards. Research practices complied with UDOT Report No. UT-07.10 GUIDELINES FOR PREPARING UTAH DEPARTMENT OF TRANSPORTATION RESEARCH REPORTS, Revised 2007.

2 RESEARCH METHODS

A systematic review of existing processes and standards developed for commercial and government enterprises was performed at local, state, national, and international levels. The project team researched ongoing development and evolving software and standards for geospatial data in an effort to ensure the utility data protocol development: 1) was compatible and aligned with emerging software and practices, 2) fully leveraged available asset management development efforts, and 3) did not replicate previous efforts. In general, research and development activities covered the following:

- Researched existing UDOT practices, policies, and standards for survey, mapping, utility permitting, as-built submittals, and geographic information system development (e.g., UGATE and uPlan).
- Researched State of Utah Department of Technology Services (DTS) and the Automated Geographic Reference Center (AGRC) practices and standards.
- Researched existing standards developed by others for infrastructure data management, including MetroGIS in Minnesota, the Federal Geographic Data Committee (FGDC), the Open Geospatial Consortium (OGC), the International Organization for Standards (ISO), and the Spatial Data Standards for Facilities, Infrastructure and Environment (SDSFIE - recognized as an enterprise standard across the entire Department of Defense business mission area and managed by the Defense Installations Spatial Data Infrastructure (DISDI) Group. SDSFIE is now an ANSI standard.)
- Researched geodetic data management as prescribed by the National Oceanic and Atmospheric Administration National Geodetic Survey.
- Researched National Council of Examiners for Engineering and Surveying "Model Law for Surveyors and GIS Professionals".
- Researched Bentley Geospatial Server V8i and Bentley Map.
- Researched current practices for infrastructure data management by local municipalities and private utilities.
- Performed a technology transfer of a utility database prototype developed by TTI for

Texas Department of Transportation (TxDOT) and then added additional elements for managing in a draft Microsoft Access database.

- Developed procedures, standards, and formats for submitting digital utility data from the identified pre-construction, construction, and permitting activities.

3 RESEARCH FINDINGS

The research included UDOT systems, standards and procedures to assure proposed methods conform with existing practices. Additionally, research extended to practices and standards employed at the state and federal level, at other state DOTs, and within private industry and the international community. The research findings have been allocated to the following categories:

3.1. Current UDOT GIS Initiatives

3.2. Current UDOT Geo-Referencing Standards

3.3. Current Utah State Geospatial Systems and Practices

3.4. Current Federal and National Geospatial Systems and Practices

3.5. Practices by Other Local Agencies and Private Enterprises

3.6. Texas Department of Transportation (TxDOT) Prototype Utility Database

3.7. TxDOT Business Process with respect to Utilities and UDOT's Design Process

3.8. Current UDOT Utility Data Submittal Requirements

3.9. NAD-83 vs. WGS-84

3.10. Section Summary

Existing practices and standards were evaluated with the intended outcome of enhancing the UDOT standard to meet or exceed other existing standards currently implemented within the state and at the national level, and generate a practical, functional, and robust legacy utility database. Below is a comprehensive list of standards that were reviewed followed by an explanation which is in the form of Findings – Recommendation – Reasoning.

3.1 Current UDOT GIS Initiatives

3.1.1 UDOT UGATE

Findings: UGATE is the "UDOT GIS Access to the Transportation Enterprise". When explored for this study, UGATE was still in the Beta Version. UGATE is not a database, but provides access to other databases in a user-friendly interface. As of April 2010 UGATE provided access to the following databases:

1. PONTIS Bridge locations
2. ePM Projects (Electronic Program Management Projects)
3. AADT Data (Average Annual Daily Traffic)
4. Pavement Condition Survey Data

Access to additional databases is planned for UGATE. The information is layered for viewing individually or multiple layers at the same time. ESRI ArcGIS server is part of the UGATE database access architecture and UDOT's GIS tools. The UGATE data is optimized through ArcGIS server for export into uPlan (discussed below in Section 3.1.2) or other application programming interface (api). UGATE structure utilizes Oracle SDO_GEOMETRY datatypes with Representational State Transfer (REST)-based map services.

Recommendation: Integrate the utilities database into UGATE after testing in real world applications.

Reasoning: This is consistent with the purpose of UGATE.

3.1.2 UDOT uPlan

Findings: When explored for this study (April 2010) uPlan was UDOT's GIS-based prototype planning process and incorporates pertinent databases and analysis tools. Frank Pisani, GIS Coordinator in the UDOT Planning Division, stated uPlan uses ArcGIS Flex API as a data viewer. The management of utility data is consistent with the intent of uPlan and/or UGATE. Figure 1 provides a screenshot of uPlan depicting Rocky Mountain Power utilities; uPlan currently only displays Rocky Mountain Power utilities in the "Utilities Infrastructure" Layer. If someone is interested in using uPlan for business purposes, they should first work with the Planning Division to become familiar with its function and limitations. Note that uPlan and UGATE are currently separate tools, both with beneficial features for UDOT business.

The basic uPlan GIS interface was developed by the Planning Division with consultants and AGRC. In the third square icon from the left in Figure 1, one can see the various

shapefile/layer groups are shown representing some of the databases managed by AGRC with the help of UDOT and other agencies. These include various environmental, traffic, road condition, infrastructure, project planning, modeling, etc., layers which can be turned on or off as required. Utility infrastructure layers currently available in uPlan come from Rocky Mountain Power. In the fourth square icon from the left in Figure 1, there are various project planning examples (Megaprojects, Chokepoints, etc.) under which can access PDF-file project summaries can be accessed; this helps illustrate the usefulness of uPlan's process and the associated databases.

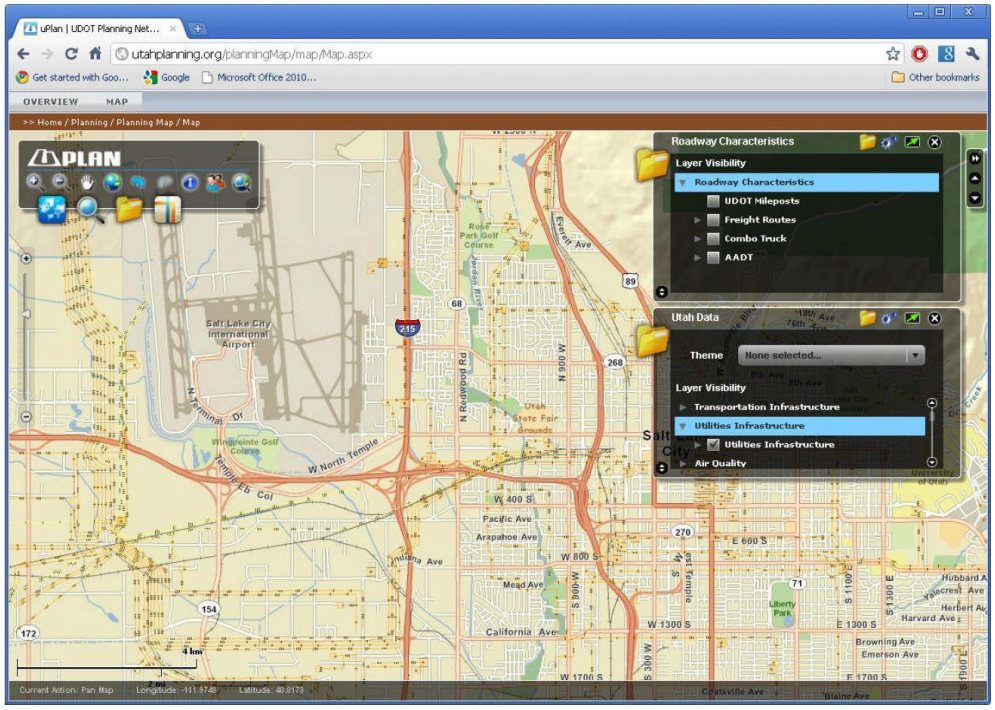

Figure 1 uPlan display of Rocky Mountain Power infrastructure.

Recommendation: Push basic utility infrastructure information into uPlan.

Reasoning: One of the strategies for managing infrastructure data is for planning use. However, consideration will have to be made to protect public from homeland security threats and to protect proprietary nature of private facilities. Recommend displaying only basic function of facilities in a schematic format for general usage. Login access protection is necessary for safeguarding advanced information.

3.1.3 UDOT GIS Toolset Standards – July 2009

Findings: Database environment should be compatible with Oracle and the Open Geospatial Consortium (OGC) Web Map Server (WMS). A Web Map Service (WMS) is a standard protocol for serving georeferenced map images over the Internet that are generated by a map server using data from a GIS database. The specification was developed and first published by the Open Geospatial Consortium in 1999.

WMS is a widely supported format for maps and GIS data accessed via the Internet and loaded into client side GIS software. Major commercial GIS and mapping software that support WMS include Autodesk's Map 3D and Civil 3D products, Bentley Systems's GIS products, and ESRI's ArcGIS products.

Recommendation: Design the utility application to utilize Oracle REST API which supports formats including: html (HyperText Markup Language), kmz (compressed KML, or Keyhole Markup Language), nmf (ArcGIS Explorer map file), ve (Virtual Earth), and gmaps (Google Maps).

Reasoning: UDOT GIS Toolset Standards are consistent with recommended practices for utility data management. For example, the recommended utility database architecture readily allows creation of Keyhole Markup Language (KML) files which can be displayed in numerous user friendly, free, and universally available applications such as Google Earth.

3.1.4 UDOT ATMS

Findings: UDOT Automated Traffic Management System (ATMS) manages a good inventory system, but currently does not manage accurate spatial coordinates for infrastructure.

Recommendation: Include means to synchronize utility database with UDOT ATMS inventory system.

Reasoning: Spatial component for ATMS systems can be managed within utility database. Pertinent attribute information within ATMS inventory system can be synchronized with the utility database system.

3.2 Current UDOT Geo-Referencing Standards

3.2.1 UDOT Survey and Mapping Standards

Findings: Requirements were obtained from "Mapping and Aerial Photogrammetry, Utah Department of Transportation, March 1999" and James Olschewski of the UDOT Right of Way Division. Accordingly, UDOT requires "at least 90 percent of all well defined planimetric features to be mapped within 0.65 meters (2.1 feet) of their true position, and 100 percent shall meet Class I standards". This statement is interpreted as applicable primarily for establishing survey control, as Class I surveys are typically for control where accuracy greater than 1:10,000 is required, such as, but not limited to:

- Extension of the geodetic control from existing networks into areas where cadastral surveys are to be established in accordance with the official protraction diagrams; and
- Establishing control survey networks to National Geodetic Survey accuracy.

For surveyed features, a more applicable accuracy standard is the FGDC Geospatial Positional Accuracy Standards Part 3: National Standard for Spatial Data Accuracy (NSSDA), which uses root-mean-square error (RMSE) to estimate positional accuracy, reported in ground distances at the 95% confidence level. Accuracy reported at the 95% confidence level means that 95% of the positions in the dataset will have an error with respect to true ground position that is equal to or smaller than the reported accuracy value. The reported accuracy value reflects all uncertainties, including those introduced by geodetic control coordinates, compilation, and final computation of ground coordinate values in the product. Control check shots and closure analysis shall be conducted so the surveyor of record can accordingly certify compliance with UDOT standards for mapping.

Current UDOT mapping standards appear to sufficiently meet or exceed recommended FGDC Geospatial Positional Accuracy Standards Part 3: National Standard for Spatial Data Accuracy.

Mr. Olschewski stated all UDOT projects use State Plane coordinates; however, each project is then setup to have its own project coordinate system. The 1999 *Mapping and Aerial*

Photogrammetry guidelines state the North American Datum of 1983 (NAD 83) in meters is required for all new mapping projects; however, this requirement appears to be loosely enforced. Unless otherwise specified, all mapping shall be placed on a ground datum (Mapping and Aerial Photogrammetry, Pg. 3). Utah statutes define the State Plane Coordinate System for the State of Utah is based on the NAD 83. Turn in Package requirements for Electronic Survey Systems are as follows (Mapping and Aerial Photogrammetry, Pg. 8):

- copies of the original field survey data as recorded;
- a printout of all data reduction computations including control point computations (X, Y, Z), azimuth closure and position closure;
- a printout of adjusted Coordinates (X, Y, Z);
- all of the above data in ASCII Format on an electronic media acceptable to the Project Manager; and
- copies of Recovery Notes and Descriptions.

Minimum Field Data Requirements: For each observation station, sufficient data shall be recorded to develop the following position values (Mapping and Aerial Photogrammetry, Pg. 11):

- The horizontal position (N,E) stated in values of the Utah State Plane Coordinate System for the zone specified in the project description. The horizontal position shall be referenced to the NAD 83 datum coordinate system in meters unless otherwise specified.
- The geoid height difference, the ellipsoid orthometric height difference, and the computed station elevation shall be referenced to the North American Vertical Datum of 1988 (NAVD88).
- All control positions set shall have been computed by a minimum of four (4) triangles, to verify global positioning.

Near the end of the research effort for this project, Jason Henley of the UDOT Right of Way

Division informed the research team that the new survey unit standard for UDOT is U.S. Survey Feet.

Recommendation: Apply same criteria for utility data mapping with the addition: "Submittals shall include observed latitude and longitude tied to latest adjustment for NAD 83 and orthometric height (elevation) in meters (and, per UDOT preference, U.S. Survey Feet) based on NAVD88 using the latest geoid model."

Reasoning: Existing mapping standards meet or exceed recommended metadata and spatial data requirements for utilities. The following advantages are achieved with metric elevations and geodetic units:

1. Reduction in errors associated with conversion to and from planar projections (e.g, state plane)

2. Elimination of inevitable confusion arising from the two versions of English feet units, specifically U.S. Survey Feet and International Survey Feet, with either one of these potentially labeled simply as 'Feet'. Meters exist in only one version and are easily converted to and from feet of either version. (UDOT preference, however, is to store orthemetric height in both metric and U.S. Survey feet.)

3. Compliance with NGS guidelines (and corresponding published software) which recommend and utilize geodetic and metric units.

4. Compliance with UDOT's Location Reference Task Force Standards Recommendations (see Section 3.2.3) for storage of geodetic (e.g., latitude and longitude) datum coordinates.

5. Compatibility with emerging technologies that utilize geodetic coordinates (e.g, GPS, Google Earth™). Geodetic coordinates are derived and recorded with every GPS observation, but typically are stripped from survey data after the project local planar coordinates are computed. Modern survey processing software permits easy management of geodetic coordinates with survey data sets; accordingly, storage of coordinate data in geodetic with vertical metric units is trivial for the survey

professional and should not preclude or inhibit project development with local coordinates and English units.

3.2.2 UDOT Spatial Database Standards Draft – Jun '09, Rev. Mar '10

Findings: UDOT standard spatial reference system includes geodetic (lat/long) for points and ROW mapping. Spatial tolerance for x, y, and z data is +/- 0.01 meters (0.4 inch). Oracle Spatial data layer standards allow spatial object column naming convention for geodetic data as follows:

- Spatial Type – Point
- Lat as Numeric (s, p) > 0
- Long as Numeric (s, p) < 0 (negative for west longitude)
- Spatial Object Name – Pt_Lat / Pt_Long

Recommendation: Utilize UDOT Spatial Database Standards as prescribed. However, spatial tolerance of 0.01 meters at a 95% confidence level for utility surveys is not practical using current GPS techology, nor warranted. Therefore, RTK GPS survey methods for Class RT2 and RT3 prescribed in the *NATIONAL GEODETIC SURVEY USER GUIDELINES FOR SINGLE BASE REAL TIME GNSS POSITIONING (v. 1.0 January 2010 William Henning, lead author)* are recommended for providing two sigma (95 percent confidence) precisions typically 2 to 4 centimeters (0.8 to 1.6 inches) horizontal, 3 to 5 centimeters (1.2 to 2 inches) and 4 to 6 centimeters (1.6 to 2.4 inches) horizontal, 4 to 8 centimeters (1.6 to 3.2 inches) vertical respectively.

Reasoning: The UDOT Spatial Database Standards are consistent with recommended practices for utility data management, although the spatial tolerance prescribed is apparently unrealistic with current technologies. Therefore spatial tolerances presented in the latest NGS guidelines for RTK GPS survey should be allowed to supersede.

3.2.3 UDOT's Location Reference Task Force Standards Recommendations

Findings: UDOT's Location Reference Task Force Standards Recommendation was last

updated in April of 2007. This standard sets guidelines of how to refer to a roadway by denoting a specific identifier including date, route, direction, type, and interchange of roadway number. The standard also provides lookup tables for how to denote routes that are concurrent or overlapped with other roadways and routes that are broken in continuity.

This standard also goes into great detail of how measurements along roadways should be taken and reported. The standard provides approved means for assigning a location address, location of a bridge, geographical coordinates, and number of traffic lanes among other items.

An excerpt from Section 6 of the standard, shown below in italics, covers standard recommendations for geographic coordinates:

> *6. GEOGRAPHICAL COORDINATES*
>
> *Latitude and Longitude will be stored decimal degrees in the database (not in degrees, minutes, and seconds).*
>
> *Format: 12.8 for Latitude and Longitude.*
>
> *Example: A typical longitude in Utah would be -111.12345678 and typical latitude would be 40.12345678.*
>
> *NAD83 (North American Datum of 1983) spheroid model will be used for coordinate projection.*

Decimal degrees of latitude and longitude representing data allow for the following:

1. Conversion to other coordinate systems can be accomplished easier
2. Flexibility if the standard is revised
3. Easier conversion of other sources of coordinate data
4. Easier interface with external systems

Recommendation:

1. Utilize the naming conventions outlined in this standard for populating the data field referred to as "Indirect Spatial Reference"; and
2. Store horizontal coordinates using the recommended geographic standard (i.e., decimal degrees tied to the NAD 83 National Spatial Reference System 2007 adjustment (NSRS2007) datum).

Reasoning:

1. Instead of giving an intersection in layman's terms, this standard provides a logical, consistent means to pinpoint where the facility is positioned;
2. The standard's four points provided above for using decimal degrees are relevant for managing utility information; and
3. All state plane coordinates used for UDOT projects are based on the NAD 83 datum, not WGS84.

3.2.4 Datum and Stored Coordinates

Findings: State of Utah geographic data standards require universal transverse mercator (UTM) Zone 12 metric coordinate data tied to NAD 83 horizontal and NAVD 88 vertical datums. UTM is a grid-based geographic coordinate systemfor specifying locations on the surface of the Earth using a practical 2-dimensional Cartesian coordinate system. UTM involves non-linear scaling in both Eastings and Northings to ensure the projected map of the ellipsoid is conformal. UDOT, however, prefers projects in English units, therefore typically requires State Plane coordinates in feet. The State Plane Coordinate system provides coordinates on a flat grid for easy computation while maintaining a difference between geodetic and grid distance of one part in 10,000 or better. Outside a specific state plane zone accuracy rapidly declines, thus the system is not useful for regional or national mapping. UDOT project control is supposed to be tied to NAD 83 and NAVD 88 datums. UDOT is bound by U.S. Bureau of Land Management (BLM) survey rules.

Recommendation: Store all positional data for utilities in geodetic (latitude / longitude)

coordinates tied to the latest NAD 83 adjustment and elevation in meters (and, per UDOT preference, U.S. Survey Feet) tied to NAVD 88 derived using the latest geoid model (currently GEOID09). The data collection ("DC") files from utility surveying, including metadata, should also be submitted and stored in the utility database. The survey control network used for collecting this data should also be supplied with the data.

Reasoning: Latitude and longitude are always recorded using GPS methods, and can easily be derived using conventional total station equipment if survey control is tied to NAD83 as required by current Utah and UDOT standards. To avoid confusion between U.S. Survey Feet and International Feet, orthometric height (i.e., elevation) is stored in meters. However, due to UDOT preference, orthometric height will also be stored in U.S. Survey Feet.

UDOT standards require benchmarks (that are tied to NAD 83 and NAVD 88) spacing to not exceed 400 meters along project corridors, allowing survey of utility infrastructure within UDOT right of way using conventional total station equipment. However, real-time reference networks, such as TURN (see Section 3.3.1 below), established within Utah make RTK GPS survey operations simple, accurate (e.g., +/- 2 cm), efficient, and without the need for post processing.

3.3 Current Utah State Geospatial Systems and Practices

3.3.1 The Utah Reference Network GPS (TURN GPS)

Findings: Utah has a new real-time differential correction network (RTN) service for Global Positioning Systems (GPS) that became available beginning April 16, 2007. This service, named The Utah Reference Network GPS (TURN GPS) provides high accuracy GPS correction signal for surveyors and GIS mapping. Phase I covers an area roughly from Logan south to Manti and from Tabiona west to Tooele. TURN GPS services are administered by AGRC and are available on a subscription basis according to a Legislature approved rate schedule. TURN GPS greatly increases productivity, efficiency, and cost-effectiveness of high accuracy GPS work by eliminating the need to setup and takedown temporary GPS base stations and repeaters for each project.

TURN makes it possible to achieve highly accurate positional data on utilities, albeit only if

very specific procedures are followed when using GPS survey methods.

Recommendation: Develop recommended survey procedures which utilize TURN to promote efficient and accurate GPS surveys.

Reasoning: With TURN, accurate real time kinematic (RTK) GPS survey methods are practical and should be utilized whenever possible to achieve reliable, centimeter accuracy and minimize risk. Coordinate data based on untied handheld GPS methods should be avoided, as positional errors in the tens of feet can result, which is undesired for transportation corridor planning and design work.

3.3.2 Utah Automated Geographic Reference Center (AGRC)

Findings: The Automated Geographic Reference Center (AGRC) was created by the state of Utah as part of the Department of Technology Services (DTS). The mission of AGRC is to encourage and facilitate the effective use of geospatial information and technology for Utah.

AGRC provides a wide range of Geographic Information System (GIS) and other geospatial support services. AGRC strives to ensure a high level of coordination among Utah GIS users and effective, efficient use of GIS resources. Services provided include; internet based mapping services, ArcGIS Server Application Design and Hosting, ArcGIS Server-based web services for embedding the display, query, and analysis of maps and geographic data, and ArcIMS Application Design and Hosting.

Other services include stewardship of the State Geographic Information Database (SGID), facilitation of programs and activities to implement GIS technology across the state, and coordination of GIS policy development and implementation activities. The SGID is the warehouse of the State of Utah's geospatial data. Datasets are available in two main categories; vector data sets wherein geographic features are represented by points, lines and polygons; and raster data sets, which represent geographic phenomena using a grid of raster cells or pixels. The SGID currently has hundreds of GIS layers sorted alphabetically by category. A Utilities category already exists with the following layers: *CommunicationTowersGNIS, ElectricalLines, GasPipelines, OilGasPipelines, Pipelines,*

PowerLines_10MileBuffer, PowerLines_5MileBuffer, SewerLines, StormDrains, TelephoneInfrastructure, TelephoneServiceAreas, TransmissionLines and WaterDistribution. Each Layer can be downloaded as a shapefile of the entire state or by each county.

AGRC also provides consulting services to federal, state, and local government and other organizations, including GIS analysis and application development, GIS training courses, and Internet Map Service development and hosting.

Recommendation: Utilize AGRC as portal for the utility data as a means to provide access to cities and counties throughout Utah.

Reasoning: All cities and counties have the same issues and needs as UDOT, and they don't have an effective means for managing utilities within public right of way. Furthermore, cities and counties lack budget to develop or purchase, and maintain individual utility database systems; however, through AGRC a unique opportunity arises to share resources and support for a single utility repository system, thereby cutting costs for each entity utilizing the system.

3.3.3 Utah State Statutes and NCEES Model Law for Surveying

Findings: The 2002 Geographic Information Systems/Land Information Systems (GIS/LIS) Addendum to the Report of the Task Force on the National Council of Examiners for Engineers and Land Surveyors (NCEES) Model Law for Surveying recommends "GIS-based databases and maps that are intended to be used as the authoritative document for the location of parcels, fixed works, survey monuments, elevation measurements, etc., must be compiled under the responsible charge of a Professional Surveyor or Land Surveyor." Utilities are fixed works (of engineering); consequently, utility coordinate data should be acquired and processed under the direct supervision of a professional land surveyor to ensure appropriate, systematic measures are used to properly tie features to the NSRS.

Recommendation: Adopt NCEES Model Law Surveying recommendations for requiring utility coordinate data to be compiled under the responsible charge of a professional land surveyor.

Reasoning:

- Utilities pose tremendous risk to the public (i.e., cost, health and safety, commerce, service disruption, etc.). The purpose of Utah Department of Commerce Professional Engineers and Professional Land Surveyors Licensing Board, as established by state statutes, is to protect the public welfare from incompetent performance of engineering and land surveying services. Requiring professional endorsement will help ensure work products are prepared in accordance with the required standard of care; furthermore, failure to meet these standards can result in appropriate legal recourse.
- Although well established, the procedures to accurately tie coordinates with statistical confidence to the NSRS do require specialized knowledge in geodesy which is required for professional land surveyors.

3.4 Current Federal and National Geospatial Systems and Practices

3.4.1 MetroGIS

Findings: MetroGIS is a voluntary collaboration of organizations in the Minneapolis-St. Paul Metropolitan Area that use geographic information systems technology to carry out their business functions. The discussions that resulted in the establishment of MetroGIS began in the fall of 1995.

MetroGIS's primary purpose is to promote and facilitate widespread sharing of commonly needed geospatial data and information among organizations that serve the Minneapolis-St. Paul Metropolitan Area. More specifically, the goal is to institutionalize sharing of accurate and reliable geospatial data and information so that MetroGIS's data user and producer communities can both share in the efficiencies of users being able to effortlessly obtain data needed from others, in the form needed, and when it is needed.

MetroGIS carefully evaluated and adapted the Federal Geographic Data Committee (FGDC) standards for positional accuracy and geospatial metadata to develop their own internal guidelines and standards. The MetroGIS standards, such as the Minnesota Geographic Metadata Guidelines Version 1.2 – October 7, 1998, are well conceived and provide a

common approach for documenting all types of geographic data. They have been designed to be staightforward, intuitive and complete.

Recommendation: Adopt the MetroGIS standards for documenting positional coordinate data.

Reasoning: The MetroGIS standards have been proven to work well, including management of "authoritative" certified survey data.

3.4.2 MetroGIS Metadata Standards

Findings: Minnesota's MetroGIS reviewed and adapted FGDC metadata standards. Data fields for the following metadata categories were established (see Figure 2):

- Identification Information
- Data Quality Information
- Spatial Data Organization Information
- Spatial Reference Information
- Entity and Attribute Information
- Distribution Information
- Metadata Reference Information

Discussions with Randy Johnson of MetroGIS indicate their adaptation of the FGDC metadata fields has worked well.

The Seven Sections
of the
Minnesota Geographic Metadata Guidelines

Version 1.2
October 7, 1998

1 Identification Information	2 Data Quality Information	3 Spatial Data Organization Information	4 Spatial Reference Information	5 Entity and Attribute Information	6 Distribution Information	7 Metadata Reference Information
Originator	Attribute Accuracy	Native Data Set Environment	Horizontal Coordinate Scheme	Entity and Attribute Overview	Publisher	Metadata Date
Title	Logical Consistency	Geographic Reference for Tabular Data	Ellipsoid	Entity and Attribute Detailed Citation	Publication Date	Metadata Contact Person
Minnesota Clearinghouse ID	Completeness	Spatial Object Type	Horizontal Datum		Distributor Contact Person	Metadata Contact Organization
Abstract	Horizontal Positional Accuracy	Vendor Specific Object Types	Horizontal Units		Distributor Organization	Metadata Contact Position
Purpose	Vertical Positional Accuracy	Tiling Scheme	Distance Resolution		Distributor Position	Metadata Contact Address
Time Period of Content Date	Lineage		Altitude Datum		Distributor Address	Metadata Contact City
Currentness Reference	Source Scale Denominator		Altitude Units		Distributor City	Metadata Contact State or Province
Progress			Depth Datum		Distributor State or Province	Metadata Contact Postal Code
Maintenance and Update Frequency			Depth Units		Distributor Postal Code	Metadata Contact Voice Phone
Spatial Extent of Data			**If Raster**		Distributor Voice Phone	Metadata Contact Fax Phone
West Bounding Coordinate			Cell Width		Distributor Fax Phone	Metadata Contact E-mail Address
East Bounding Coordinate			Cell Height		Distributor E-mail Address	Metadata Standard Name
North Bounding Coordinate			**If Geographic**		Distributor's Data Set Identifier	Metadata Standard Version
South Bounding Coordinate			Latitude Resolution		Distribution Liability	Metadata Standard Online Linkage
Place Keywords			Longitude Resolution		Transfer Format Name	
Theme Keywords			**If UTM**		Transfer Format Version Number	

Figure 2 MetroGIS metadata guidelines derived from FGDC recommended standards.

Recommendations: Adopt the MetroGIS version of the FGDC metadata standards.

Reasoning: MetroGIS metadata requirements for property boundaries, etc. parallel those required for storage of authoratative coordinate data for utilities.

3.4.3 Open Geospatial Consortium, Inc. (OGC)

Findings: The Open Geospatial Consortium, Inc (OGC) is an international industry consortium of 404 companies, government agencies and universities participating in a consensus process to develop publicly available interface standards for geospatial and location based services. One of OGC's strategic goals is to lead in the creation and establishment of standards that allow geospatial content and services to be seamlessly integrated into business and civic processes, the spatial web and enterprise computing. OGC encourages applicants to submit their existing standards. The OGC community then reviews the application, offers suggestions, and votes on whether the group's standard's will be

accepted into the OGC community.

Two examples of services the OGC provides are Web Map Services (WMS) and Web Feature Services (WFS). These services provide a simple HTTP formatted, geo-referenced map of the area requested.

OpenGIS® Standards support interoperable solutions that "geo-enable" the Web, wireless and location-based services, and mainstream IT. The standards empower technology developers to make complex spatial information and services accessible and useful with all kinds of applications.

OpenGIS® is a Registered trademark of the OGC and is the brand name associated with the Standards and documents produced by OGC. OpenGIS standards are developed in a unique consensus process supported by OGC industry, government and academic members to enable geoprocessing technologies to interoperate, or "plug and play". The OpenGIS® trademark is associated with products that implement or comply to Bentley standards.

Recommendation: If these services are not already within other UDOT spatial services, compare and evaluate costs for implementing WMS and WFS services for utility data distribution and communication purposes. (Note: the above recommendation is beyond the scope of services required under the present work authorization; consequently, no further action has been taken for this project.)

Reasoning: WMS and WFS may provide an attractive means for disseminating utility information to users. All geoprocessing and location services procurement and technology development programs are recommended to conform with OpenGIS standards. The utility database architecture provided through this project appears compatible for meeting requirements for OGC OpenGIS standards.

3.4.4 NCHRP Report 460 titled “Guidelines for the Implementation of Multimodal Transportation Location Referencing System” from NCHRP Project 20-27

Findings: The NCHRP 20-27(2) is not a linear referencing system or method. The 20-27(2) model is a conceptual model for integrating linearly referenced data which might be

available from a variety of sources (e.g., route/mile point, project stationing, etc.). As a conceptual model, it does not provide scripts, equations, or anything similar to facilitate the transformation. Individual agencies have to put those elements in place. NCHRP 20-27(2) appears to have not been implemented anywhere. This is not surprising given that, over the last few years, absolute coordinate referencing has really taken off (no doubt facilitated by GPS and applications such as Google Maps and Bing).

The more recent NCHRP 8-36(80) report included a survey. UDOT was one of the agencies that responded and is using route/mile point in accordance with the UDOT Location Reference Task Force Standards Recommendations, last updated April 2007 (see Section 3.2.3).

In terms of linearly referencing utility data, this exercise is straightforward as UDOT already has a linear referencing system. Utility coordinate data (e.g., latitude/longitude or State Plane coordinates) is processed through a GIS function that maps each point to the closest network element. Mapping does not involve physically snapping point data to the network (which would distort the positional accuracy of the data). It involves "virtually" snapping the point to the network (i.e., calculating where the point is along the route and determining the corresponding mile point). Some code may need to be written to automate the task (e.g., to process batch data instead of processing each point independently). UDOT already has this functionality; the basic GIS functions to do this have been around for 10-15 years.

Recommendation: Store coordinate data in geodetic units (lat/long) and compute linear referencing as necessary.

Reasoning: Less opportunity for error. Absolute coordinates (lat/long) tied to NAD 83 (NSRS 2007) will not change with time and derivation of linear referencing is a straightforward process. Geodetic coordinates can also be readily utilized by many off the shelf GPS applications such as those developed by Magellan, Google, Trimble, TopoGrafix, ESRI, MicroStation, Caterpillar, etc.

3.4.5 NGS Guidelines for RTK GPS

Findings: The National Geodetic Survey (NGS) recently produced an apt guideline for

Real Time Kinematic (RTK) GPS survey work called *NATIONAL GEODETIC SURVEY USER GUIDELINES FOR SINGLE BASE REAL TIME GNSS POSITIONING (v. 1.0 January 2010 William Henning, lead author)*. Section VII of the NGS User Guidelines is about real-time networks (RTN's) such as TURN. Section VIII is a Best Methods Summary. In addition, Sections IV and V cover procedures before beginning the field work and field procedures. All 150 pages should be read and understood by the individuals in charge of utility location surveys. The document also contains "Guidelines and Procedures for NGS Real-Time Accuracy Classes", which are summarized as follows:

- Class RT1 requires a collection interval of 1 second for 3 minutes. Precisions: typically 0.01 m – 0.02 m horizontal, 0.02 m – 0.04 m vertical (two sigma or 95 percent confidence). Typically used for project control, construction control points, check on traverse levels, scientific studies and paving stakeout.
- Class RT2 requires a collection interval of 5 seconds for 1 minute. Precisions: typically 0.02 m – 0.04 m horizontal, 0.03 m – 0.05 m vertical (two sigma or 95 percent confidence). Typically used for densification of control, topographic control, photopoints and utility stakeout. Important vertical features such as pipe inverts, structure inverts, bridge abutments, etc. should have elevations obtained from leveling or total station locations, but RT2 derived horizontal locations are acceptable.
- Class RT3 requires a collection rate of 1 second for 15 seconds. Precisions: typically 0.04 m – 0.06 m horizontal, 0.04 m – 0.08 m vertical (two sigma or 95 percent confidence). Typically used for topography, cross sections, agriculture, road grading and site grading.
- Class RT4 requires a collection rate of 1 second for 10 seconds. Precisions: typically 0.1 m – 0.2 m horizontal, 0.1 m – 0.3 m vertical (two sigma or 95 percent confidence). Typically used for site grading, wetlands, GIS population, mapping and environmental.

These classes are described in greater detail on pages 46-48 of the NGS guidelines.

Recommendation: Apply same criteria for utility data mapping with the following modifications: 1) submittals shall include observed latitude and longitude tied to NAD 83 and orthometric height (elevation) in meters (and per UDOT preference U.S. Survey Feet) based on NAVD88; 2) all RTK GPS surveying shall be performed in compliance with the *NATIONAL GEODETIC SURVEY USER GUIDELINES FOR SINGLE BASE REAL TIME GNSS POSITIONING (v. 1.0 January 2010 William Henning, lead author)*.

- Class RT2 should be used for features to be designated as CI/ASCE 38-02 Quality Level (QL) A, and Class RT3 should be used for collecting the bulk of utility QL B data.
- Accordingly survey work for all utilities should require support from a professional land surveyor or individual specializing in geodesy.

Reasoning: Existing mapping standards meet recommended metadata and spatial data requirements for utilities. Drainage pipe installation work typically requires level or total station observations, hence the requirements stipulated for RT2 do not pose additional labor requirements or cost. The recommended NGS guidelines will increase the overall land survey effort somewhat, but the increased costs are marginal when compared to value gained and risk removed by having precise positional coordinate data tied to the NSRS.

3.4.6 ANSI INCITS 353-2006 Geographical Information Systems Spatial Data Standards for Facilities, Infrastructure, and Environment (SDSFIE)

Findings: SDSFIE provides an enterprise standard across the entire Department of Defense business mission area and the result of a joint effort between the American National Standard Institute (ANSI) and the International Committee for Information Technology Standards (INCITS). INCITS is an ANSI accredited committee that develops national standards for information technology. ANSI INCITS 353-2006 is managed by the Defense Installations Spatial Data Infrastructure (DISDI) Group, a formal governance body reporting to the Department of Defense's Installations & Environment Investment Review Board. The DISDI is chaired by the Program Manager and made up of leaders from each of the Services' programs for Installation Geospatial Information and Services (IGI&S) as well as

the U.S. Army Corps of Engineers. As part of the SDSFIE 3.0 implementation, the standard will become an integral part of the data standards used in the National System for Geospatial-Intelligence (NSG), as required by Department policy. In the first decade of the SDSFIE development, it was generally seen as a technical activity with a project-level scope. Given the standard's new enterprise role, the DISDI Group developed a vision and a strategy which triggered a complete re-engineering of the standard – SDSFIE 3.0 is an adaptable logical data model, tailored to defense business requirements and processes. Although tailored to Department of Defense needs, federal, state, and local stakeholders are welcome to use the standard and help mature it in future releases. A review of feature attribute fields developed for utility infrastructure reveals the SDSFIE 3.0 to be sufficiently comprehensive and robust for UDOT use.

Figure 3 presents an example of the SDSFIE 3.0 data organization for a water main. Following the figure are the data fields associated with the water main example.

Recent leadership changes at the SDSFIE has caused the end goal of the database to be somewhat in flux. Consequently, the SDSFIE 3.0 standards are not yet implemented for GIS facility inventory systems at Department of Defense bases. However, the SDSFIE 3.0 provides tremendous advances toward normalizing infrastructure inventory data which can be utilized for UDOT GIS development.

Recommendation: Adopt specific SDSFIE 3.0 utility infrastructure attribute fields within the utility data model. Add tables and attribute data fields as needed to create a robust and functional system. Submit required changes to be incorporated into the SDSFIE 3.0 standard.

Reasoning: Conforming with a national standard ensures the ability to utilize corresponding software and hardware applications and also streamline data sharing with many Federal agencies. Furthermore, the standard allows UDOT to take full advantage of previous work funded by others.

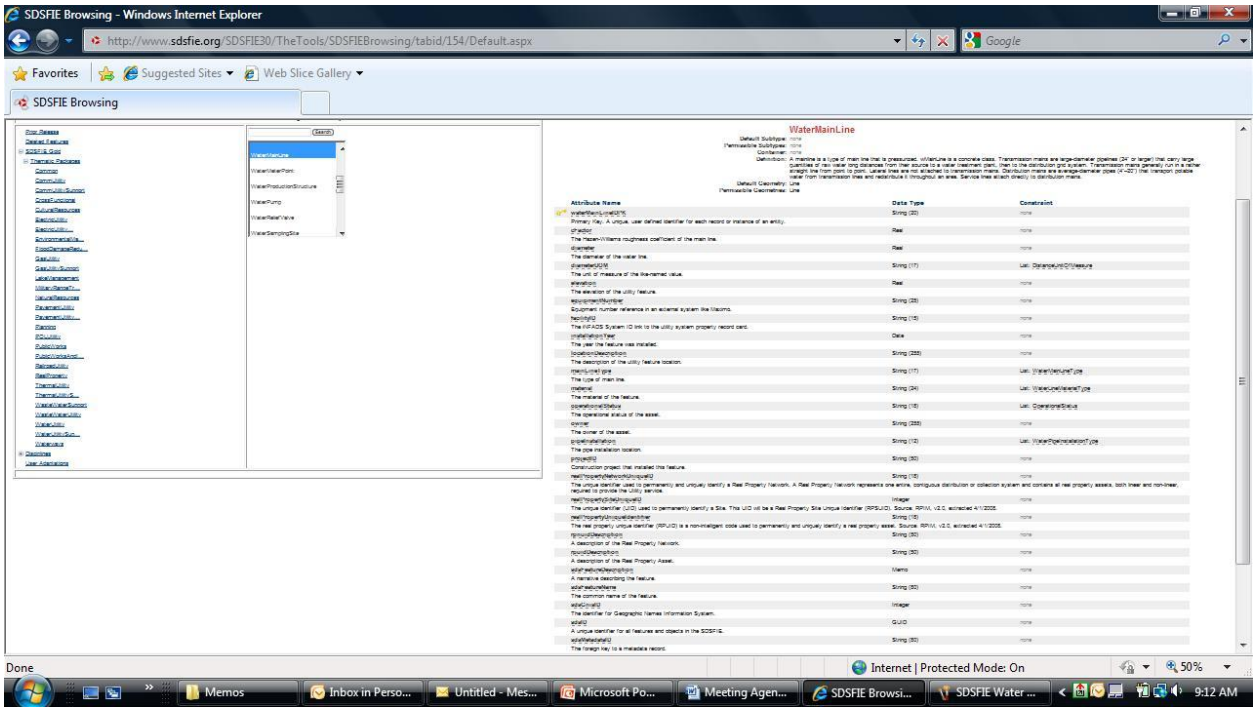

Figure 3 Example of SDSFIE 3.0 Data Structure and Data Fields

- waterMainLineIDPK
- cFactor
- diameter
- diameterUOM
- elevation
- equipmentNumber
- facilityID
- installationYear
- locationDescription
- mainLineType
- material
- operationalStatus
- owner
- pipeInstallation
- projectID
- realPropertyNetwork UniqueID
- realPropertySiteUniqueID
- realPropertyUniqueIdentifier
- rpnuidDescription
- rpuidDescription
- sdsFeatureDescription
- sdsFeatureName
- sdsGnisID
- sdsID
- spmLocation
- ucsCode
- waterType
- sdsMetadataID

3.4.7 Transportation Research Board (2011) SHRP 2 R01(A) Technologies to Support Storage, Retrieval, and Utilization of 3-D Utility Location Data

Findings: As of the end of 2011 this project was behind schedule and without literature or information for review. A TRB August 10, 2011 webinar revealed very little; however, a TRB February 15, 2012 webinar indicated significant consistencies with the recommendations of this research effort. The objectives of the R01(A) research, as stated in the February 15th webinar, are:

- Create a system that provides a single, up-to-date repository for 3-D utility location data within a project boundary.
- Leverage existing permitting and one-call processes to create a change notification system.
- Develop supporting administrative procedures.
- Utilize existing state Dept. of Transportation 2-D and 3-D CAD design software.

The research effort, as also stated, is to include adopting and adapting a 3-D utility data model (proprietary or industry standard) and utilize a spatial document management system. Interestingly the Februrary 2012 R01(A) webinar identified the following as criteria for the data model: 1) the data model should consist of location and attribute data; 2) the data model should include feature quality and and accuracy, including CI/ASCE 38-02 quality levels; 3) administrative practices should include integration with (ROW) permit and One-Call (811) processes; and 4) quality and accuracy management should include a gatekeeper function, certification of the record drawing, and appropriate measures to balance access with security. These criteria are largely consistent with recommendations previously derived (between February 2010 and June 2011) for UDOT and presented herein with this report *Recommended Protocol and Standards for Utility Data Submittals*.

Recommendation: Continue monitoring the R01(A) effort, but in the meantime proceed with adopting the recommendations provided within this document.

Reasoning: R01(A) appears to be advocating an approach for developing a utility data model and standard procedures consistent with the findings of this investigation.

3.4.8 Table and Field Naming Conventions

Findings: UDOT has standard naming conventions for the following: table, column/data fields, index, constraint, and sequence. These are established to be compatible with Oracle name requirements.

Recommendation: Utilize UDOT naming convention for all tables and fields in the utility repository, except those established within the SDSFIE 3.0 for feature attributes.

Reasoning: The SDSFIE 3.0 names are compatible with Oracle naming constraints. Furthermore, SDSFIE is an established ANSI standard; consequently, it is better to maintain the conventions of an accepted standard to assure compatibility with other software and posture to take advantage of further updates and technological developments by others, including among others, the U.S. Department of Defense.

3.5 Practices by Other Local Agencies and Private Enterprises

3.5.1 Practices by Others – Qwest, City of West Valley

Findings: Qwest and the City of West Valley, Utah manage inventory systems of their infrastructure. None of the systems appear to follow national or international standards. Also, while attribute information seems to be fairly comprehensive, positional information is not managed in a manner required for engineering purposes. The GIS systems investigated are designed and suited primarily for internal use only. The recommended UDOT database architecture for managing utility data appears to be sufficiently robust and comprehensive to accommodate the data needs of these individual agency inventory systems.

Recommendation: Evaluate data architecture for each agency's inventory system, then develop an export format that will allow information to flow seamlessly from the UDOT utility data repository into each agency's inventory system. UDOT should encourage infrastructure owners to adopt and use the UDOT system and standards for uploading as-

built information, with the assurance that they in turn will get a digital export file that can be easily uploaded into their system.

Reasoning: Avoid double handling of data. As-built data collected and submitted to proposed UDOT standards for uploading into the recommended UDOT utility database can then be exported into a format for seamless uploading into a particular agency's system. Agencies outside of UDOT will have less objection toward participating in UDOT's process if they know it will not substantially impact their current efforts. Furthermore, the proposed web based interface for uploading data into UDOT's utility repository will likely be easier to use than the methods currently employed within each agency.

3.5.2 Bentley MicroStation, Map, and Geospatial Server

Findings: A software program capable of receiving relational database management system (RDBMS) point data from user defined data fields kept in an Oracle Spatial database, organizing the data while keeping all attribute and metadata information, and then conveying the data to a MicroStation platform for other users to access is imperative to the success of this project. Bentley Map and Bentley Geospatial Server are two software programs currently being investigated to meet this application's needs.

Bentley Map allows a user to produce custom data models and editing tools for a wide variety of geospatial applications. This data can then be labeled and formatted to produce interactive maps in a wide variety of formats.

Bentley Geospatial Server is necessary when one is looking to manage large amounts of maps along with their respective geospatial data and metadata. Geospatial Server also aids in project, document, and workflow management. A flowchart depicting how Bentley Map and Bentley Geospatial Server work together in this application is shown below.

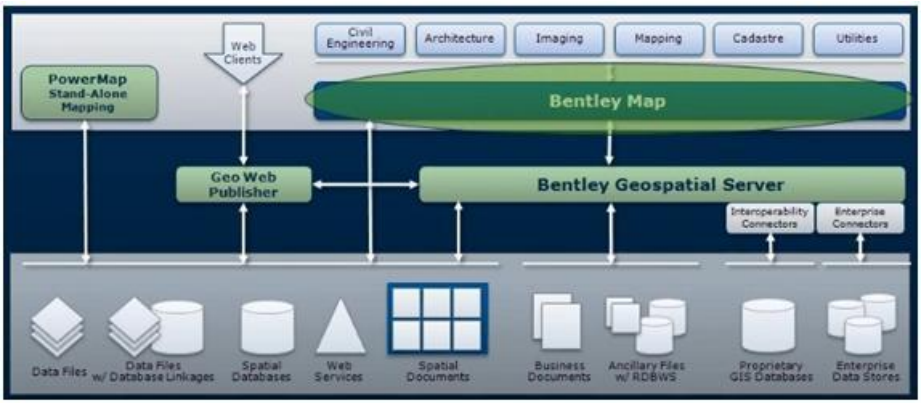

Figure 4 Bentley Product Workflow Chart

Both Bentley Map and Bentley Geospatial Server are fully OGC compliant, which makes data stored even more accessible to a wider variety of users if so desired.

On March 30, 2010, the project team reviewed an e-seminar by Bentley Software. This presentation was focused on how Bentley products can help manage and integrate spatial data while allowing access and editing rights to other users.

Two options Bentley provides to keep databases up to date are data exchange and data collaboration. Data exchange relies on users using well-known data formats and utilizing a pre-determined exchange format to allow for quick and efficient imports and exports. Data collaboration uses a separate geodatabase, like Oracle, to allow all users access to the information on a read-only availability. Users with Bentley's software are able to edit the data files which are then updated in the geodatabase.

The seminar then gave two options for connecting Bentley's geodatabase to other user's databases which may not be using Bentley's software. The first option is a customized interface with its own set of rules and guidelines. The second option is to utilize existing protocols, specifically ISO/OGC standards. Recently, Bentley has begun supporting industry protocols, like OGC which sanctions Web Map Service (WMS) and Web Feature Service (WFS) interface.

Bentley Map allows a user to produce custom data models and editing tools for a wide variety of geospatial applications. This data can then be labeled and formatted to produce interactive maps in many different formats. Bentley Map essentially works over top of

MicroStation as the GIS operator in collaboration with the spatial database. At this time, Bentley Map is only capable of working with an Oracle database. Bentley Map is capable of taking point data from different coordinate systems and displaying the results on the same map very accurately in one, user defined coordinate system. Bentley Map is also capable of creating a format that is OGC compliant. The largest issue against using Bentley Map software is that there is currently no automated procedure to link the attribute information to the collected data points. Manually filling in all required data fields for each survey would be a daunting, time consuming task.

Recommendation: The focus for this project is to establish a relational database management system (RDBMS) utility data repository that can manage data with user defined attribute and metadata fields in Oracle. Bentley products were investigated to evaluate compatibility requirements, and to make assurances that development work is not being replicated. While the Bentley Map product appears promising, it apparently is still undergoing some development work and beta testing; however, the RDBMS utility repository architecture proposed through this project appears highly compatible with the intent of Bentley Map. For now, in lieu of WMS or WFS interface protocol, a recommendation is made to simply develop a query to generate an ASCII, comma delimited text data file which can be readily imported into MicroStation using GEOPAK or InRoads software. The process will require converting decimal latitude and longitude to project coordinates (e.g., Utah State Plane) either through a direct calculation or through use of a third party software such as Trimble Geomatic Office (TGO). Further evaluation of the Bentley Map product is recommended.

Reasoning: The RDBMS architecture for the utility repository can be implemented immediately while other third party software, such as Bentley Map are being developed which will ultimately allow MicroStation to act and feel like a GIS package. The RDBMS utility repository architecture is compatible, yet independent of Bentley products; this allows UDOT indepedence to utilize the most advantageous application software on the market.

3.6 TXDOT Prototype Utility Database

Findings: The prototype utility database developed by TTI for TxDOT provided insight as follows:

- An audit was conducted by TTI to catalog the many varieties of utilities encountered within TxDOT right of way.
- A prototype relational database was developed for managing the identified facilities. The database does not manage sufficient metadata for documenting "authoritative" (i.e., certifiable by a registered professional land surveyor) positional information, nor does the architecture allow accomodation of varying degrees of quality level designation along a single facility alignment. Consequently, a revised data schema, was developed to address these issues. This approach assigns appropriate metadata (per FGDC / Minnesota Geographic Metadata Guidelines Version 1.2 – October 7, 1998) to be assigned.
- The identified utility types used by TxDOT were mapped into the most current draft upgrade to the ANSI INCITS 353-2006 Geographical Information Systems Spatial Data Standards for Facilities, Infrastructure, and Environment (SDSFIE Version 3.0). The results indicate the recommended SDSFIE vs. 3.0 standard, to be finalized and implemented during the Fall of 2010, is sufficiently comprehensive to accommodate the array of utilities known to exist within TxDOT public right of way.

Recommendation: Abort adaptation of the TTI prototype database and develop a completely new data model that includes: 1) FGDC / MetroGIS recommended metadata for documenting authoritative survey data; 2) manages utility data, including CI/ASCE 38-02 quality level, so users will know the basisfor the depicted alignments for future needs; and 3) utilizes the SDSFIE vs. 3.0 to document utility attributes.

Reasoning: The recommendations will produce a more robust, legacy database that stems from very sound, well established national standards.

3.7 TXDOT Business Process with respect to Utilities and UDOT's Design Process

Findings: Texas A&M Texas Transportation Institute (TTI) report INTEGRATION OF UTILITY AND ENVIRONMENTAL ACTIVITIES IN THE PROJECT DEVELOPMENT PROCESS (Report 0-6065-1 and Project 0-6065) performed in cooperation with the Texas Department of Transportation and the Federal Highway Administration, and published in January 2010, reveals similar project development process and business practices utilized by UDOT in regard to identifying and managing utility issues, as follows:

- involve environmental and right-of-way staff in planning and programming,
- establish planning advisory teams and support tools,
- coordinate environmental and utility data collection,
- enhance and coordinate preparation of scopes of services,
- require utility owners to verify utility facility information,
- gather CI/ASCE 38-02 Quality Level B (e.g., ownership, attribute, and horizontal alignment) data prior to and during preliminary design,
- include some drainage design elements during preliminary design,
- include some design elements during preliminary design,
- address utility issues in constructability review during preliminary design, and
- develop and/or update curricula for utility coordination stakeholders.

A key finding from this report is the benefit and value obtained by having accurate utility information available early. Involving environmental and right-of-way personnel more formally in the early stages of planning and programming would enable TxDOT to identify major environmental and right-ofway issues systematically, which, in turn, could result in time and money saved during project development and construction. Figure 5 presents a flow diagram for a project development process that has a focus on utility coordination.

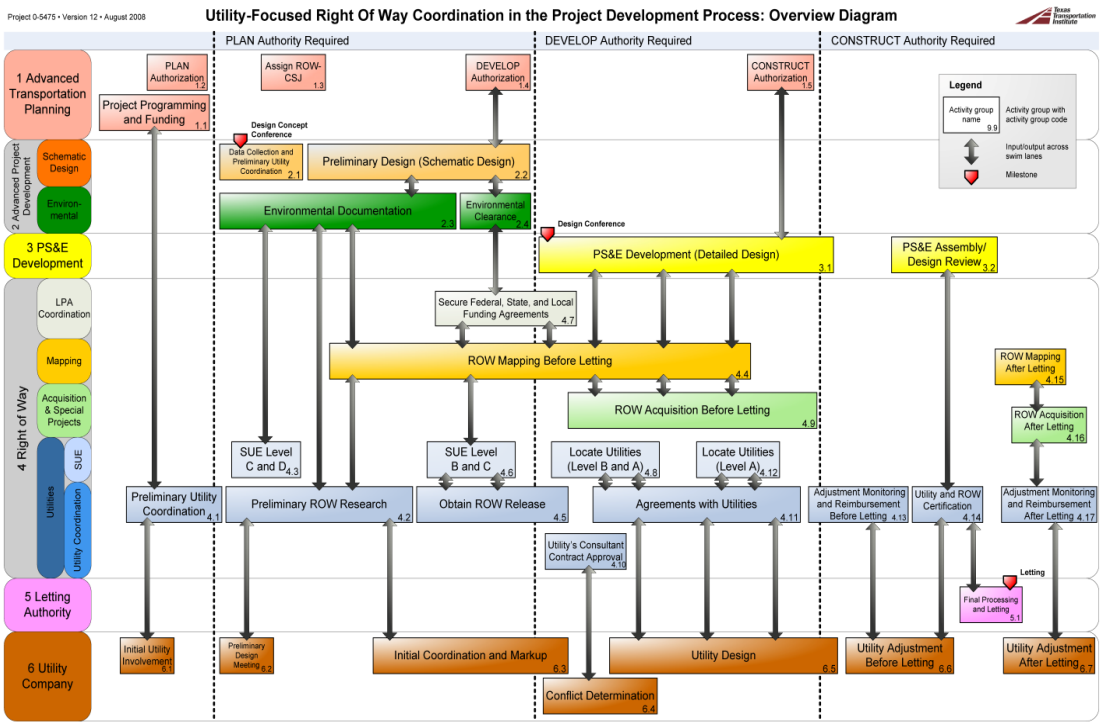

Figure 5 Utility-Focused ROW Coordination in Project Development Process: Overview Diagram

Recommendation: Use the report as a reference to justify management of utility data within public right of way.

Reasoning: Texas local, state, and federal design development process is very similar to UDOT; consequently, value realized through having accurate utility data on hand for project pre-design and environmental processes provides justification and support for systematic storage and management of utility data.

3.8 Current UDOT Utility Data Submittal Requirements

3.8.1 UDOT Construction Permits

Findings: Administrative Rule R930-6 ACCOMMODATION OF UTILITIES Section 5.4 GPS Requirements state utility owners to submit GPS survey data to UDOT when projects are completed. The document states "it is the utility company's responsibility to maintain a set of certified reproducible plans and an electronic file showing the location of all utility facilities located in the State Highway right-of-way. For new facility installations, the utility company uses survey grade Global Positioning System (GPS) to survey their facilities in order to establish its location." The section also states at the end

"If the utility fails to provide the information requested by UDOT within the schedule established by UDOT, UDOT will hire a Subsurface Utility Engineering consultant and bill the utility company for the cost of locating their facilities." These requirements are somewhat vague and currently not being enforced, because there are not any standards and specifications for acquiring the data, or a repository to store and utilize the information.

Recommendation: Provide specifications and standards for collecting utility data and a web based interface for uploading utility data into a repository. Develop a customized export form for each utility owner that enables utility data to be downloaded from the UDOT repository and uploaded into the utility owner inventory database in a seamless fashion, thereby avoiding the issue and cost associated with double handling of as-built data.

Reasoning: Reintroducing the as-built requirement with specifications and required standards would be straightforward. Some training and meeting time will be necessary to obtain support and compliance from utility owner; offering to provide a custom file for import into facility owner GIS or inventory database systems will avoid double handling of data, thereby making it easier for obtaining buy-in from utility owners. Once the submittal standards are in place the requirement would be easier to enforce.

3.8.2 UDOT Utility Permitting

Findings: Administrative Rule R930-6 (see Section 3.8.1) also applies to new facilities installed outside of UDOT construction projects. As before, this rule is not currently enforced.

Recommendation: AR R930-6 should be modified to include a statement to the following effect: "Coordinate and attribute data for utility company facilities will be acquired and uploaded in accordance with UDOT standards and procedures for utility data." In addition, the repository system should be designed to provide the utility owner with an output file that is customized for import into the utility owner GIS inventory repository.

Reasoning: By uploading the information into the UDOT repository in accordance with UDOT standards the utility owner should be relieved from the obligation of maintaining a set of certified plans, etc. In addition, the custom import file will relieve the utility owner from having to double handle the data. Alternatively, if the utility owner has a sophisticated data repository, the utility owner can generate an export file that meets UDOT's requirements for import into the UDOT utility repository. Research indicates most utility owners are maintaining a digital GIS inventory of their facilities; consequently, R930-6 needs to be revised to standardize the acquisition and storage effort so both parties can benefit.

3.8.3 UDOT Procedures for As-Built Construction Plans

Findings: Stan Adams from UDOT Central Construction referred the project team to UDOT policy number 08-03 "Completing and Archiving As-built Construction Plans" (effective October 1, 2002) in which procedures are given in section 08-03.1 "As-Built Construction Plans." Mr. Adams stated that all the as-builts are submitted as PDF's and stored on a Project-wise server. This information was verified in section 08-03.1. The actual procedures listed in the policy are as follows:

As-Built Construction Plans *UDOT 08-03.1*

Responsibility: *Contractor*

1. *Return to the resident engineer, after project completion, all surveying and design data and "as staked/constructed" drawings clearly showing all final dimensions, lines, grades, tie-ins and deviations from contract plans.*
    a. *In MicroStation format or*
    b. *A red-lined hard copy plan set.*

Responsibility: *Resident Engineer*

2. *Review red lined drawings or modified CADD files once project is constructed for accuracy and completeness.*

Responsibility: *Project Manager, Resident Engineer, Construction Engineer, Preconstruction Engineer and Design Engineer*

3. *Review red lined drawings or modified CADD files once project is constructed.*

Responsibility: *Design Engineer*

4. *Lessons Learned information submitted to Lessons Learned*
5. *Modify CADD files if not already modified.*
6. *Place As-Built drawings back into the CADD Standard project directory structure.*

Responsibility: *Project Manager*

7. *Notify the ISS Engineering Support Manager of completion of As-Built construction Plan and the address on the server where they can be retrieved and archived.*

Responsibility: *ISS Engineering Support Manager*

8. *Archive As-Built Plan for future reference and retrieval.*

The parts of this policy most applicable to the utilities database project are 5, 6, 7, and 8. These sections state that project as-builts are updated in the CADD file and then archived into the CADD Standard project directory structure. Again, Stan Adams from UDOT stated that the as-builts are stored as PDF's on a Project-wise server.

UDOT presently requires the contractor to submit as-built plans which have to be drafted and stamped. However, the plans are paper and PDF format (see Figure 6), and contain only limited attribute information, and do not preserve coordinate and essential metadata such as CI/ASCE 38-02 quality levels. Consequently, the usage of the information presented on as-built plans is greatly compromised and limited.

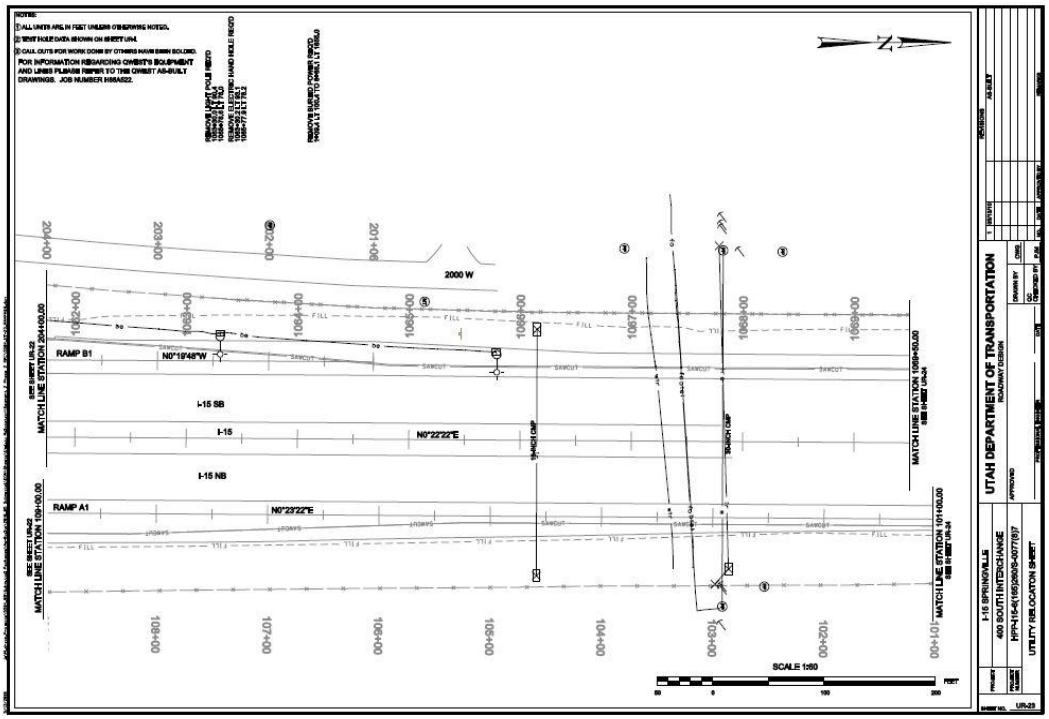

Figure 6 Example of current UDOT standard for as-built plan submittal in PDF format

Recommendation: In lieu of paper and PDF as-built submittals, simply require the contractor to upload utility data to the web-based UDOT repository along with certification that the data was compiled under the responsible charge of a Professional

Surveyor or Land Surveyor, as recommended by the NCEES Model Law for Surveying for authoritative documents for the location of fixed works.

Reasoning: The effort required to upload utility data to the UDOT repository would be in most cases less than that currently required to prepare as-built plans.

3.8.4 UDOT Subsurface Utility Engineering

Findings: UDOT currently does not have submittal standards for utility data generated through subsurface utility engineering investigative work, other than adherence to the CI/ASCE 38-02 standard guidelines which focus on acquiring data and depicting buried utilities on plan sheets. CADD work is simply to comply with current UDOT CADD standards. Also, UDOT presently has minimal prequalification requirements for SUE services; as a result, work methods and work products vary greatly in quality, content, cost and adequacy. Some work presented as SUE is being performed that would be considered substandard based on CI/ASCE 38-02 guidelines, FHWA recommended practices, and criteria used by other states.

Recommendation:

- Upgrade standards to require SUE providers to acquire and organize data in a manner that allows information to be readily uploaded into the UDOT utility repository. Proper utility designating and locating procedures currently dictate acquisition of spatial and attribute data for preparing standard CADD files for existing utilities; consequently, upgrading standards will only modify data management procedures and should not result in a significant change in effort.
- Upgrade prequalification requirements for SUE providers to ensure firms are proficient and able to collect and manage attribute and positional data and corresponding metadata in a manner that meets new standards. For example, SUE providers must have: a) established and enforced standard operating procedures that can stand up in court; b) experienced, qualified personnel who understand the physics, geophysical equipment, operating methods and pitfalls associated with detecting and mapping buried infrastructure; c) engineers who understand utility

supply and distribution systems; d) a quality program that ensures and documents procedures performed were in accordance with CI/ASCE 38-02 guidelines; and e) data management program to ensure the integrity of these comprehensive data sets is preserved. A significant recommended change entails involvement of professional land surveying support to ensure coordinate data is properly tied to NGS's National Spatial Reference System (NSRS), specifically the NAD83 horizontal datum and NAVD88 vertical datum.

Reasoning: The goal is to acquire and store authoritative, quality information considered "legacy data". Utility data (i.e., positional, attribute, and corresponding metadata) must be acquired, stored and managed with an elevated standard of care. Utilities pose high risk to:

- project planning, design, utility coordination, and construction;
- utility owner operations, including their ability to expand services and compete within a deregulated free market environment;
- daily commerce activities (especially in this day and age of ecommerce); and
- public and worker health and safety.

Faulty utility data can result in unforeseen issues and conflicts that pose significant risk to the project and public in the form of delay, infrastructure damage, commerce disruption, and human injury or life loss; mishaps often result in litigation. Because utilities are fixed features of engineering, the codes, statutes and ethics of professional engineering apply, implying usage of industry best practices and standards of care necessary to protect the public welfare. Consequently utility data acquisition must be not trivialized as a glorified one-call/pickup survey or vac-truck service left to unsupervised technicians. To the contrary, the process of utility data acquisition, engineering and risk analysis, and utility data management must be performed by qualified professionals; accordingly, subsurface utility engineering or SUE is considered a branch of civil engineering and is subject to all applicable statutes and responsibilities of the engineering profession.

3.9 NAD-83 vs. WGS-84

Findings: NAD 83 was the first civilian horizontal datum to have it's origin at or near earth-mass-center. Our knowledge of the location of earth center was derived from using data from the TRANSIT DOPPLER satellite system, which is the system which preceded GPS. The accuracy of Doppler positions are approximately 1 meter in each component. Consequently, our knowledge of earth center is +/- 2 meters. The initial solution of WGS 84 also used Doppler data and consequently had a +/- 2 meter origin.

Improvements in GPS and other space-based positioning technologies (e.g. Very Long Baseline Interferometry, Satellite Laser Ranging etc.) have improved our knowledge of earth center to approximately 4-5 cm. These improvements have been the work of the International Earth Rotation Service (http://hpiers.obspm.fr/) using data submitted by many national surveying agencies and international academic institutions. The IERS publishes these data as part of the International Terrestrial Reference System (ITRS).

In 1994, the Defense Department National Imagery and Mapping Agency (NIMA) redefined the origin and orientation of WGS 84 to be consistent with the ITRS. This is commonly referred to as the International Terrestrial Reference Frame of 1994 (ITRF94). This redefinition means that WGS 84, now more accurately referred to as WGS 84 (G873) (see http://www.nima.mil/GandG/pubs.html - "TR 8350.2 World Geodetic System 1984 It's Definition and Relationship with Local Geodetic Systems") is now equal to ITRF94 +/- 10 cm.

NAD 83 has had several improvements of the international precision using GPS. These improvements are referred to as the High Accuracy Reference Networks (HARN), and Continuously Operating Reference Stations (CORS). Consequently the internal or relative relationships of these points in NAD 83 are at the 1-4 cm level. However the origin or orientation of NAD 83 has not been altered as has been done with WGS 84 (G873). Therefore, the "absolute" difference between points in NAD 83 and WGS 84 are approximately 2 meters. This can be seen by looking at the data sheets for any CORS site - http://www.ngs.noaa.gov/CORS/ , selecting "Site Metadata", then "coordinates" and then selecting any CORS site with positions in NAD 83 and ITRF94. One will notice

the positional differences are approximately 1 meter in both horizontal and ellipsoid height.

Recommendation: Require all horizontal coordinate data to be tied to and based on the NAD 83 (NSRS2007) datum. Do not allow coordinate data that is based on WGS84.

Reasoning: This will avoid 1 to 2 meter positional errors that will arise if coordinate data is based on different datums. Also, use of NAD 83 is consistant with UDOT survey and mapping standards, and with NOAA National Geodetic Survey (NGS) recommendations. Furthermore, Utah State Plane Coordinates are based on the NAD 83 Datum.

3.10 Section Summary

The focus for this project is to research requirements for developing a relational database management system (RDBMS) to become a utility data repository. This report is a reference to justify management of utility data within public right of way.

In this section recommended architecture and practices for collecting and storing data on infrastructure within UDOT right of way were provided. Below is a summary which provides a brief overview of these recommendations:

1. The utility database should be integrated into UGATE. The utility infrastructure information should be made available in uPlan. The utility database should utilize AGRC as the portal for the utility data as a means to provide access to cities and counties throughout Utah. Also, the utility database should be synchronized with UDOT ATMS inventory system. Develop recommended survey procedures which utilize TURN to promote efficient and accurate GPS surveys.

2. Require all horizontal coordinate data to be tied to and based on the NAD 83 (NSRS2007) datum. Do not allow coordinate data that is based on WGS84. Store all positional data in geodetic (latitude / longitude) coordinates.

3. Require that vertical coordinate data be stored in meters as orthometric height observations tied to the NSRS 2007 NAVD 88 datum, and also, per UDOT

preference, in U.S. Survey Feet.

4. Adopt NCEES Model Law Surveying recommendations for requiring utility coordinate data to be compiled under the responsible charge of a professional land surveyor. Survey work for all utilities should require support from a professional land surveyor or individual specializing in geodesy. In lieu of paper and pdf as-built submittals, simply require the contractor to upload utility data to the web-based UDOT repository. Upgrade prequalification requirements for SUE providers to ensure firms are proficient and able to collect and manage attribute and positional data and corresponding metadata in a manner that meets new standards. Adopt the MetroGIS standards for documenting positional coordinate data. Adopt the MetroGIS version of the FGDC metadata standards.

5. Utilize UDOT Spatial Database Standards as prescribed. However, spatial tolerance of 0.01 meters at a 95% confidence level for utility surveys is not practical using current GPS techology, nor warranted. Therefore, a recommendation is made to adopt RTK GPS survey methods for Class RT2 and RT3 prescribed in the *NATIONAL GEODETIC SURVEY USER GUIDELINES FOR SINGLE BASE REAL TIME GNSS POSITIONING (v. 1.0 January 2010 William Henning, lead author)*.

6. Adopt an SDSFIE 3.0 approach to tables and attribute fields within the utility data model. Utilize UDOT naming convention for all tables and fields in the utility repository. Develop a complete data model that:

   - includes FGDC / MetroGIS recommended metadata for documenting authoritative survey data;
   - manages utility data, including CI/ASCE 38-02 quality level, so users will know the basis for the depicted alignments and can insert supplemental data, such as QL A test hole data, as required for future needs; and
   - utilizes the SDSFIE vs. 3.0 to document utility attributes.

7. Design the utility application to utilize Oracle REST API.

8. Develop a customized export function:

- for each utility owner that enables utility data to be downloaded from the UDOT repository and uploaded into the utility owner inventory database;
- that will allow information to flow seamlessly from the UDOT utility data repository into each agency's inventory system; and
- to generate an ASCII, comma delimited text data file which can be readily imported into MicroStation using GEOPAK or InRoads software.

4 RECOMMENDATIONS AND IMPLEMENTATION

Gathering location information for utilities creates a massive amount of data which can be reused if properly managed and consolidated. This consolidation of data must be in a form that allows it to be easily reused. A relational database is a common and recommended method for storing large amounts of data. If consolidated correctly from various sources, it can become a functional and useful tool.

A major requirement is the database must be a single centralized database. Time has proven that multiple desktop databases or spreadsheets provide a poor solution at the project level and fail completely after a project is completed. Although data is useful in electronic form during a project, when this expensive information is stored in standalone form it is rarely reused. The result is a complete loss of investment for any further use.

The centralized database must be an enterprise class system. It must be accessible to those outside UDOT who need access to the data, therefore, it must be available online. While there are numerous enterprise database systems available, the system must also be capable of manipulating spatial data. Two leading recommended candidates are Oracle 11g with Oracle Spatial and Oracle Locator or Microsoft SQL Server 2008 R2 or above.

Implementing a new system can be difficult. It may provide all the functions required by the data managers, but often, if the end users are not compelled through edict, contract or collaborative necessity, the system will not be used. This means key UDOT employees must buy into the idea and function of the utility management system, and then induce others external of UDOT who have an interest in utility information to use the system.

The functioning system should be the required delivery method for all contracts that require the gathering of utility location and attribute data. All utility permits should require both proposed and final alignment submission through the centralized utility management system. All ‘as built’ and SUE utility data gathered should be required to be submitted using the utility management system.

Utility owners should submit coordinate and attribute information of all previously installed infrastructure currently utilizing public right of way. While coordinate data on previously

installed infrastructure may not be survey grade, all future submissions should meet this higher standard, accordingly the data set will improve in quality over time. This approach will quickly provide a well populated source for planning and collaboration for UDOT and for utility companies.

The following sections provide recommended requirements and schema for a UDOT utility data repository and steps for development of the utility management system. Note that a summary of recommended architecture and practices for collecting and storing data on infrastructure within UDOT right of way is provided in Section 3.10 of this report.

4.1 Database Schema

A data schema has been developed and drafted using Microsoft ACCESS. Sample database forms are shown in Appendix B. Noteworthy elements for the data schema are the following:

- Utility attributes are based on the ANSI INCITS 353-2006 Geographical Information Systems – Spatial Data Standard for Facilities, Infrastructure, and Environment (SDSFIE) Version 3.0
- Positional coordinate data are based on FGDC-STD-001 June 1998 Content Standard for Digital Geospatial Metadata, Metadata Ad Hoc Working Group, Federal Geographic Data Committee.
- Positional accuracy data should be based on FGDC-STD-007.3-1998 Geospatial Positioning Accuracy Standards Part 3: National Standard for Spatial Data Accuracy and include refinements made by Minnesota Geographic Metadata Guidelines Version 1.2 - October 7, 1998, A State Version of the FGDC Content Standards for Geospatial Metadata Developed by the Minnesota Governor's Council on Geographic Information GIS Standards Committee.
- Utility positional metadata include “quality levels” as defined by the CI/ASCE 38-02 standard guidelines.

The database schema can be broken into four major sections: 1) Surveys, 2) Spatial Data, 3)

Features, and 4) Owners and Contacts.

4.1.1 Surveys

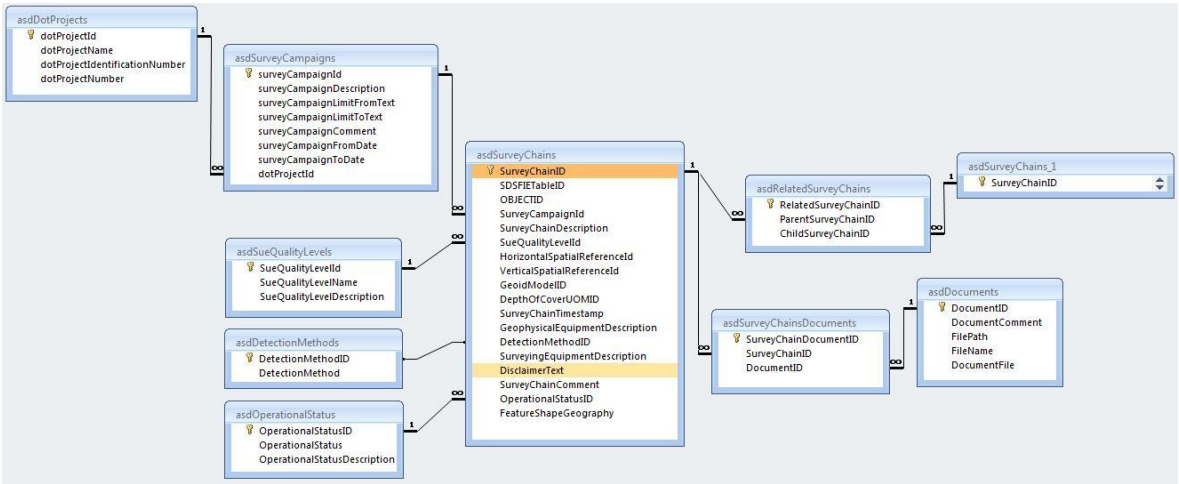

Figure 7 Survey section of the database

DotProjects are unique DOT projects with a project name and project number. Project data from a project domain may be related using the *dotProjectIdentificationNumber* or *dotProjectNumber*. A project record has many related *SurveyCampaigns*, each describing the area and date range of the campaign. A campaign has many related *SurveyChains*.

Many of the fields in the *SurveyChains* table are required. The only foreign keys not required are *OBJECTID* and *DetectionMethodID*. *OBJECTID* is discussed in further detail in the **Features** section below. A detection method is not required because detection of a feature (survey chain) is not always necessary. For instance, an overhead electrical line is visible to the eye and none of the detection methods provided in Figure 8 are applicable.

DetectionMethodID	Detection Method:
1	Acoustic Method
2	Electrical Fish Tape
3	Electronic Maker System (EMS)
4	EM Sonde
5	Ground Penetrating Radar (GPR)
6	Magnetic Gradiometer
7	Seismic Method
8	Surface EM Induction (EMI)
9	Tracer Wire/Direct Connection

Figure 8 Detection Methods

The *SurveyChainDescription* is not a foreign key and is the only non-foreign key field required in the *SurveyChains* table. The *SurveyChainDescription* serves as an easy identifier for finding the survey chain within lists or query results.

The *SueQualityLevels*, *DetectionMethods*, and *OperationalStatus* tables are lookup tables to help describe the survey chain (feature).

SurveyChains_1 is an instance of *SurveyChains* to visually illustrate the relationships of tying two or more survey chains to one another. The *RelatedSurveyChains* table stores the ID of the parent survey chain with the ID of the child survey chain as a record. One survey chain may be related to any other survey chain and each of those survey chains may be related to any other survey chain.

The *Documents* table stores information about a file (the file name and path) or the actual file itself. A survey chain may have many files pertaining to the survey chain. The *SurveyChainsDocuments* table stores the ID of the survey chain with the ID of the document.

4.1.2 Spatial Data

The *SurveyChains* table stores information applicable to each facility alignment. These include the horizontal spatial reference, vertical spatial reference, geoid model, and the depth of cover unit of measure (UOM). *SpatialReferences* is a lookup table containing the applicable horizontal and vertical spatial references. The *VerticalSpatialReference* field is a Boolean datatype simply identifying the vertical spatial references within the table. Therefore, the *SpatialReference_1* table is an instance of the *SpatialReference*

table visually illustrating that the *VerticalSpatialReferenceID* foreign key in the *SurveyChains* table is using a lookup table to supply the list of available vertical spatial references.

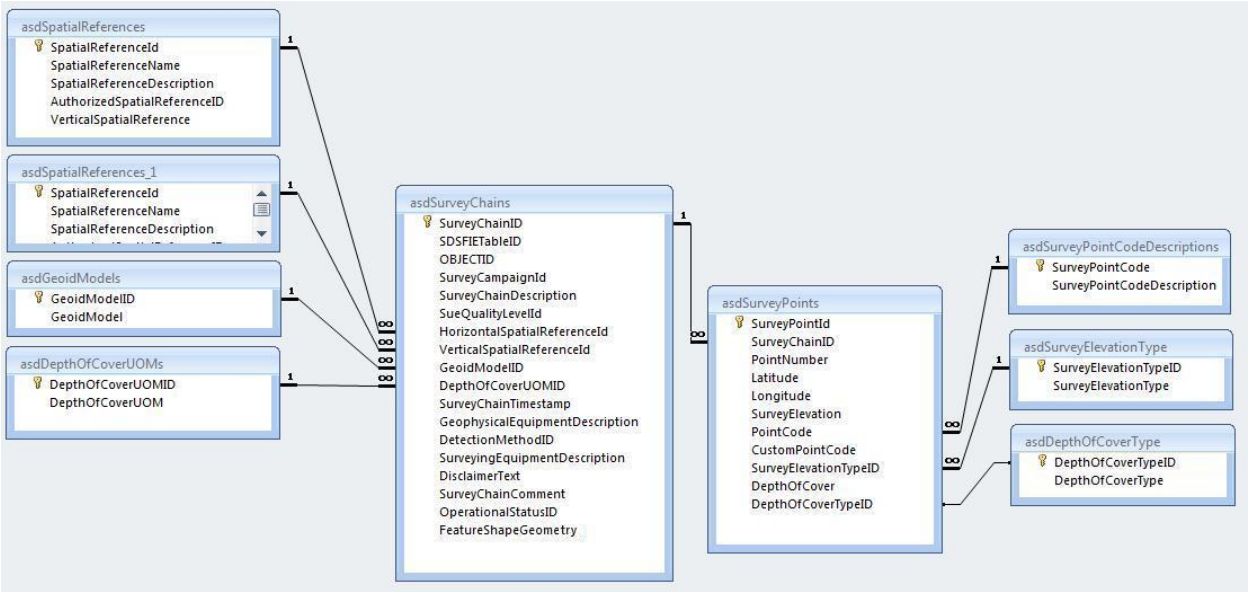

Figure 9 Spatial Data linked to Survey Chains

A survey chain may contain one or more survey points. The *SurveyPoints* table stores the necessary data to describe the position and shape of objects on the earth. If the feature alignment is represented by a single point, such as a valve or fire hydrant, then only one related record exists in the *SurveyPoints* table. If, however, the feature is represented by a linestring, such as an electric underground line segment, then many related records exist in the *SurveyPoints* table. Many related records will also exist in the *SurveyPoints* table for features represented by a polygon, with the exception that the first and last records have the same point, i.e., latitude and longitude coordinates. Notice there are three lookup tables provided when manually entering survey points into the *SurveyPoints* table. These are *SurveyPointCodeDescriptions*, *SurveyElevationType*, and *DepthOfCoverType*. The *SurveyPointCodeDescriptionID* field stores the ID of the feature code from the available feature codes. The ID, in this case, is the alphanumeric feature code itself. This design facilitates uploading of survey points directly into the *SurveyPoints* table. The *SurveyElevationTypeID* and *DepthOfCoverType* fields are also designed in this manner for the same reason.

The Microsoft Access Database (currently in draft form) stores the spatial data for a feature using latitude and longitude coordinates with an elevation. The longitude, latitude, and elevation are each stored in separate fields (or columns). In order to use any of the spatial methods provided by the spatial component of Oracle, use these coordinates to create a representation of each feature using the *Geometry* datatype. This field is represented in the *SurveyChains* table as the *FeatureShapeGeometry* field. Additionally, each survey chain is associated with only one spatial reference system and the *Geometry* datatype requires each point be associated with the spatial reference system on which they are based. Therefore, this data model integrates with the spatial component of Oracle.

4.1.3 Features

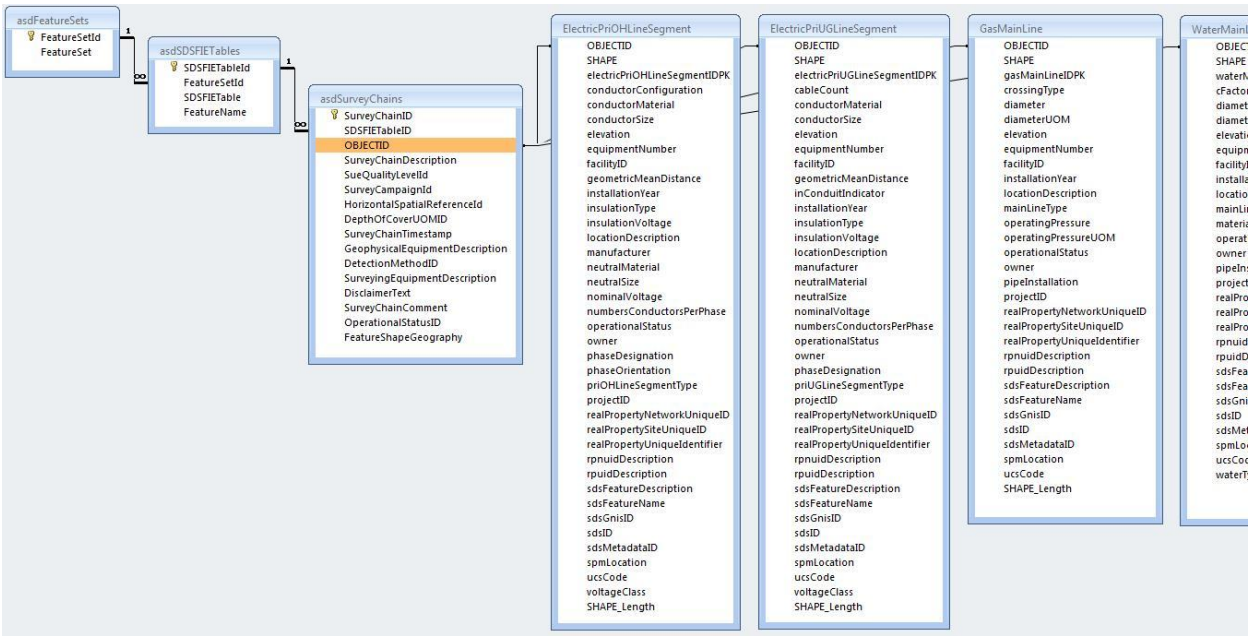

Figure 10 Feature Tables related to Survey Chains

The *FeatureSets* table stores each category or type of utility feature available in SDSFIE. The *SDSFIETables* table stores each feature, i.e., each SDSFIE table name with its applicable feature name. For example, one specific record stores "ElectricPriOHLineSegment" in the *SDSFIETable* field and stores "Electric Primary Overhead Line Segment" in the *FeatureName* field. Notice that there is a table named *ElectricPriOHLineSegment*. This table is an SDSFIE table. Each SDSFIE table made

available in this data model will have a record in the *SDSFIETables* table. The *FeatureName* field is used when creating a survey chain (adding a record to the *SurveyChains* table) to indicate what kind of feature is being created. The specific attributes required for a feature depends on what kind of feature it is. Hence, a unique SDSFIE table is used for each feature. The *SurveyChains* table is storing the attributes that all features have in common. The combination of the *SDSFIETableID* and *OBJECTID* in the *SurveyChains* tables lets an application know where the specific feature attributes are stored for each record.

4.1.4 Owners and Contacts

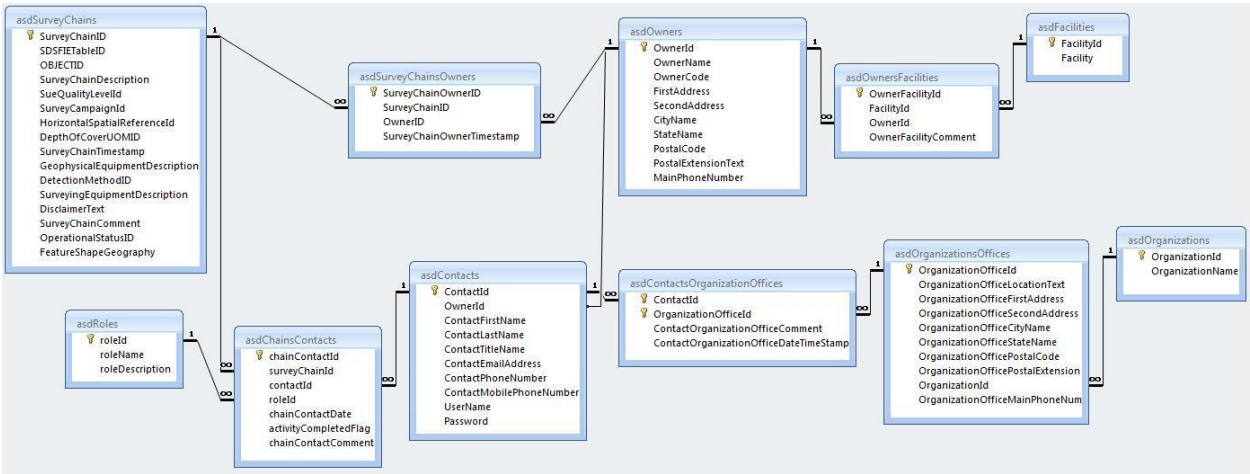

Figure 11 Owners and Contacts related to Survey Chains

Utility owner and contact for a given feature is critical to utilizing the data stored in the repository. New projects and newly permitted utilities in the same general area will require accurate information on the owner and their primary contact within that organization.

The schema allows for a feature to have multiple owners. This is important because utility features frequently change hands through company aquistions or company streamlining by selling unprofitable portions of their service. Historical information will prove valuable when trying to identify the correct owner for features that have multiple ownership changes in a short period of time. The current owner is identified as the owner with the latest *SurveyChainOwnerTimestamp* field in the *asdSurveyChainsOwners*

junction table.

The *asdChainsContacts* table allows for multiple contacts with a given feature. A contact may be changed within an organization or a contact may change employment and become part of an organization that has become the new owner of a feature or group of features. Either way, historical information about previous contacts will prove valuable. The current contact is identified by the *chainContactDate* field in the *asdChainsContacts* table.

4.2 Coordinate Data

The following are recommended requirements for utility coordinate data:

- Horizontal coordinates shall only be stored in geodetic latitude and longitude decimal degree units (to eight decimal units). The horizontal datum to be referenced will be the US National Spatial Reference System of 2007 (NSRS2007), also called NAD83(2007), which is a refinement of the NAD83 datum using data from a network of very accurate GPS receivers at Continuously Operating Reference Stations (CORS).
- Vertical coordinates shall be stored in meters as orthometric height observations tied to the NSRS 2007 NAVD 88 datum, and, per UDOT preference, in U.S. Survey Feet.
- All RTK GPS surveying shall be performed in compliance with the NATIONAL GEODETIC SURVEY USER GUIDELINES FOR SINGLE BASE REAL TIME GNSS POSITIONING (v. 1.0 January 2010 William Henning, lead author). Class RT2 should be used for features to be designated as CI/ASCE 38-02 Quality Level (QL) A, and Class RT3 should be used for collecting the bulk of utility QL B data.
- Surveyed coordinates for all utilities shall be certified by a professional land surveyor or an individual specializing in geodesy.
- Designated QL A points and QL B utility alignments shall have coordinates established through land survey methods and will be considered “authoritative”.

- Survey data shall be managed with corresponding attribute data as described below.
- QL A observations and many surface features such as valves, manholes, and pedestals will consist of a single point.

4.3 Attribute Data

The following are recommended requirements for utility attribute data:

- Utilities should be categorized by theme (feature set) and feature, with attributes assigned as prescribed by the SDSFIE 3.0 standards. SDSFIE may not contain all the desired attribute fields so these fields should simply be added as needed to each feature.
- Utility data will be segregated and stored as unique alignments, with attributes assigned to individual and unique alignments.

4.4 Metadata

It is recommended that UDOT adopt the MetroGIS version of the FGDC metadata standards as discussed in Section 3.4.2 of this report.

4.5 Implementation Plan

The implementation plan for this utility management system will require significant development time. Major steps in development would include and not be limited to:

- Build database repository.
- Create the database schema within the chosen database management system.
- Create the security system for login and record control.
- Develop the accepted workflow diagrams for specific scenarios (ie. New permit, as built, SUE, utility company historical information, etc.).
- Develop working forms and reports to support the logic required to support the workflow diagrams.

- Develop additional functionality based on additional research.
- Beta test on a test project.
- Determine internal requirements and adjustments.
- Determine external requirements.
- Test project data submittals.
- Evaluate storage size of data usage on small project to project full system storage requirements.
- Modify Contract Language for future projects to ensure population and usage of the data repository.
- Perform a success evaluation.

This project will require multiple IT and engineering skillsets to complete. The largest manpower requirements will involve the actual development of the working system. Second to this effort are the collaborative efforts required to gain consensus about the working requirements and usage of the system from managers, engineers and administrative staff. Considerable care should be taken to include those who will directly benefit from the success of this project. Valuable insight will be gained from administrative staff who will work directly with the results of implementing this project.

Data integrity can only be maintained by quality control. A large portion of this responsibility resides with those submitting data. Therefore, it is important that procedures be in place that prevent malformed data and inaccurate data from being uploaded into the system. Periodically, a UDOT employee should be enlisted to ensure the data is accurately and correctly being submitted. Training for those who wish to or are required to submit data to the system should be offered on a periodic basis.

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APPENDIX A - ACRONYMS

AADT	Average Annual Daily Traffic
AASHTO	American Association of State Highway and Transportation Officials
AGRC	Utah Automated Geographic Reference Center
ANSI	American National Standard Institute
ASCE	American Society of Civil Engineers
ASCII	American Standard Code for Information Exchange
ATMS	Advanced Traffic Management System (from CommuterLink)
BLM	U.S. Bureau of Land Management
CADD	Computer Aided Design and Drafting
CI/ASCE 38-02	Construction Institute of the American Society of Civil Engineers *Standard Guidelines for the Collection and Depiction of Existing Subsurface Utility Data*
CORS	Continously Operating Reference Stations
DISDI	Defense Installations Spatial Data Infrastructure Group
DTS	Utah Department of Technology Services
FGDC	Federal Geographic Data Committee
FHWA	Federal Highway Administration
GIS	Geographic Information System
GPS	Global Positioning System
HARN	High Accuracy Reference Networks
IERS	International Earth Rotation Service
IGI&S	Installation Geospatial Information and Services
INCITS	International Committee for Information Technology Standards
ISO	International Standards Organization
ITRF94	International Terrestrial Reference Frame 1994
NAD83	North American Datum 1983
NAVD88	North American Vertical Datum 1988
NCEES	National Council of Examiners for Engineers and Land Surveyors
NCHRP	National Cooperative Highway Research Program

NGS	National Geodetic Survey
NIMA	Defense Department National Imagery and Mapping Agency
NOAA	National Oceanic and Atmospheric Administration
NSG	National System for Geospatial-Intelligence
NSRS	US National Spatial Reference System
NSSDA	National Standard for Spatial Data Accuracy
OGC	Open Geospatial Consortium, Inc.
QL	Quality Level as defined by CI/ASCE 38-02
RDBMS	Relational Database Management System
RMSE	Root Mean Square Error
ROW	Right of Way
RTK	Real Time Kinematic
RTN	Real-Time differential correction Network
SDSFIE	Spatial Data Standard for Facilities Infrastructure and Environment
SGID	State Geographic Information Database
SUE	Subsurface Utility Engineering
TGO	Trimble Geomatic Office
TRB	Transportation Research Board
TTI	Texas Transportation Institute of the Texas A&M University System
TURN	The Utah Reference Network
TxDOT	Texas Department of Transportation
UDOT	Utah Department of Transportation
UGATE	UDOT GIS Access to the Transportation Enterprise
UOM	Unit of Measure
UPLAN	UDOT GIS Planning Process and Interface
UTM Zone 12	Universal Transverse Mercator (Zone 12 vertically aligns with AZ and UT)
WFS	Web Feature Service
WGS84	World Geodetic System 1984
WMS	Web Map Service

APPENDIX B – DATABASE SAMPLE FORMS

The forms for this research database were developed to show the process for entering, uploading, editing and deleting utility features and utility feature attributes. In practice, a more robust user interface will be required.

A login system will be required to control access to the data. Once the user is logged in the system, the user will be locating or uploading features displayed in these forms as survey chains.

Data is logically organized by project. Over time the project name will decrease in value as users forget them but the user will easily interact with their data while the project is still active. Individual survey campaigns can further help the user group the features being added or edited. Within a survey campaign, many metadata fields will have common values across features. This relationship reduces data entry.

Figure 12 Application Screen – Project, Survey Campaign, Survey Chain

The features are organized by project, then survey campaign, and finally the survey chain (or feature). A survey campaign is an effort during the project. There may be multiple campaigns during a given project. Choosing a campaign narrows the scope of features presented to the user very quickly or if entering new features it groups that new feature properly.

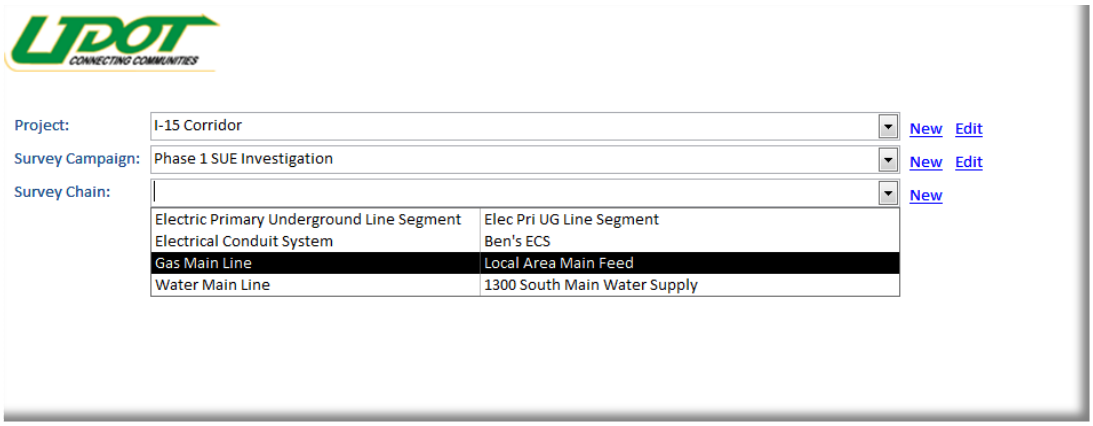

Figure 13 Application Screen – Choosing a Survey Chain

Once the user has chosen the desired feature (or created a new feature), they have numerous attribute and metadata fields that must be filled out. Drop down menus help to expedite the process and maintain data integrity.

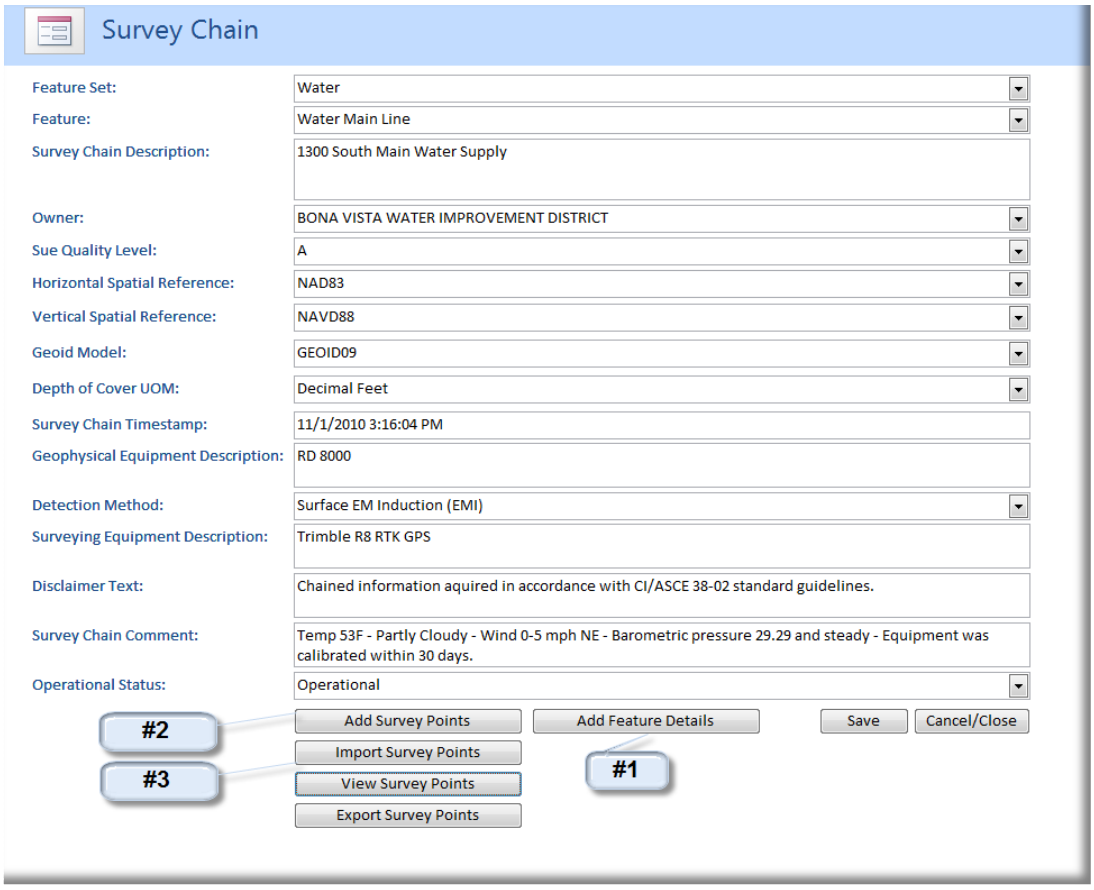

Figure 14 Application Screen – Survey Chain Details

Button #1 in Figure 14 takes the user to the feature details. These will vary depending on which feature the user has chosen or created. In this case, a water line has multiple attributes that may or may not be available to the user entering the data, but they are available to be completed whenever possible.

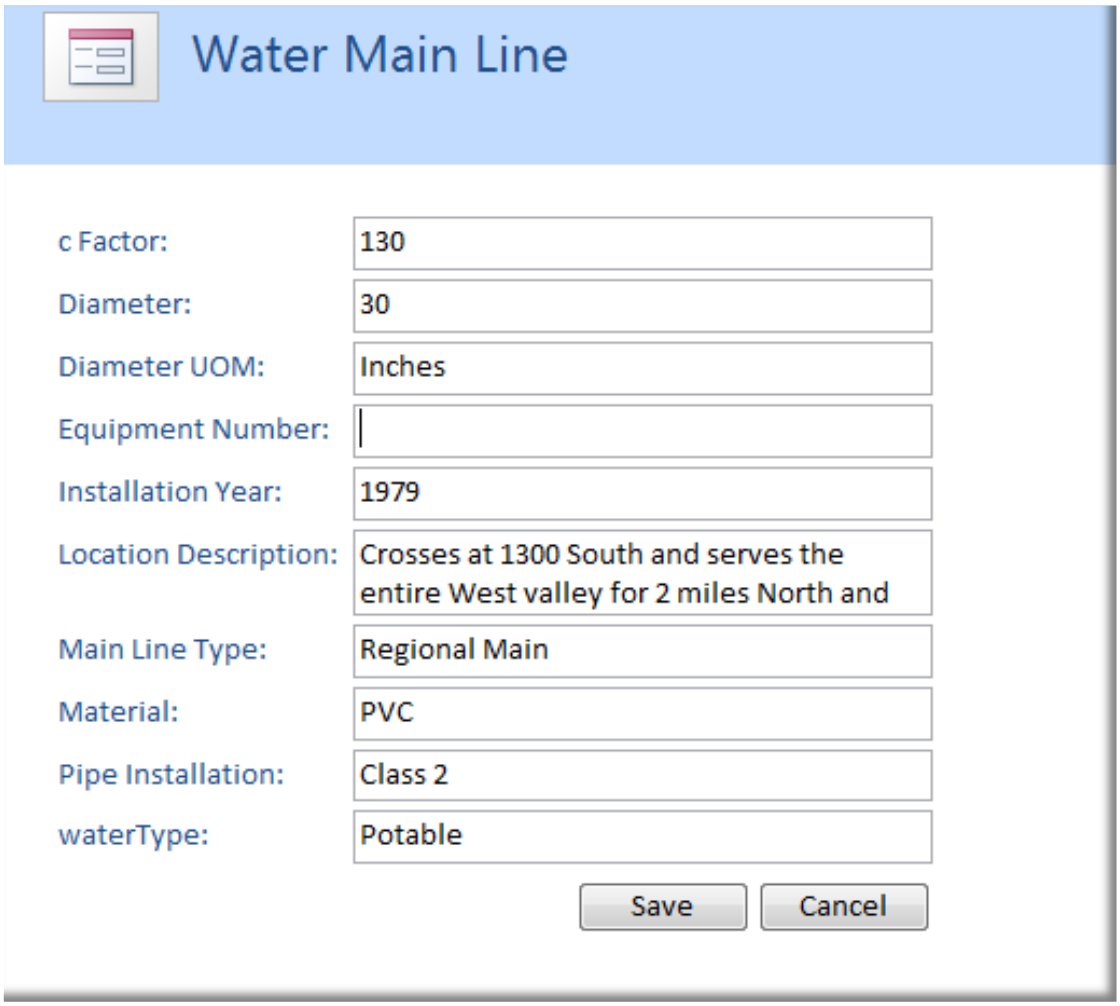

Figure 15 Survey Chain Details - Feature Attributes

Adding Survey information can be done either manually or uploaded in bulk depending on the feature type and the technical capabilities of the user. Manual entry is laborious and prone to data entry errors, therefore bulk uploading of survey data is preferred.

Button #2 in Figure 14 allows the user to add survey points manually. This form requires very detailed information to be added for nearly every field. This is most appropriate when adding features that require only 1 data point.

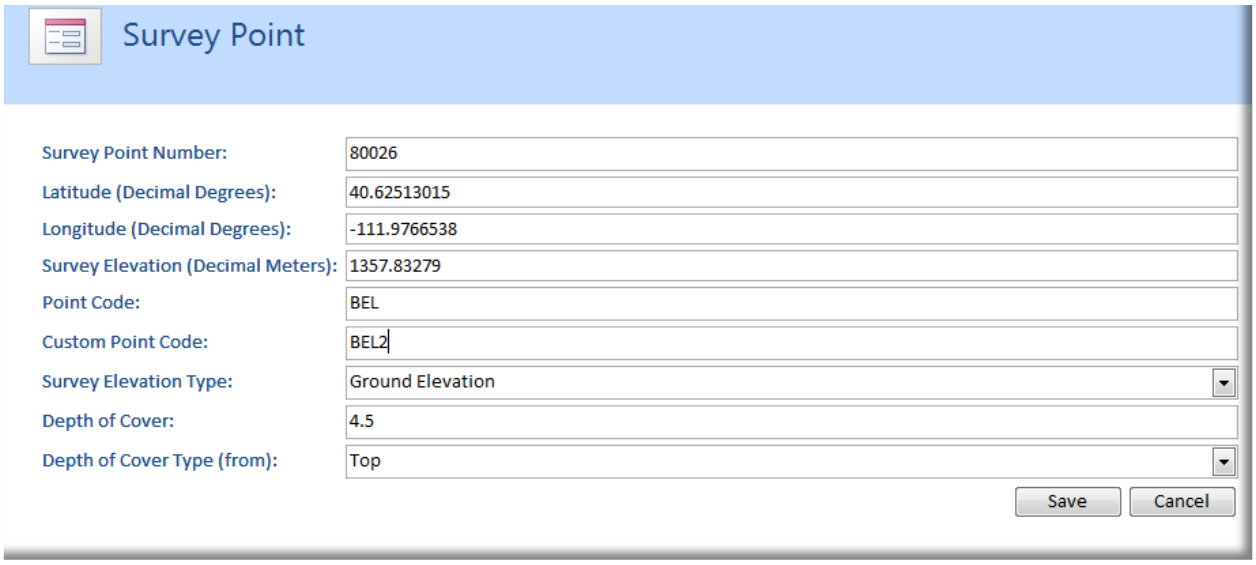

Figure 16 Survey Chain - Add Survey Point Manually

Bulk uploading survey data (Button #3 in Figure 14) can easily be accomplished using a simple spreadsheet to create a comma separated value (csv) file. Several standard import options should be available depending on the level of detail available as the data was gathered.

Survey Point Number	Latitude	Longitude	Survey Elevation	Point Code	Custom Point Code	Survey Elevation Type	Depth of Cover	Depth of Cover Type
80004	40.62517241	-111.9766537	1357.78128	BEL	BEL2	Facility/Feature Elevatio	2	Top
80005	40.62515534	-111.9766543	1357.83949	BEL	BEL2	Facility/Feature Elevatio	2	Top
80006	40.62513015	-111.9766538	1357.83279	BEL	BEL2	Facility/Feature Elevatio	2	Top
80007	40.62509806	-111.9766527	1357.84742	BEL	BEL2	Facility/Feature Elevatio	2	Top
80008	40.62506538	-111.9766525	1357.8971	BEL	BEL2	Facility/Feature Elevatio	2	Top
80009	40.62504021	-111.9766569	1357.97787	BEL	BEL2	Facility/Feature Elevatio	2	Top
80010	40.62499062	-111.9766558	1358.01658	BEL	BEL2	Facility/Feature Elevatio	2	Top
80011	40.62495813	-111.9766556	1358.03121	BEL	BEL2	Facility/Feature Elevatio	2	Top
80012	40.62491043	-111.976653	1358.04554	BEL	BEL2	Facility/Feature Elevatio	2	Top
80013	40.62485464	-111.9766535	1358.08821	BEL	BEL2	Facility/Feature Elevatio	2	Top
80014	40.62480178	-111.9766555	1358.17538	BEL	BEL2	Facility/Feature Elevatio	2	Top
80015	40.62475546	-111.9766572	1358.23482	BEL	BEL2	Facility/Feature Elevatio	2	Top
80016	40.62472145	-111.9766577	1358.25006	BEL	BEL2	Facility/Feature Elevatio	2	Top
80017	40.62468201	-111.9766569	1358.31163	BEL	BEL2	Facility/Feature Elevatio	2	Top
80018	40.62464525	-111.976656	1358.37625	BEL	BEL2	Facility/Feature Elevatio	2	Top
80019	40.62459696	-111.9766554	1358.39972	BEL	BEL2	Facility/Feature Elevatio	2	Top
80020	40.62455277	-111.9766555	1358.41861	BEL	BEL2	Facility/Feature Elevatio	2	Top
80021	40.62451315	-111.9766557	1358.48262	BEL	BEL2	Facility/Feature Elevatio	2	Top
80022	40.62448416	-111.9766572	1358.52956	BEL	BEL2	Facility/Feature Elevatio	2	Top
80023	40.62443537	-111.9766599	1358.58808	BEL	BEL2	Facility/Feature Elevatio	2	Top
80024	40.62441222	-111.9766608	1358.6146	BEL	BEL2	Facility/Feature Elevatio	2	Top
80025	40.62438433	-111.9766611	1358.62192	BEL	BEL2	Facility/Feature Elevatio	2	Top

Figure 17 Survey Chain - Bulk Uploading Survey Points

The process should be very easy for the end user. Complex data can be simplified with a sophisticated user interface. The forms presented here are simple but lack sophistication. Every effort should be made to allow the user to work in a natural environment.

	A	B	C	D	E	F	G
1	PointNumber	X	Y	Z	FeatureName	SurveyPointCode	Comment
2	12879	102339.9	1081593	43.44	ELINOR34	ELINOR	ELINOR
3	12878	102341	1081593	43.43	ELINOR34	ELINOR	ELINOR
4	12877	102341.9	1081593	43.4	PBOXOR120	PBOXOR	PBOXOR
5	12876	102343.7	1081591	43.1	ELINOR34	ELINOR	ELINOR
6	12875	102350.3	1081588	43.5	ELINOR34	ELINOR	ELINOR
7	12874	102365.1	1081584	43.55	ELINOR34	ELINOR	ELINOR
8	12873	102365.6	1081584	43.55	ELINOR34	ELINOR	ELINOR
9	12872	102383.5	1081578	43.57	ELINOR34	ELINOR	ELINOR

Figure 18 Survey Chain - Bulk Uploading Survey Points From Excel

The spreadsheet in Figure 18 presents a simple spreadsheet containing actual survey data. Spreadsheets are a simple work environment that provides end users of modest computer skills a very comfortable environment.

APPENDIX C – UNIT CONVERSION

1 centimeter (cm)	0.39 inches (in)
1 inch (in)	2.54 centimeters (cm)
1 centimeter (cm)	0.032 feet (ft)
1 foot (ft)	30.48 centimeters (cm)
1 meter (m)	3.28 feet (ft)
1 foot (ft)	0.30 meters (m)
1 kilometer (km)	0.62 miles (mi)
1 mile (mi)	1.61 kilometers (km)