6 Data Collection

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6 Data Collection

6.1 OVERVIEW

6.1.1 Introduction

It is necessary to identify the types of data required prior to conducting an engineering analysis. The effort necessary for data collection and compilation must be tailored to the importance of the project. Not all data discussed in this chapter will be needed for every project. A well-planned data collection effort results in a more orderly and effective analysis and design, commensurate with:

- Project scope;
- Project cost;
- Complexity of site hydraulics; and
- Regulatory requirements.

Data collection for a specific project must be tailored to:

- Site conditions;
- Scope of the engineering analysis;
- Social, economic and environmental requirements;
- Unique project requirements; and
- Regulatory requirements.

Uniform or standardized survey requirements for all projects is uneconomical, and in some cases data may not be sufficient for a specific project. Special instructions outlining data requirements will have to be provided to the survey party by the hydraulic designer for unique sites.

6.1.2 Data Requirements

The purpose of this chapter is to outline the types of data normally required for drainage analysis and design, possible sources, and other aspects of data collection. The following subjects are presented in this chapter:

- Types of data needed
- Sources of data;
- Data-collection processes;
- Field reviews
- Drainage-survey information; and
- Data reliability.

6.1.3 Survey Methods / Computation Accuracy

In any hydraulic computation, it is important to understand how the accuracy of computations is limited by the accuracy of the input data. For example, in conducting 1-Dimensional hydraulic analysis using U.S. Army Corps of Engineers HEC-RAS model, there are several data related factors that have significant effects on the accuracy of the results:

- Accuracy of the survey data;
- Spacing between cross sections;
- Correct establishment of upstream and downstream study limits; and
- Selection of roughness coefficients.

Similarly, for 2-Dimensional modeling, effects of using accurate topography, selecting appropriate mesh size (density of ground points), selecting element roughness coefficients, and using appropriate boundary conditions are also expected to affect the accuracy of results.

The accuracy of aerial survey technology for generating cross-sectional coordinate data is governed by mapping industry standards. Cross sections obtained from contours of topographic maps developed by photogrammetric methods are generally not as accurate as those generated from LiDAR data and from field data-collection methods. Aerial photography corrected using ground control points from established survey benchmark monuments is best used to supplement field-survey cross sections. The use of LiDAR and aerial photography allows additional coordinate points and cross sections (1-Dimensional modeling) or point clouds and digital elevation maps (2-Dimensional modeling) to be obtained at only a small incremental cost. Using these technologies, topographic information is formatted for direct input into hydraulic computer programs.

For further information on determining the relationship between computational accuracy and survey technology employed for determining stream cross-sectional geometry, degree of confidence in selecting Manning's roughness coefficients, and resulting accuracy of 1-Dimensional hydraulic computations, refer to the USACE publication, RD-26, *Accuracy of Computer Water Surface Profiles*. This publication also presents methods of determining upstream and downstream limits of data collection for a hydraulic study requiring a specific degree of accuracy. For 2-Dimensional modeling, a similar relationship between computational accuracy and survey technology exists. However, quantification of this relationship is much more complicated due to the addition of turbulence terms in computations. A sensitivity analysis by altering surveyed parameters within expected range of variation could provide engineers a range of expected modeling accuracies and help identify if additional data accuracy is required.

6.2 SOURCES OF DATA

6.2.1 Objectives

Objectives of this section include:

- Identify possible sources of data;
- Encourage reliance on CDOT experience for sources likely to yield desired data; and
- Acquaint the designer with available data, and CDOT procedures for acquiring the information.

6.2.2 Sources

Much of the data and information necessary for design of highway drainage facilities may be obtained from sources listed in Appendix A of this chapter. For each data source on the list the following information is given:

- Type of data;
- Address of source; and
- Comments on data.

Geographic Information Systems: State geographic information systems (GIS) may be used as a source of georeferenced hydrologic data required in hydraulic design decision making. For example, a GIS database may have been developed containing the land cover, soil type, and topography for the entire state. This database may then be used to produce the existing and ultimate-development hydrographs and an array of maps, graphs, and tables needed to complete the hydrologic analysis. Available GIS database for cities and counties commonly include community boundaries, parcels, building footprints, utility locations, topographic surfaces, flood risk boundaries and metadata, and available reports & master plans. This information may be the source of or supplement data for the hydrologic analysis.

National Flood Insurance Program: Many streams have been analyzed for local flood insurance studies as part of the National Flood Insurance Program (NFIP). In these cases, data collection requirements may be reduced or unnecessary if discharges and hydraulic models are available from FEMA. Although these studies are a good source of data, their technical content should be reviewed prior to using the data. Many of the studies are outdated and will not reflect changes that may have occurred in the study reach since their publication. In cases where flood insurance studies are not available or are outdated, new hydrologic analysis must be conducted.

6.3 TYPES OF DATA NEEDED

6.3.1 General

The designer must compile specific data depending on the project scope and site. Major types of data that may be required include:

- Permit requirements;
- Watershed characteristics;
- Stream-reach data (especially in the vicinity of the facility);
- Topographic data including laser-based Light Detection and Ranging (LiDAR) data that is available through Colorado GeoData Cache, local county and city GIS departments, or Colorado Office of technology (OIT).
- Other physical data in the general vicinity of the facility, such as utilities, right-of-way, or easements;
- Hydrologic and meteorologic data (streamflow and rainfall data related to maximum or historical peak, as well as low-flow discharges and hydrographs applicable to the site);
- Existing and proposed land-use data in the project drainage area and general vicinity of the facility;
- Anticipated changes in landuse and/or watershed characteristics; and
- Floodplain and environmental regulations.

Watershed, stream-reach and site-characteristic data, as well as data on other physical characteristics, can be obtained from a field reconnaissance of the site. Examination of available maps and aerial photographs of the watershed is also an excellent means of defining physical characteristics of the watershed.

6.3.2 Drainage Surveys

A complete field or aerial drainage survey of the site and its contributing watershed should always be undertaken as part of the hydraulic analysis and design. Survey requirements for small drainage facilities, such as 36-inch culverts, are less extensive than those for bridges and major facilities.

However, the purpose of each survey is to provide an accurate picture of the conditions within the zone of hydraulic influence of the facility. Section 6.7 of this chapter contains and in depth discussion on drainage survey requirements; Appendix B contains general guidelines for field surveys for hydraulic structures.

6.3.3 Watershed Characteristics

The following is a brief description of the major types of data relating to drainage-facility analysis and design.

Physical Characteristics

Contributing Size - The size of the contributing drainage area, expressed in acres or square miles, is determined from some or all of the following:

- Direct field surveys using conventional surveying instruments;
- Topographic maps, together with field checks, to determine changes in the contributing drainage area caused by: terraces; lakes; local depression areas; debris or mud flow barriers; reclamation and flood-control structures; and, irrigation diversions;
- USGS topographic maps, which are available for most areas of the state;
- Topographic maps obtained from municipal and county entities;
- Digital elevation modeling software (e.g., WMS, StreamStats);
- Landowner alterations;
- Other topographic maps of the drainage area from local governments and developers
- State Transportation-Planning Survey Maps; and
- Aerial maps and photographs.

When determining the size of the contributing drainage area, document any natural springs' subterranean flow-loss zones (e.g. karst formations), where flow is diverted from surface water. Also, define any off-site flow, or flow from areas outside the physical boundaries of the drainage area whose runoff is diverted into the drainage area being analyzed. In addition, it must be determined if flood waters can be diverted out of the basin before reaching the site.

Slopes - The slope of the stream and average slope of the watershed (basin slope), must be determined. Determine the stream slope in the vicinity of proposed structures that will be used for the hydraulic analysis, and the average slope of the watershed that will be used for the hydrologic analysis.

Watershed Land Use

It is important to define and document the present and expected future land use, particularly the location, degree of anticipated urbanization, and the source of the data. Information on existing land use and future trends may be obtained from:

- Field review;
- Aerial photographs (conventional and infrared);
- Zoning maps and master plans;
- USGS, U.S. Forest Service, and other federal-agency maps;
- GIS data;
- Municipal planning agencies; and

- Landsat (satellite) images.

Specific information about particular tracts of land often can be obtained from owners, developers, realtors, and local residents. Care should be exercised in using data from these sources as their reliability may be questionable, and as these sources may not be aware of future-development plans within the watershed that might affect specific land uses.

Existing land use data for small watersheds can best be determined or verified by a field survey. Field surveys should also be used to update information on maps and aerial photographs, especially in basins that have experienced changes in development since the maps or photos were prepared. Infrared aerial photographs may be particularly useful in identifying types of urbanization at a point in time.

Streams, Rivers, Ponds, Lakes and Wetlands

The hydraulic engineer should secure the following data at all streams, rivers, ponds, lakes, and wetlands that will affect or may be affected by the proposed structure or construction. These data are essential in determining the expected hydrology and may be needed for regulatory permits:

- Boundary (perimeter) of the water body for the ordinary highwater;
- Classification of the water body;
- Elevation of normal and high water for various frequencies;
- Detailed description of any natural or manmade spillway or outlet works including dimensions, elevations, and operational characteristics;
- Detailed description of any emergency spillway works including dimensions and elevations;
- Description of adjustable gates, soil and water control devices;
- Profile along the top of any dam and a typical cross-section of the dam;
- Use of the water resources (stock water, fish, recreation, power, irrigation, municipal or industrial water supply, etc.);
- Inadvertent detention;
- Existing conditions of the stream, river, pond, lake or wetlands as to turbidity and silt; and
- Riparian ownership as well as any water rights.

Environmental Considerations

Environmental data is needed in engineering analysis and design in order to identify and mitigate impacts due to specific design configurations. The hydraulic engineer should coordinate with the CDOT Environmental group and other state environmental offices. Environmental data needed include:

- Information necessary to define environmental sensitivity of a site’s impacted surface waters, including water use, water quality and relevant standards, aquatic and riparian wildlife biology, and wetlands information;
- Physical, chemical and biological data. Information for many streams is available from the Environmental Protection Agency, the USGS, and from municipalities, water districts and industries using surface waters as a source of water supply. In some instances, a data collection program tailored to the site and which may last several years may be required.
- Information necessary to determine the most environmentally-compatible design, including circulation patterns and sediment-transport data. Data on circulation, water

velocity, water quality, and wetlands is available from the U.S. Army Corps of Engineers, universities, and state, federal, and local agencies.

- Information on sediment transport, which is vital to define the suitability of a stream for the most beneficial uses, such as fish habitat, recreation and water supply. Data collection for projects in critical water-use areas (e.g., near municipal or industrial water supply intakes) should be accomplished early in project development to ensure proper coordination.
- Information necessary to define the need for and design of mitigation measures, inlcuding fish characteristics (type, size, migratory habits), fish habitat (depth, cover, pool-riffle relationship), sediment analysis, water use and quality standards. Fish and fish habitat information is available from the U.S. Fish and Wildlife Service and the Colorado Division of Wildlife.
- Data on wetlands. Data needs can be identified through coordination with the Corps of Engineers, Environmental Protection Agency, U.S. Fish and Wildlife Service, and the Colorado Division of Wildlife.

6.3.4 Site Characteristics

A complete understanding of the physical nature of the natural channel or stream reach is fundamental to a good hydraulic design, particularly at the site of interest. Any work being performed, proposed, or completed that changes the hydraulic efficiency of a stream reach must be studied to determine its long-term effect on the stream flow and stream health. The designer should be aware of plans for channel modifications, and any other changes that might affect the facility design. A stream may be classified as:

- Rural or urban;
- Improved or unimproved;
- Narrow or wide;
- Shallow or deep;
- Rapid or sluggish flow;
- Stable, transitional, or unstable;
- Sinuous, straight, braided, alluvial, or incised; and
- Perennial or intermittent flow.

Geomorphological Data

Geomorphological data is important in the analysis of channel stability and scour. The following types of data are necessary if the stream reach is to be analyzed:

- Sediment transport and related information;
- Stability of form over time (braided and meandering, pool-riffle relationship);
- Evidence of scour, scour history; and
- Bed and bank material identification.

Following the 2013 flood, the Colorado Water Conservation Board (CWCB) initiated a program to re-map the predicted 1% chance regulatory floodplain (100-year flood zone) of the most affected waterways. The program was named the “Colorado Hazard Mapping Program” or “CHAMP.” Most recently, Colorado Water Conservancy Board is in the process of developing Colorado Hazard mapping and Risk MAP Portal with a Fluvial/Erosion Hazard Mapping page.

Roughness Coefficients

Roughness coefficients, ordinarily in the form of Manning's *n* values, should be estimated for the entire flood limit of the stream. A tabulation of values for Manning's *n*, with descriptions of their applications, can be found in Chapter 8 - Channels.

Stream Profile

Streambed profile data must be obtained and should extend sufficiently upstream and downstream to determine the average slope, and to encompass any proposed construction or aberrations. Identification of headcuts which could migrate to the site under consideration is particularly important. Profile data on live streams must be obtained from the water surface. When there is a nearby stream gauge, obtain discharge, date, and time of the reading near that location.

Stream Cross Sections

Stream cross-section data must be obtained representing typical conditions at the structure site and at other locations where stage discharge and related calculations are required.

Existing Hydraulic Structures

It is necessary to know location, size, description, condition, observed flood stages, and channel section relative to existing hydraulic structures on the stream reach near the site to determine their capacity and effect on the streamflow. Any upstream or downstream structures that may cause backwater or retard streamflow must be investigated. Also, note the history of how existing hydraulic structures have been functioning regarding scour, overtopping, debris and ice passage, fish passage, etc.

For bridges, required information includes elevations (low girder, bridge deck, curb, railing), span lengths, types and orientations of piers with main flow direction, and substructure characteristics (foundation types, footer elevations, supporting pile types and tip elevations, orientation of elements). These usually can be obtained from existing structure plans. Required culvert data include size, inlet and outlet geometry, slope, end treatment, culvert material, and flow-line profile. Highway construction plans may be available to provide required bridge and/or culvert data. The hydraulic engineer should verify the documented as-built conditions by field checks. Photographs, high-water profiles or marks of flood events at the structure, and past flood-scour data aid in assessing the hydraulic performance of the existing facility.

Allowable High Water

Improvements, property use, and other developments adjacent to the proposed site, both upstream and downstream, may determine allowable high water. Critical inundation elevations of these improvements or fixtures must be noted. In the absence of upstream development, acceptable flood levels are based on freeboard requirements of the highway itself. In this case, any downstream development becomes particularly important as it relates to potential overflow points along the road grade.

Flood History

The history of past floods and their effect on existing structures is especially valuable for flood-hazard evaluation studies and for sizing structures. Information may be obtained from CDOT Hydraulic units, Maintenance sections, newspaper accounts, local residents, flood marks, and other evidence of the height of historical floods. Changes in channel and watershed conditions since the occurrence of the flood must be evaluated to relate historical floods to present conditions.

Recorded flood data is available from several agencies:

- U.S. Army Corps of Engineers;
- USGS;
- NRCS;
- FEMA;
- Colorado Water Conservancy Board, CWCB;
- Colorado Division of Homeland Security and Emergency Management, DHSEM
- U.S. Bureau of Reclamation; and
- Local and State agencies.

Following the 2013 flood, the Colorado Water Conservation Board (CWCB) initiated a program to re-map the predicted 1% chance regulatory floodplain (100-year flood zone) of the most affected waterways. The program was named the "Colorado Hazard Mapping Program" or "CHAMP." Most recently, Colorado Water Conservancy Board is in the process of developing Colorado Hazard mapping and Risk MAP Portal with a data library.

Debris and Ice

The quantity and size of debris and ice carried or available for transport by a stream during flood events must be investigated for use in the design of structures. In addition, times of occurrence of debris and ice in relation to occurrence of flood peaks should be determined. The effect of backwater caused by debris and ice jams on recorded flood heights should be considered when using streamflow records. In some cases, data related to debris and ice conditions can be obtained from maintenance personnel, maintenance records, and bridge-inspection reports.

Scour Potential

Scour potential is an important consideration for the long-term stability of hydraulic structures. It is determined by erodibility analysis of bed material existing at the facility site, tractive shear forces exerted by flows, and sediment-transport characteristics of the stream. Data on scour potential of existing materials forming the bed may be obtained from field tests or laboratory analysis of samples collected from the site. This data may also be available from previously conducted field tests and/or analyses from CDOT Hydraulics, CDOT Geotechnical, or from USGS.

Samples of bed and bank material for classifying channel type, stability, sediment gradations, as well as geotechnical analysis of substrata in cases where significant scour potential exist are commonly required. These data are also needed to determine presence of bed forms and associated Manning's roughness coefficients, as well as in modeling channel bed aggradation/degradation process and in computing theoretical local scour. Depending on the methodology used to assess scour potential and bed material erosion, additional information pertaining to bed material may be needed. This data must be obtained either by additional sampling or derived from previous work.

Controlling Factors Affecting Design Criteria

Many controlling variables affect the criteria applied to the final design of drainage structures, including allowable headwater and flood levels, allowable velocities and resulting scour, and other site-specific considerations. Related information can be obtained from federal, state and local regulatory agencies, and site investigations. This information is necessary to determine what natural or man-made controls must be considered in the design. In addition, there may be downstream and upstream controls that should be documented:

Downstream Control - Any downstream ponds or reservoirs, along with their spillway elevations and design levels of operation, must be noted as their effect on backwater and/or streambed aggradation may directly influence a proposed structure. Also, any downstream confluence of two or more streams must be studied to determine the effects of backwater or stream bed change resulting from the confluence. In addition, the following may have an effect:

- Downstream landowner alterations;
- Highway crossings; and
- Railroad crossings.

Upstream Control - Upstream control of runoff in the watershed must be noted. Conservation and/or flood control reservoirs in the watershed may effectively reduce peak discharges at the site, and may also retain some of the watershed runoff. Capacities and operation designs for these features must be obtained. Complete reports concerning operation and design of proposed or existing conservation and flood-control reservoirs often may be obtained from:

- The Office of the State Engineer;
- Colorado Water Conservation Board;
- Natural Resources Conservation Service;
- U.S. Army Corps of Engineers;
- U.S. Bureau of Reclamation;
- Consulting engineers; and
- Other reservoir owners.

Redirection of flood waters can significantly affect hydraulic performance of a site. Irrigation facilities, debris jams, mud flows, highways, and railroads can redirect flood water.

6.4 SURVEY INFORMATION

6.4.1 General

Complete and accurate survey information is necessary to develop a design that will best meet the requirements of a site. The project manager in charge of the drainage survey must have a general knowledge of drainage design to successfully coordinate the data collection with the designer. Coordination between the project manager and hydraulic engineer before the survey and initial field work are conducted will ensure acquisition of all required data. The amount of survey data gathered should be commensurate with design requirements, importance and cost of the proposed structure, and expected flood hazard.

At some sites, existing aerial photogrammetry (obtained by aircraft, drones, etc.), Light Detection and Ranging (LiDAR) datasets, Digital Elevation Models (DEM), Digital Surface Models (DSM), Digital Terrain Models (DTM), and Triangular Irregular Networks (TIN), georeferenced aerial photos, are sufficient to obtain the topographical components of drainage surveys. Planimetric analysis of these topographic data covering a wide area can easily and cost-effectively be obtained in many geographic areas using various commonly available software tools. A supplemental field survey may be required to provide additional data in areas obscured on aerial data acquisition systems (underwater, under trees, etc.).

6.4.2 CDOT Requirements

The CDOT instructions for hydraulic surveys are contained in the CDOT *Survey Manual.* An outline of these requirements is presented in Appendix B of this chapter. Example forms and checklists are provided in Appendix C.

6.5 DATA COLLECTION

6.5.1 Digital and Satellite Data Models

Several methods to use electronic data for hydraulic and hydrologic studies are available. Design of drainage systems can be accomplished using CAD software and electronic surface data. Hydrologic and hydraulic models can also be developed using this data.

The types of data normally used by digital models are:

- Elevation data;
- Hydraulic structures, channel controls, utilities;
- Features (e.g., streams, levees and roadways);
- Landuse; and
- Soil types and their infiltration properties.

Some of the electronic data is readily available, though not always with the desired resolution. Elevation data is available from the USGS in Digital Elevation Models (DEM) format. The data is normally available in UTM coordinates and in 10- to 30-m resolution, depending on the location. NRCS also maintains soil and land-use data basis in GIS formats in certain areas. Detailed hydraulic and hydrologic studies may require higher resolution elevation data than is normally available through USGS and NRCS. Higher resolution data, including the laser-based Light Detection and Ranging (LiDAR) data, is available through Colorado GeoData Cache, local county and city GIS departments, or Colorado Office of technology (OIT) through a formal request process.

Satellite imagery is commonly available through local, private, and government agencies. This georeferenced imagery can be used to determine land uses, channel and overland flow roughness values, and the presence of natural and man-made channel controls in the system. Due to the scarcity or obsolescence of elevation data, the normal approach is to develop topographic surveys for a project. There are two basic methods to develop topographic surveys: i) aerial photogrammetry and LiDAR surveys; and ii) field data collection.

Aerial Photogrammetry and LiDAR Surveys

Under aerial photogrammetry surveys, topographic mapping is developed using overlapping pictures of the ground taken from an aircraft or satellite. Ground controls are established using field survey methods to calibrate the elevations and contours are developed from point cloud data.

Aircraft used for taking photographs can be fixed wing (airplane), helicopter, or drones. Fixed wing aircraft still is the most economical method in covering large areas; however, helicopter- and drone-based surveys offer low altitude flights, resulting in much higher accuracy. The pictures taken can also be used as data for hydraulic investigations and studies.

High-resolution satellite and multi-spectral imagery are available and may be substituted for other methods if necessary. Because satellite data is stored for a period of time, multi-spectral satellite imagery can also be used to investigate flooding, actually after an event has occurred. Potentially, the technology can be used to develop "before-and-after" images and topography to investigate a flood event or other significant change in an area of interest.

Modern method of aerial topography generation uses laser or radar beams from an aircraft carrying differential GPS. LiDAR, or radar-generated data, have the advantage of being inexpensive when compared to traditional photogrammetry. However, the accuracy is highly dependent on the technology available to the vendor in aerial equipment and available software to filter trees and other covered land areas. Colorado Governor's Office of Information Technology (OIT) reports that as of 2018, 70 percent of Colorado (73,000 square miles) has LiDAR coverage. According to Colorado OIT, the coverage is QL2 or better where QL2 refers to 2 points per meter horizontal and 0.1 m for vertical accuracy. State LiDAR data is managed by USGS 3D Elevation Program (3DEP), with partnering agencies of FEMA, USGS, NRCS, Counties, Cities, Regional Groups, DIA, and others and provides LAS (point cloud), DEM, contours, and metadata. This data is currently available through Colorado GeoData Cache (https://geodata.co.gov/) and is suitable to conduct 1-Dimensional and 2-Dimensional watershed and streamflow analysis studies.

Field Data Collection

Field data collection is normally accomplished using electronic survey equipment such as Total Stations and Real-time Kinematic (RTK) equipment with Global Navigation Satellite Systems (GNSS). In instances where location accuracy is not crucial, hand-held GPS units that have sub-meter horizontal precision are also used. In addition to total stations and RTK equipment, for bathymetric (under water) surveys, depending on the complexity of the study area, cable and weight or sonar equipment are used.

Using a Total Station as a data collection tool, the engineer can develop topographic mapping directly from the fieldwork, with little additional processing. This information can be directly used in certain highway or hydraulics software, saving time and resources in the tedious process of survey decoding and data entry. Digital Elevation Models or Digital Surface Models can be developed using the data collected using this method. Other feature data (e.g., flood limits, bank full indicators, vegetation markers, point bars, flow boundaries) can also be located by a surveyor and automatically decoded along with the elevation data. The accuracy of this method can be very high and is dependent on the experience of the field personnel.

Real-time Kinematic (RTK) positioning is a satellite-based navigation technique used to enhance the precision of position data derived from satellite-based positioning systems such as GPS (USA), GLONASS (Russian), Galileo (Europe), and BeiDou (China). It uses measurements of the phase of the signal's carrier wave in addition to the information content of the signal and relies on a single reference station to provide real-time corrections, providing centimeter-level accuracy. Over the past decade, Real-time Kinematic (RTK) surveying with Global Navigation Satellite Systems (GNSS) has become common practice in geomatics. RTK surveying is a relative positioning technique which measures positions using two GNSS antennas in real time. One is set up on a static point with known coordinates (survey benchmark monument) and is known as the base station. It uses a high frequency radio to transmit its raw elevations to the second unit known as the rover. The rover unit uses its observation along with the base station observation (corrections) to compute a position relative to the base-location in real time. RTK surveying requires reliable communication between the base and rover units and works best with short baselines as the precision of RTK measurements decreases as the baseline length increases. Real time Networks

(RTN) have been developed as a method extending range limitations between base-to-rover. RTNs make use of a several base stations together to collect GNSS observations that can be used with a rover to compute a position relative to the network solution in real-time. RTK surveying allows achieving relative positioning with 1-centimeter (0.03 ft) precision, however there are several important factors that need to be considered (equipment calibration, errors, multipath, geometry, etc.).

Finally, hand-held GPS units that have sub-meter horizontal precision are commonly available and can be used for certain field data collection functions. Vertical precision of these units to collect elevation data is not sufficiently accurate for many design functions. However, this method makes a one-person survey crew possible with minimal training. GPS data can be obtained by survey personnel during a field visit. This facilitates rapid development of field data that may be used for biological assessment studies, for delineating environmental resources, historical structures, and facilities for quick office evaluations.

6.5.2 Data Merging

Merging of electronic surface data is common during highway design. More accurate data is usually collected within the highway area, while data for the area outside the expected cut/fill lines may be less precise. Because watershed limits fall well beyond the highway cut/fill lines, hydraulic engineers often must work with data having multiple resolutions. In general terms, in arriving at a final elevation data, first the lower resolution base data is laid out for the entire study region. Next, higher resolution LiDAR and professional land survey (PLS) data is overlaid on the base map overriding the lower resolution data. Finally, bathymetric survey not covered by LiDAR and field surveys are introduced to finalize the topographic map.

Available electronic data is differentiated by software products, type of data structure (DEMs and TINs), coordinate systems (UTM, State Plane, Latitude-Longitude), units (feet or meters), resolution and datums. When merging data in different formats, extreme care must be taken to ensure proper conversion prior to merging. Standardizing all data to the most current format is the best way to ensure compatibility. Software tools are available to accomplish the data “translation.” Since CDOT projects are designed in modified Colorado State Plane NAD 83 (2011) coordinate system for appropriate regions of the State (North, Central, South), it is appropriate to convert all data to CDOT project coordinates to allow data sharing between different disciplines.

A more serious problem in merging data is caused by differences in data resolution. For example, a digital surface model developed from photogrammetry is typically of lower resolution compared to a surface model developed from LiDAR or a field data-collection survey. When merging data, particular attention must be given to resolution of elevation differences at boundaries of different data areas.

There is often a problem with artificial pits (sinks) and peaks due to the creation of DEMs and TINs. The engineer must evaluate the data and correct these inconsistencies.

6.5.3 Accuracy of Data

In any engineering computations, it is important to understand that accuracy limits of computations depend on accuracy of the data. In 1-Dimensional (1-D) and 2-Dimensional (2-D) computations, there are several factors that affect accuracy of the results. These include accuracy of the survey data, spacing between cross sections (1-D) or lateral or longitudinal mesh size (2-D), correct establishment of upstream and downstream study limits and selection of proper boundary conditions at these limits (lateral flow distribution, water surface elevations), and selection of roughness coefficients at different cross sections across channel (1-D) or regions (2-D) as well as specifying aerial and vertical distribution of soil types.

The accuracy of aerial survey technology for generating cross-sectional (1-D) or aerial topography (2-D) data is governed by mapping-industry standards. Cross sections obtained from contours of topographic maps developed by photogrammetric methods are generally not as accurate as those generated from LiDAR and field data-collection methods. Aerial photography and LiDAR can supplement professional land surveys and hydraulic surveys in generating proper modeling topography. LiDAR and aerial elevation survey data corrected using ground control points (GCP) permit additional coordinate points and cross sections (1-D) or Digital Elevation Maps (DEM) (2-D) to be obtained at a relatively small cost. The 1-D and 2-D data can be input into commonly used hydraulic and watershed modeling software.

For further information on determining the relationships between survey technology and accuracy for 1-Dimensional models in determining stream cross-sectional geometry, degree of confidence in selecting Manning's roughness coefficients, and the resulting accuracy of hydraulic computations, refer to the U.S. Army Corps of Engineers' publication, *Accuracy of Computer Water Surface Profiles*. This publication also presents methods of determining upstream and downstream limits of data collection for a hydraulic study requiring a specified degree of accuracy.

For 2-Dimensional modeling, the effects of using accurate topography, mesh size (density of ground points), selecting roughness coefficients, and using appropriate boundary conditions are also expected to affect the accuracy of results. A sensitivity analysis by altering these parameters within expected range of variation could provide engineers a range of expected modeling accuracies and identify need for data accuracy.

6.6 FIELD REVIEWS

6.6.1 Onsite Inspection

An on-site field review must be organized and conducted by the Hydraulics Section to become familiar with conditions in the project area. The inspection team typically includes maintenance and hydraulics personnel. The most complete survey data cannot adequately depict all site conditions or substitute for personal inspection by someone experienced in drainage design. Factors that most often need to be confirmed by the hydraulics engineer are:

- Verify basin boundaries;
- Selection of roughness coefficients;
- Evaluation of apparent flow direction and diversions;
- Flow concentration;
- Channel controls;
- Observation of land use and related flood hazards;
- Geomorphic relationships;
- High-water marks or profiles, and related frequencies;
- Sizes and types of existing structures;
- Bank erosion;
- Debris problems;
- Scour; and

- Existence and delineation of wetlands.

A field visit to the project site must be made before any detailed hydraulic design is undertaken. Information obtained may be combined with information from site visits by others, such as roadway and structural designers, maintenance personnel, environmental reviewers, and local officials. The designer should consider equipment that will be needed for the field visit, and most importantly, critical information to be obtained at the site.

As a minimum, photos must be taken looking upstream and downstream from the site as well as along the proposed highway centerline in both directions. Details of the streambed and banks should also be photographed, along with structures in the vicinity, both upstream and downstream. Close-up photographs, complete with a scale or grid, should be taken to facilitate estimates of the streambed gradation.

In certain instances the designer may determine that a field visit is not required if the magnitude of the project does not warrant an inspection, or if the required information can be obtained from maps, aerial photos, or from other sources.

6.6.2 Preparation of Preliminary Drainage Data

Transfer Road Alignment to Digital Topographic Map

To prepare for preliminary drainage data collection, the hydraulics engineer should first have the project's roadway alignment transferred to an appropriate digital topographic map. CDOT's roadway project manager will provide the preliminary plan and profile for the proposed highway project. To transfer the road alignment, the hydraulics engineer should perform the following steps:

1. Obtain the appropriate digital topographic map of the area.
2. Obtain as-built plans. Relevant as-built plans for the appropriate section of the highway are found by searching the CDOT's record system. These may be in a variety of formats, including online PDF files, microfilm, or paper plans. Make copies of the plans and record the reference information on the copy.
3. Transfer the roadway alignment. Use the appropriate plan scale, transfer existing drainage crossing locations and proposed highway alignment information from the preliminary plan sheets to the digital topographic map. Delineate the proposed highway stationing for each crossing. Check with the old plans to ensure that each existing crossing is in the correct location. The old plans may provide other useful hydraulic information for the preliminary hydraulics design.

Determine Drainage Areas

Before the field review, determine the related drainage area for all drainage crossings within the project limits shown on the quadrangle map. These calculations will be verified during the field review. The drainage areas can be determined using the web-based USGS Colorado Streamstats program, GIS-assisted methods, WMS software or traditional, by-hand methods. The drainage area of non-contributing areas also should be determined as these areas will retain rainfall from the design event.

Determine Channel Slopes

Calculate channel slopes as defined by the relevant USGS publications for estimating peak-flow magnitude and frequency.

6.6.3 Conducting the On-Site Inspection

The following questions should be addressed before making the field visit:

- Can any necessary information be obtained from available maps, aerial photos, or by contacting private, local, or government agencies?
- What type of equipment should be taken to the field, and most importantly, what are the specific critical items to be observed at the site?
- In addition to photos of the general project area, should photos be taken looking upstream and downstream from the site, along the proposed highway centerline in both directions?
- What details of the streambed, banks, and of existing hydraulic structures be photographed?
- Are there any hydraulic structures affecting flows in the vicinity of the project site either upstream and downstream?
- Should close-up photographs, complete with a scale or grid, be taken to facilitate estimates of the streambed gradation?

6.6.4 Checklist

Forms used by CDOT for identifying and cataloging field information are included in Appendix C.

6.7 DRAINAGE SURVEY INFORMATION

6.7.1 General

The hydraulics engineer should conduct an in-office review of the project to determine the required field and aerial drainage surveys for the hydraulic analysis and design. Survey requirements for small drainage facilities and small culverts are less extensive than those for bridges. However, the purpose of the survey is to provide an accurate picture of the conditions within the zone of hydraulic influence for the facility. Following are the types of data that may be obtained or verified:

- Stream-reach data (e.g., cross sections, thalweg profile);
- Existing hydraulic structures (size and elevation properties for hydraulic computations);
- Location and survey for development, existing structures, etc., that may affect the determination of allowable flood levels, capacity of proposed drainage facilities, or acceptable outlet velocities;
- Drift/debris characteristics;
- General ecological information about the drainage area and adjacent lands; and
- High-water elevations, including the dates of occurrence (if possible).

Many of these data types should be verified during the site inspection. It is often much easier to interpret published sources of data after an onsite inspection. Only after a thorough study of the project area and collection of all required information should the hydraulics engineer proceed with the final design of the hydraulic facility. All pertinent data and facts gathered through the survey should be documented as discussed in Chapter 4 - Documentation.

Uniform or standardized drainage survey requirements for some projects may prove uneconomical, and available data may be deficient for a specific project. Special instructions outlining data requirements may need to be provided to the survey party by the hydraulic engineer for unusual sites.

6.7.2 Survey Locations

A preliminary drainage survey should identify locations where drainage structures will be required. The hydraulic engineer may need to describe necessary information to the appropriate survey personnel. Information may be provided as part of the project scope, or requested by survey personnel when they initiate the field survey. Project corridor limits, provided by the project manager, are needed by the hydraulic engineer to identify the larger drainage basins. The hydraulics engineer will then provide a list of locations and limits of surveyed areas required for each drainage basin.

6.7.3 Drainage Survey Needs

General

The basic information necessary for all drainage surveys is as follows:

- Obtain any observed highwater elevations and, if possible, the date of the highwater. This information allows the hydraulic engineer to calibrate the hydraulic model developed to analyze existing, and size future structures.
- For any existing box culvert or large culvert encountered, obtain the flow-line (invert or top of floor) elevation and coordinates of the inlet and outlet ends. The coordinates of all four corners should be recorded for box culverts. Elevations and coordinates at the end of any apron are optional. This data is important for any crossing, but especially for any culverts that will be extended, or for fish passage considerations.
- Obtain the lowest elevation of any upstream buildings.
- Document any obstructions. Dams should always be documented because they may adversely affect the highway crossing. For dams, provide the spillway crest elevation, width, and shape.
- Obtain the waterway opening and height at locations where the roadway is overtopped for any structure within 4 miles upstream and downstream of the project site on the same drainage channel. For bridges, obtain a channel cross section of the bridge opening. For culverts, provide the number, widths, and heights. If this information is available from some other source (e.g. bridge maintenance inspection files), reference that information. When crossing lake bed areas, the overflow outlet should be located and overflow elevation established.
- Submit the completed drainage data information sheet to the hydraulic engineer when the survey for the remainder of the project is transmitted. Appendix C provides an example drainage data information sheet to be completed by the surveyor.

Drainage Basins

The following three levels of survey needs are provided as an example of how survey requirements may increase as the project area increases:

<u>Drainage Basins Less than 200 Acres</u> - Drainage basins with an area less than 200 acres normally do not require special survey needs.

<u>Drainage Basins from 200 to 1,000 Acres</u> - The survey coverage limits for drainage basins from 200 to 1,000 acres should include the area that defines the main channel for a distance of at least 500 ft upstream of the proposed crossing location in order to define any flood-storage capacity in that area. The standard roadway corridor coverage is adequate for the downstream channel. However, ensure that the channel flow line is defined within this corridor and coded accordingly.

Drainage Basins Greater than 1,000 Acres - Drainage basins greater than 1,000 acres require the most extensive survey coverage. The survey coverage limits should include:

- The area that defines the main channel for a distance of at least 1,000 ft downstream to 1,000 ft upstream of the proposed crossing location. Where the roadway alignment is uncertain it may be necessary to increase these limits to ensure that adequate coverage is obtained. Define the center of the low channel and note any abrupt change in the channel flow line. After project scoping has been completed prior to commencing the survey, and those areas of possible alignment shifts have been confirmed, coverage limits do not need to be increased. For larger rivers, the survey limits may need to be increased to provide sufficient data for the hydraulic model. Hydraulics staff should determine when this is necessary.
- Special care should be taken to ensure that survey limits adequately define main channel limits to allow analysis of its flow capacity. For those floodplains where the valley beyond the main channel is very wide and flat, survey limits should include the main channel and a minimum distance of at least 50 ft beyond the top of the banks onto the floodplain. If the immediate area of the main channel is adequately covered by the ground survey, office personnel can extend the limits as needed by using other sources (e.g., digital elevation or quadrangle maps). Obtain sufficient ground points and include sufficient referencing lines to properly define the irregular geometry of natural waterways.
- Ensure that enough ground points are surveyed near the existing structure so that the structure (bridge) opening can be determined from the survey data. This often requires obtaining underwater survey data.

6.7.4 Survey Data Files

Survey data is normally provided in a format compatible with CDOT software. The hydraulic engineer will process the data to develop contour plots, channel profiles, and hydraulic-model cross sections. If survey data files are not compatible with CDOT software, the surveyor is responsible for plotting the drainage survey. The hydraulic engineer must be consulted for required contents and plotting format prior to plotting the survey. Stationing of the channel profile must begin at the downstream end and proceed upstream. For projects where the survey is not required to be in CDOT's software format, the surveyor must provide the drainage survey data in a format required by those who will be using the data.

6.8 DATA RELIABILITY

6.8.1 Objective

Once the needed data is collected, it must be compiled into a usable format. The designer must determine whether the data contains inconsistencies or other anomalies that might lead to erroneous results. The purpose for analyzing the various forms of data is to organize the information into a comprehensive and accurate representation of the hydrologic and hydraulic characteristics of a particular site.

6.8.2 Reliability

Knowledge, experience, and judgment are important requirements for data evaluation. Reliable data must be separated from unreliable data, and historical data combined with results of measurements. The data must be evaluated by the hydraulic designer for consistency, and to identify any changes from established patterns. Review may include previous studies, old plans, etc., for types and sources of data, how the data was used, and indications of accuracy and reliability. Historical data must be reviewed to determine whether significant changes have occurred in the watershed, and whether related data can be used. Data acquired from publications of established sources, such as the USGS, can be considered valid and accurate. Basic data, such as stream flow derived from nonpublished sources, must be evaluated and summarized before use. Maps, aerial photographs, Landsat images, and land-use studies must be compared with one another and with the results of the field survey, and any inconsistencies resolved. General references should be consulted to help define the hydrologic character of the site or region under study, and to aid in analysis and evaluation of data.

6.8.3 Sensitivity

Sensitivity studies can be used to evaluate data and the importance of specific items to the final design. These studies consist of performing a design with a range of values for specific data items. The effect on the final design can then be established. This is useful in determining what specific data items have major effects on the final design, and the relative importance of possible data errors. Time and effort can then be spent on more sensitive data items, making sure this data is as accurate as possible. This does not mean that inaccurate data is acceptable for less-sensitive data items, but it allows prioritization of the data-collection process within the budget and schedule.

This type of data evaluation will maximize reliability of the site description and optimize use of resources. The effort of data collection and evaluation must be commensurate with the importance and extent of the project.

REFERENCES

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APPENDIX A – SOURCES OF DATA

Principal Hydrology Data Sources

- Meteorological Data

  US National Oceanic and Atmospheric Agency (NOAA)
  National Climatic Data Center
  Battery Park Avenue
  Federal Building
  Asheville, North Carolina 28801
  (704) 271-4800
- Regional and local flood studies;
- U.S. Geological Survey regional and site studies;
- Surveyed high-water marks, and site visits by CDOT ;
- CDOT Maintenance;
- Hydrology data from other available sources (see below);
- NOAA Atlas 14;
- UDFCD Master Plans;
- Community Collaborative Rain, Hail, and Snow Network (CoCoRaHS); and
- Natural Resource Conservation Service (NRCS) Reports.

Principal Watershed Data Sources

- Colorado GeoData Cache
- Colorado Office of Information Technology (OIT). Internet site for delivery of elevation, imagery and other spatial data owned by state and local agencies in Colorado: https://data.colorado.gov/dataset/Colorado-GeoData-Cache/p6nr-fvcw
- U.S. Geological Survey maps

  U.S. Geological Survey
  Rocky Mountain Mapping Center
  Mall Stop 504
  Denver Federal Center
  Denver, Colorado 80225
  (303) 236-5829
- EROS aerial photographs

  U.S. Geological Survey
  Mundt Federal Building
  47914 252nd Street
  National Center for Earth Resource Observation & Science (EROS)
  Sioux Falls, South Dakota 57198-0001
  (605)594-6511
- Colorado Geological Survey

  1801 19th Street
  Golden, Colorado 80401
  (303) 384-2655
- State geological maps

- Natural Resource Conservation Service soil maps

  Natural Resources Research Center
  2150 Centre Ave
  Fort Collins, Colorado 80526
  (970) 295-5000

- Bureau of Land Management (BLM) soil maps

  US Land Management Bureau
  Conservation Department
  5353 Yellowstone Rd
  Cheyenne, Wyoming 82009
  (307) 775-6256

- Site visits by CDOT
- Watershed data from other available sources (see below)

Principal Site Data Sources

- CDOT files of aerial drainage surveys
- CDOT project files for existing facilities at CDOT Staff Bridge (Asset Management)
- Site visits by CDOT
- Field or aerial surveys from other available sources (see below)

Principal Regulatory Data Sources

- Federal Floodplain delineations and studies

  Federal Emergency Management Agency
  Flood Map Distribution Center
  6930 (A-F) San Tomas Road
  Baltimore MD 21227-6227
  (800) 358-9616

- State and local floodplain delineations and studies
- FHWA design criteria and practices

  Federal Highway Administration
  12300 West Dakota Ave #180
  Lakewood, Colorado 80228
  (720) 963-3000

- Federal Registers

  Superintendent of Documents
  US Printing Office
  Washington D.C. 20402
  (202) 783-3238

- USACE Section 404 Permit Program

  Denver Regulatory Office
  9307 South Wadsworth Blvd
  Littleton, Colorado 80128
  (303) 979-4120

- Laws of the State of Colorado
- Local ordinances and master plans
- CDOT Policy Statements

- Urban Drainage and Flood Control District (UDFCD) Master Plans
  2480 W. 26th Aven # 156B
  Denver, CO 80221
  (303) 455-6277

Principal Environmental Data Sources

- Corps of Engineers Section 404 permit program
  Denver Regulatory Office
  9307 South Wadsworth Blvd
  Littleton, Colorado 80128
  (303) 979-4120
- U.S. Environmental Protection Agency (EPA)
  EPA Region 8 Headquarters
  1595 Wynkoop St.
  Denver, Colorado 80202
- Colorado Department of Public Health and Environment
  4300 Cherry Creek Drive South
  Denver, Colorado 80246
  (303) 692-2000
- Federal Register
  Superintendent of Documents
  U.S. Printing Office
  Washington D.C. 20402
  (202) 783-3238

Other Data Sources

- U.S. Bureau of Reclamation (USBR)
  U.S. Bureau of Reclamation Center
  Denver CO 80225
  (303) 445-2600
- Regional and State U.S. Bureau of Land Management (BLM)
  Colorado Bureau of Land Management
  2850 Youngfield St.
  Lakewood, Colorado 80215
  (303) 239-3933
- Regional U.S. Environmental Protection Agency (EPA)
- Regional U.S. Federal Emergency Management Agency (FEMA)
- Regional and State U.S. Fish and Wildlife Service (USFWS)
- Regional and State U.S. Forest Service (USFS)
- Regional and State U.S. Natural Resource Conservation Service (NRCS)
- Regional and State U.S. Corps of Engineers (COE)
- Regional and State U.S. Geological Survey (USGS)
- Regional and State Federal Highway Administration (FHWA)
- National Weather Service (NWS)
  5100 Quail Run Rd.

Watkins, Colorado 80137
(303) 261-9130

- National Oceanic and Atmospheric Administration (NOAA)

  1401 Constitution Avenue NW, Room 5128
  Washington, DC 20230
  (202) 482-2000

- Urban Drainage and Flood Control District
- Denver Regional Council of Governments (DRCOG)
- Colorado Department of Local Affairs (NOLA)
- Colorado Department of Natural Resources (DNR)

APPENDIX B – HYDRAULIC SURVEY INSTRUCTIONS

General

This Appendix discusses guidelines which must be followed when drainage surveys are conducted. The guidelines are intended to ensure that all information needed for hydraulic design will be included in the survey. These guidelines should be confirmed or supplemented through direct contact with the hydraulic engineer. The project manager should contact the hydraulics engineer at least two weeks prior to the presurvey conference. After survey requirements have been determined, a transmittal of the requirements must be submitted to the Region Survey Manager.

General Guidelines for Drainage Surveys

Good surveys are necessary for complete and accurate hydraulic designs. Channel locations and changes, bridge skew, water stage, and structure relocations are all determined from the drainage survey.

Guidelines for determining the extent of a drainage survey:

For large bridges with design flows greater than 20,000 cfs or spans greater than 250 feet:

- Consult with the hydraulic engineer before scoping the survey. Requirements are discussed further at the Presurvey Conference.
- Aerial surveys should be considered for these sites. See the Photogrammetry Chapter in the CDOT *Survey Manual*.

For large culverts and medium bridges with design flows of 2,000 cfs to 20,000 cfs, CBCs 20 ft by 10 ft or larger, and bridges with a span greater than or equal to 250 feet:

- The survey must extend 1,200 feet upstream and 1,200 feet downstream from the roadway centerline. If grade-control structures or canal-intake structures are present the survey must include these structures.
- Additional survey data must be taken near the upstream and downstream edges of any existing structure, including the abutments.
- The elevation of existing structures' lowest girders or clearances must be included.
- The width of the survey corridor will be determined by the hydraulic engineer.
- Additional requirements are determined at the Presurvey Conference.

For medium to large culverts with design flows of 200 cfs to 2,000 cfs, 72-inch pipes or larger, and CBCs up to 20 ft by 10 ft:

- The survey must extend 500 feet upstream and 500 feet downstream from the roadway centerline.
- Additional survey data must be taken near the upstream and downstream edges of the existing structure, including the abutments.
- The width of the survey corridor will be determined by the hydraulic engineer.
- Additional requirements are determined at the Presurvey Conference.

For small culverts with design flows less than 200 cfs, or pipes smaller than 72 inches:

- The survey must extend 100 feet upsteam and 100 feet downstream from the roadway centerline.
- Survey data must be taken at each end of the culvert to determine the structure centerline, depth of sediment, and headwall dimensions.

- CDOT Form 283 Field Culvert Report must be completed for each culvert, except for side drains smaller than 1.5 feet. Sketches of the existing culverts should be included.

For irrigation canals:

- The water surface profile and channel invert must both be surveyed. This may result in two separate surveys, unless the surveyor can mark the water surface during flow and take the measurements at a later date when the canal is not in operation.
- The survey must extend 1,000 feet upstream and 2,000 feet downstream from the roadway centerline. If a difference in water surface elevation of 0.5 feet is achieved less than 2,000 feet downstream, the survey can be discontinued at that point. Measurements of the wate surface profile must be taken at 100-foot intervals to an accuracy of 0.05 foot. The date and time of the water surface profile must be recorded.
- The name and address of the owner of the ditch should be noted. Inquiries regarding the discharge at the time of the water surface profile measurement should be made to the ditch rider.
- Irrigation-control structures, such as turnouts, check structures, etc., within the survey limits should be identified and detailed.
- Water rights must be delineated.

For storm drains:

- The profile grade and gutter-flowline elevations of the main roadway must be surveyed. The survey must cover all areas of the roadway that contribute drainage. This may entail surveying beyond the project limits. For example, if the project ends in the middle of a crest vertical curve, the survey must continue to the top of the curve.
- The profile grade and gutter-flowline elevations of all cross streets or road approaches must be surveyed. The survey must extend 500 feet along the road approach, or to the road's highest point, whichever is less.
- The locations of all curbs, gutters, inlets, culverts and manholes must be determined. Inlet and pipe depths and sizes (rim and invert elevations) must be indicated, and the direction of flow in the pipes must be noted.
- The location of all utilities must be determined. The size, type, and depth of the utilities must be indicated.

For existing detention ponds:

- Surveys of detention ponds must be accurate enough to draw a contour map with three to five contours.
- The survey data must extend upward to the pond-overflow elevation.
- Any significant topography within a potential ponding area, such as building foundations, ground floor elevations, or outlet structures must be shown.
- For any concrete structure, the survey must include details of the entire structure.

Methods

Terrain and topography data must comply with current CDOT survey methodologies, and use the coordinate system of the project control survey.

If photographs are required by the hydraulic engineer, they must be included in the transmittal of hydraulic survey requirements. Photographs must show existing inlet and outlet configurations, areas of erosion, structures that experience distress during flooding, and natural features of the drainage basin. Digital photographs must include metadata with, at minimum, the project number, date of photo, description of photo, direction of orientation of the camera, and the photographer's name.

Coordination with the hydraulic engineer must be take place before starting any drainage survey.

For CBCs, the following photos are required:

- Looking upstream from the structure inlet;
- Looking downstream into the entrance of the structure;
- Looking downstream from the structure outlet;
- Looking into the structure outlet; and
- Roadway in the direction of increasing and decreasing roadway station.

For bridges, the following photos are required:

- Piers;
- Abutments; and
- Minor drainage and rundowns.

APPENDIX C – FIELD INVESTIGATION FORMS

Form 1

FIELD VISIT INVESTIGATION FORM

DATE:	
PROJECT:	
BY:	
Structure Type:	Pier Type:
Size or Span:	Skew:
Number of Barrels or Spans:	Inlet:
Clearance Height:	Outlet:
Abutment Types:	% Grade of Road:
Inlet Type:	% Grade of Stream:
Existing Waterway Cover:	
Overflow Begins at Elevation:	Length of Overflow:
Maximum AHW (ft):	
Reason:	Check for Debris:
	Side Slopes:
	Height of Banks:
Up or Downstream Restriction:	
Outlet Channel, Base:	
Manning's *n* Value:	
Type of Material in Stream:	
Ponding:	
Check Bridges Upstream And Downstream:	
Check Land Use Upstream And Downstream:	
Survey Required? YES NO	
REMARKS:	

Form 2
Hydraulic Survey Field Inspection Check List

I. GENERAL PROJECT DATA

1. Project Number: ____________________ 2. County: _______________
3. Road Name: ____
4. Site Name: ____________________ Station: ______________________ R.P.: ______________
5. Site Description: ☐ Crossdrain ☐ Irrigation ☐ Storm Drain ☐ Long. Encroach. ☐ Ch. Ch. ☐ Other:

   ____
6. Survey Source: ☐ Field ☐ Aerial ☐ Other _______________________
7. Date Survey Received: ____________________ From _______________
8. Site Inspected by: ____ date: ____________________

II. OFFICE PREPARATION FOR INSPECTION

1. Reviewed:

   Aerial Photos: ☐ Yes, Photo Nos. _______________ ☐ None Available

   Mapping/Maps: ☐ Yes, Map Nos. _______________ ☐ None Available

   Reports: ☐ Yes ☐ No ☐ None available at this time

   CDOT Permanent File: ☐ Yes ☐ No ☐ No file data found
2. Special Requirements and Problems Identified for Field Checking:

   ☐ Hydrologic Boundary: obtain hydrologic channel geometry

   ☐ Adverse Flood History: obtain high-water marks, dates, eye witness

   ☐ Irrigation Ditch: obtain several water-rights depths

   ☐ Permits Required: ☐ COE ☐ Ch. Ch. ☐ Dam

   ☐ Other ___________________________________

   ☐ Adverse Channel Stability and Alignment History: Check for headcutting, bank caving, braiding, increased meander activity

   ☐ Structure Scour: check flow alignment, scour at culvert outlet or evidence of bridge scour. Obtain

   bed/bank material samples at ____

III. FIELD INSPECTION

The following details obtained at the site are annotated on the Drainage Survey:

1. Survey appears correct: ☐ Yes ☐ Apparent errors:

   ____

   which were resolved by:

   ____
2. Flooding Apparent? ☐ No ☐ Yes, high-water marks obtained ☐ Yes, high-water marks not

   obtained because ____

3. Do all Floods Reach Site? ☐ Yes ☐ No, details obtained ☐ No, details not obtained because ______________________________

4. Do Floodwaters Enter Irrigation Ditch? ☐ N/A ☐ No ☐ Yes, details obtained ☐ Yes, details not obtained because ______________________________

5. Hydrologic Channel Geometry obtained? ☐ Yes ☐ No, because ______________________________

6. Channel Unstable? ☐ No

   Yes: ☐ headcutting observed ☐ amount/location obtained ☐ bank caving ☐ braiding ☐ increased meander activity

   ☐ Other ______________________________

7. Structure Scour in Evidence? ☐ No ☐ Minor

   ☐ Yes, and ☐ obtained bed/bank samples, and ☐ noted flow alignment problems

   ☐ Yes and ☐ bed/bank material samples not obtained, and ☐ flow alignment not noted because ______________________________

8. Irrigation facility? ☐ No

   Yes: ☐ Several water-rights depths obtained

   Yes: ☐ No water-rights depths obtained because ______________________________

9. Manning's *n* obtained? ☐ Yes ☐ No because ______________________________

10. Property damage due to BW? ☐ No

    Yes: ☐ Elevation/property type checked

    Yes: ☐ Elevation/property type not obtained because ______________________________

11. Environmental Hazards Present? ☐ No

    Yes: ☐ Details obtained

    Yes: ☐ Details not obtained because ______________________________

12. Ground Photos Taken? ☐ Upstream floodplain and all property ☐ Downstream floodplain and all property ☐ Site looking from downstream ☐ Site looking from upstream ☐ Channel material with scale
    ☐ Evidence of channel instability ☐ Evidence of scour ☐ Existing structure inlet/outlet ☐ Other: ______________________________

13. Effective drainage area visually verified? ☐ Yes ☐ No, because: ______________________________

IV. POST INSPECTION SURVEY ANNOTATION

1. Section II findings annotated on survey? ☐ Yes ☐ No (attach typed explanation by site station and name, and checklist section and number).
2. _____ Copies of survey originals and checklists submitted to CDOT Roadway Unit.
3. _____ Copies of survey originals and checklists submitted CDOT Hydraulic Unit for hydraulic design.

Signature:

____

Designer Inspecting Submittal