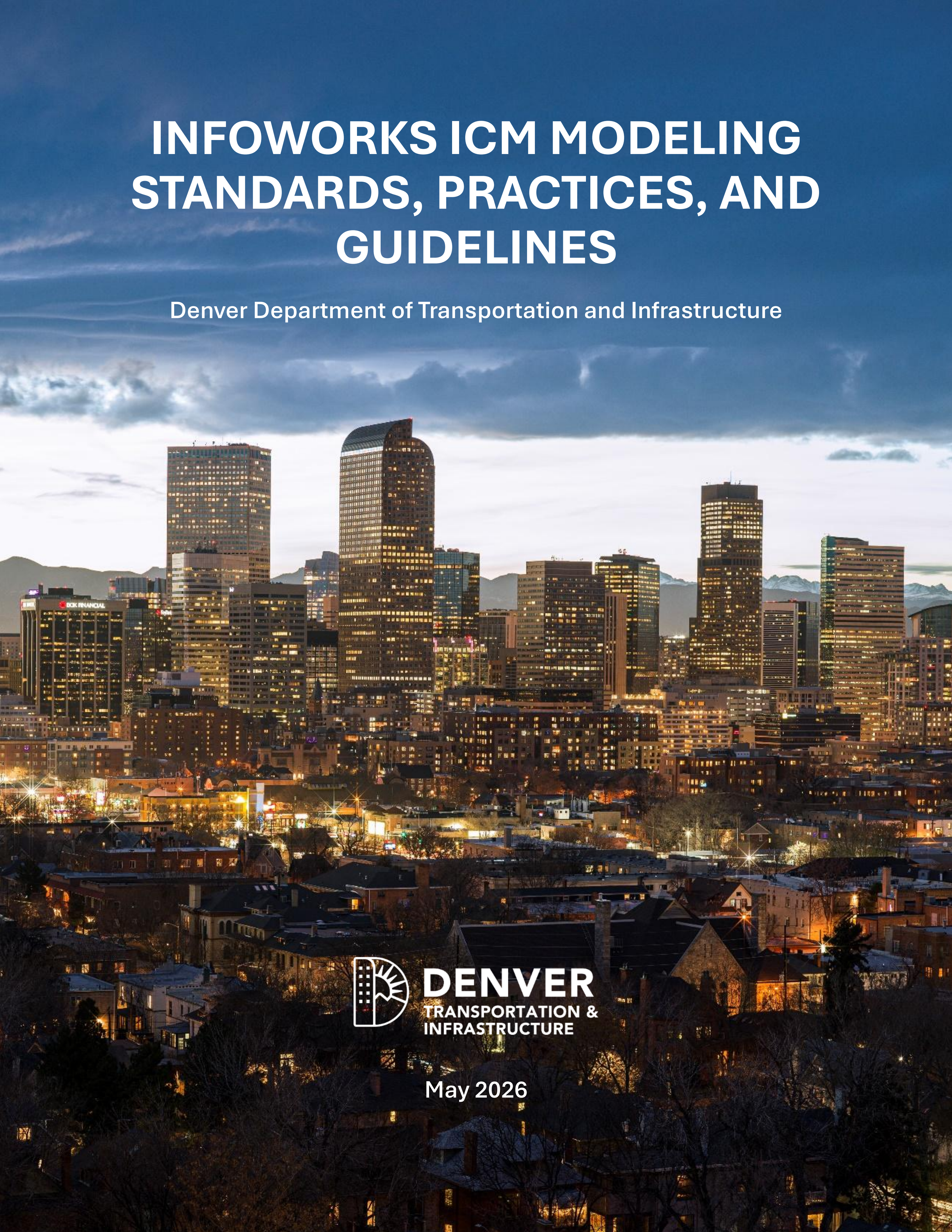

INFOWORKS ICM MODELING STANDARDS, PRACTICES, AND GUIDELINES

Denver Department of Transportation and Infrastructure

DENVER
TRANSPORTATION &
INFRASTRUCTURE

May 2026

CHANGE LOG

This InfoWorks ICM Modeling Standards, Practices, and Guidelines document is intended to supplement the *2025 Hydraulic and Hydrologic Modeling Guidance* technical memorandum (Stantec, 2025) and the *Guidance for 2D Storm Drainage Modeling and Deliverables* report (CCD, 2026).

ACKNOWLEDGEMENTS

The City and County of Denver team wishes to acknowledge the various individuals and organizations who contributed to the preparation of this InfoWorks ICM Modeling Standard, Practices, and Guidelines document:

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Robin Hegedus, PE

The City and County of Denver would like to gratefully acknowledge the following individuals and organizations for their collaboration and feedback during the development of these guidelines.

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Abbreviations & Acronyms

1D	One-dimensional
2D	Two-dimensional
CCD	City and County of Denver
CDOT	Colorado Department of Transportation
CUHP	Colorado Urban Hydrograph Procedure
DEM	Digital Elevation Model
DOTI	Department of Transportation and Infrastructure
DRCOG	Denver Regional Council of Governments
EPA	Environmental Protection Agency
FEMA	Federal Emergency Management Agency
FIS	Flood Insurance Study
GARR	Gauge-Adjusted Radar Rainfall
GIS	geographic information system
H&H	hydrology and hydraulics
ICM	Integrated Catchment Modeling
ID	identification
LiDAR	Light Detection and Ranging
MHFD	Mile High Flood District
NOAA	National Oceanic and Atmospheric Administration
NRCS	Natural Resources Conservation Service
RoM	Rain-on-mesh
SDMP	Storm Drainage Master Plan
SSURGO	Soil Survey Geographic (database)
SWMM	Storm Water Management Model
UFRA	Urban Flood Risk Area
US	United States
USDA	US Department of Agriculture

1.0. Introduction

The purpose of these Guidelines is to provide direction for future stormwater modeling efforts by the City and County of Denver (CCD). It details the new stormwater modeling approach selected by CCD, which uses Autodesk InfoWorks Integrated Catchment Modeling (ICM) software to perform rain-on-mesh (RoM) modeling with integrated one-dimensional (1D) and two-dimensional (2D) hydrology and hydraulics (H&H), and serves as a practical reference for future model building efforts. For a comparison with the previous modeling approach, as well as a high-level overview of the methodology discussed in this document, refer to the *2025 Hydraulic and Hydrologic Modeling Guidance* technical memorandum (Stantec, 2025) provided as part of the Storm Drainage Master Plan (SDMP). For additional background on legacy modeling tools, historical software workflows, and the integration of Geographic Information Systems (GIS) deliverables across previously completed basin studies, modeling practitioners should refer to the *Guidance for 2D Storm Drainage Modeling and Deliverables (CCD, 2026)*, which provides a comprehensive overview of earlier approaches and their relationship to CCD's unified ICM framework.

CCD has undertaken 2D stormwater planning and modeling efforts for many years, but the technical approaches, tools, and assumptions applied across projects have not always been consistent. Historically, various consulting teams employed different H&H modeling platforms—including EPA SWMM/PCSWMM, FLO-2D, RiverFlow2D, HEC-RAS, and TuFLOW—to evaluate risk, characterize flooding behavior, and support decision making for system improvements. When combined with externally generated Colorado Urban Hydrograph Procedure (CUHP) based inflow hydrographs, these multiplatform workflows introduced complexities and challenges. Differences in 1D pipe network representation, 2D surface routing assumptions, and data handling practices could often result in inconsistent model behavior and reduced comparability between studies.

Most planning studies completed under previous modeling approaches were conducted at the watershed or basin level, then later combined to form a citywide planning inventory. While these efforts advanced CCD's understanding of its drainage system, they also revealed several challenges:

- Increased potential for clerical discrepancies when manually transferring data among various modeling tools.
- Cumbersome and time-consuming workflows that limited rapid scenario testing.
- Variability in the granularity and consistency of results.
- Subjectivity and variations in the representation of surface and subsurface flow interaction at critical design points.

Recognizing these shortcomings, CCD adopted ICM as its unified modeling platform in 2024. This approach builds on lessons learned from previous methods while resolving many of the inefficiencies and inconsistencies exhibited in previous efforts. By integrating 1D and 2D processes into a single modeling environment and supporting RoM hydrology, ICM provides a streamlined, transparent, and technically rigorous software platform for future stormwater studies. The accuracy and level of detail provided by this approach also positions future capital improvement projects for success – recommendations are more technically robust and defensible, and the planning model is ready to support detailed design work.

Looking ahead, CCD intends to apply the new modeling approach across all drainage basins within its jurisdiction. Establishing a consistent methodology will:

- Create a common technical foundation for system-wide planning.
- Ensure stormwater infrastructure improvements are evaluated using comparable assumptions and metrics.
- Improve the efficiency of model development, review, and iteration.
- Support seamless integration with neighboring stormwater agencies at jurisdictional boundaries.

By using a single modeling framework—supported by shared data structures, repeatable processes, and standardized outputs—CCD aims to produce a citywide stormwater system assessment that is technically robust, easier to maintain, and adaptable to future development and climate considerations.

This document serves as a technical reference for CCD staff, engineering consultants, and partner agencies engaged in stormwater modeling to support planning and design within CCD. It is intended for professionals who already possess a strong understanding of hydrologic and hydraulic theory, stormwater engineering principles, and numerical modeling concepts. These Guidelines are not intended as an introduction to modeling fundamentals and instead focus on:

- A clear framework for how ICM should be applied in CCD stormwater studies.
- Recommended modeling practices that support consistency, defensibility, and efficiency.
- Practical guidance on data preparation, model construction, troubleshooting, and results presentation.
- Shared expectations that reduce unnecessary variability across modeling teams.

More importantly, the Guidelines are intended to support engineering judgment—not replace it. They describe recommended methods that have been vetted through CCD's modeling experience but are not meant to function as rigid rules. Flexibility is essential when dealing with diverse terrain, unique infrastructure conditions, or emerging technologies. Deviations from these guidelines are acceptable where warranted by project-specific needs, provided they are well-documented and coordinated in advance with CCD staff and stakeholders.

As CCD transitions into a unified modeling environment, a concise and accessible reference is necessary to:

- Ensure modeling practices remain consistent across projects and consultants.
- Communicate expectations clearly to new partners or project teams.
- Promote efficiency by reducing rework and redundant decision making.
- Capture institutional knowledge gained through prior basin-scale modeling.
- Provide transparency and repeatability in how results are generated and decisions are made.

This shared modeling approach will allow CCD and its partners to more confidently evaluate system performance, identify risk, and develop resilient stormwater infrastructure solutions. These Guidelines support that mission by equipping practitioners with the tools, context, and recommended practices needed to build models that are both technically sound and operationally practical.

2.0. Modeling Approach Overview

CCD's transition to a unified ICM modeling platform is summarized in the technical memorandum *2025 Hydraulic and Hydrologic Modeling Guidance* (Stantec, 2025). That memorandum explains previous modeling approaches, the rationale for adopting ICM, and the technical considerations supporting this transition. This section focuses on establishing the general modeling framework that underpins all CCD ICM based stormwater studies. The intent is to give practitioners a clear understanding of how the various components of the modeling workflow like data sources, terrain and asset preparation, model development, simulation setup, and post-processing of results fit together within CCD's standardized approach. By outlining these foundational concepts, this section provides context for the more detailed guidance that follows and ensures that project teams share a common understanding of how inputs, model structure, computational methods, and outputs interact across the full lifecycle of an ICM model.

2.1. InfoWorks ICM Database Structure

The file structure used by ICM represents a fundamental shift from the standalone model files that many practitioners are familiar with in software such as EPA SWMM, XPSWMM, HEC-RAS, or PCSWMM. Rather than maintaining multiple independent input files, ICM organizes model components within a unified database environment. This architecture consolidates hydraulic and hydrologic inputs, boundary conditions, terrain data, and simulation settings in a consistent, centrally managed structure as shown in Figure 1. For users transitioning from traditional file-based workflows, this section provides an overview of how the ICM database is organized, what each file type represents, and how simulations are created by linking these components. The intent is to clarify the functional role of each element without prescribing a single workflow, allowing modelers to adopt practices that fit their project needs while taking advantage of ICM's integrated framework. Descriptions of ICM database file types required for the approach outlined in these guidelines are summarized below.

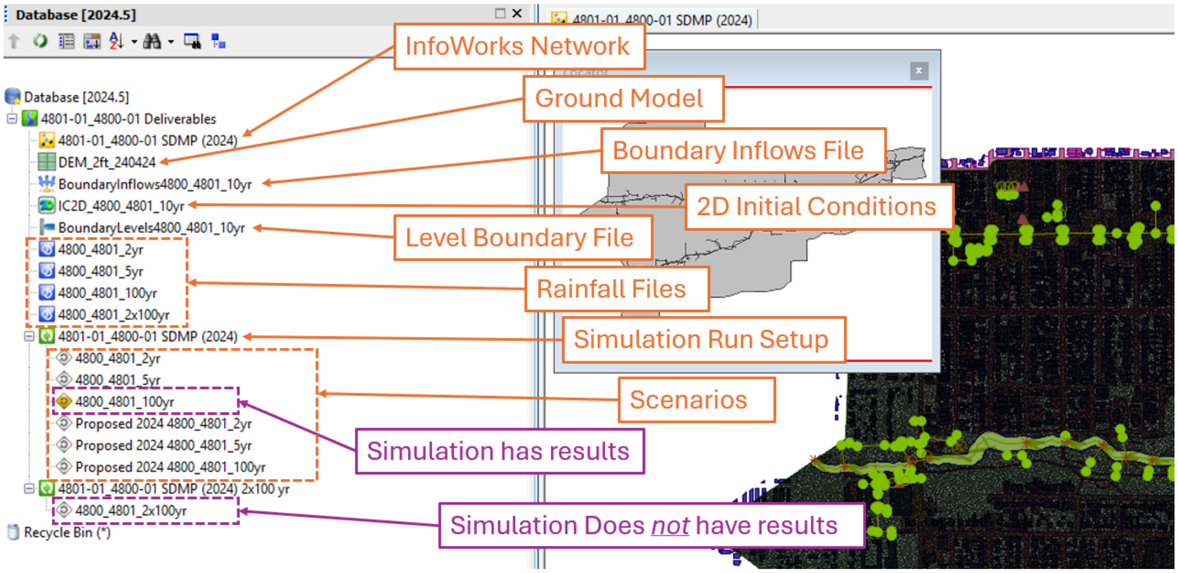


Figure 1 Example ICM Database Contents

InfoWorks Network

The network is the core representation of the ICM model—what most practitioners associate with “the model file.” It contains the hydraulic network (pipes, nodes, channels, structures), 2D mesh configuration, hydrologic elements, and associated parameters. Although it stores the spatial and tabular definition of model assets, it references several external files (e.g., ground model grids, time series inputs) rather than embedding them, allowing the model database to remain efficient and modular.

Ground Model Grid

The ground model grid stores the terrain used by ICM for building the 2D mesh and assigning ground elevations to hydraulic elements. Because terrain datasets are large, ICM saves this information separately from the InfoWorks Network to improve file performance and retrieval speed. The ground model grid is an essential input—many model components (manhole rims, inlet ground elevations, 2D elements) rely on it for elevation assignment.

Rainfall

Rainfall files contain time series hyetograph inputs used to drive both hydrologic and hydrodynamic components. These can mimic point-based rain gauge data (similar to SWMM’s gauge definition) or represent spatially varying rainfall patterns for RoM simulations. A single rainfall file can store multiple events, each referenced within a simulation as needed.

Level

Level files store boundary condition water surface elevation time series. These are typically applied at downstream outfalls, river boundaries, or ponds that interact with external water bodies. Each time series within a level file is indexed to a corresponding asset ID, allowing multiple boundaries to be organized within one file.

Inflow

Inflow files contain discharge hydrographs used as boundary conditions at upstream nodes, river inflows, or other controlled entry points. As with level files, multiple hydrographs can be stored together and assigned to specific model locations through asset IDs.

Initial Conditions 2D

Initial Conditions 2D files allow users to define water surface elevations and soil water content across portions of the 2D mesh. These are particularly useful for scenarios involving rivers, ponds, baseflow, or antecedent storm conditions, helping stabilize initial model behavior and reduce warmup time. Initial Conditions 2D files may also include infiltration initial condition data. However, for CCD's discrete storm simulations, infiltration initial conditions are generally not applicable and are not used.

Run File

The run file (or simulation file) brings the entire model together. It references the InfoWorks network, rainfall inputs, boundary condition files, initial conditions, and all other supporting datasets needed to execute a simulation. It also stores key simulation parameters such as routing time step, reporting interval, convergence settings, logging levels, and output management. In essence, the run file defines *what* is being simulated and *how* the simulation will operate.

2.2. Data Sources

Developing an ICM model from scratch requires assembling a combination of GIS datasets, standardized elevation and soils data, previously developed hydrologic/hydraulic models, and project-specific field information. The goal is to establish a reliable base dataset while allowing engineering judgment to guide how each source is applied or supplemented.

2.2.1. City and County of Denver GIS Data

The CCD Open Data Catalog (https://opendata-geospatialdenver.hub.arcgis.com/) provides the foundational geospatial layers needed for most model builds. These datasets represent the most up-to-date systemwide information and should serve as the basis for model construction:

- Storm Collection System Boundaries
- Storm Sewer Mains (pipes)
- Storm Manholes
- Storm Inlets
- Storm Outfalls
- Storm Fittings
- Storm Detention and Water Quality Facilities
- Collection System Sub-Basin Boundaries
- Natural Stream Network
- Building Outlines (2022)
- Comprehensive Citywide Impervious Surfaces

The following CCD-hosted stormwater infrastructure data are available upon request from Department of Transportation and Infrastructure (DOTI) and should be referenced as supplemental sources during model construction:

- Cleanout
- Structure
- BMP Point
- Pump
- Weir
- Open Channel
- Culvert
- Linear Drain
- Topographic Basin Boundaries

The CCD Open Data Catalog and supporting datasets should be treated as the primary starting point for model development because it provides the most current systemwide asset layers in a consistent format. However, these datasets should not be assumed complete or free of errors. Modelers should validate key features during model build and supplement with the additional sources described in the sections that follow where higher confidence is needed.

2.2.2. Denver Regional Council of Governments Regional Data Catalog

A high-resolution ground surface Digital Elevation Model (DEM) obtained from the Denver Regional Council of Governments (DRCOG) Regional Data Catalog (http://data.drcog.org/dataset/lidar-ql2-index-in-co-sp-central-2020) is also a fundamental component of the model build. The “Lidar QL2 Index in CO SP Central 2020” dataset covers CCD extents, and the raster (.tif) of study areas can be downloaded to provide the primary terrain representation used to generate the 2D ground model. This source should serve as the base elevation dataset, unless more recent or higher quality LiDAR-derived elevation data are available. The use of any alternative DEM data source shall be coordinated and approved by the CCD project manager. DRCOG datasets may also be used to extend study area model domains beyond CCD limits into adjacent jurisdictions where CCD GIS coverage is unavailable. However, where equivalent CCD datasets exist, the CCD Open Data Catalog remains the preferred and authoritative source.

2.2.3. Additional Data Sources

While the CCD and DRCOG GIS data form the backbone of the model, they should be evaluated for completeness and accuracy. Where gaps or inconsistencies are identified, modelers may incorporate the following supplemental data sources as appropriate to the project:

- **As-built drawings and design plans –** Useful for confirming pipe characteristics, inverts, inlet types, detention facility characteristics, and other asset attributes when GIS data is outdated or incomplete. These documents can validate assumptions or correct discrepancies identified during technical review of data for reliability and accuracy.
- **Soil classification data from the US Department of Agriculture (USDA)/Natural Resources Conservation Service (NRCS) Soil Survey Geographic (SSURGO) database –**

Provides soil group information to support infiltration zone development, Horton parameter selection, and general hydrologic characterization where more detailed geotechnical information is unavailable or as a basis for model parameter calibration.

- **Mile High Flood District (MHFD) HEC-RAS models –** These are especially valuable along jurisdictional boundaries or major waterways where upstream or downstream conditions have already been studied. Riverine cross sections, hydrology, and boundary conditions may be referenced to ensure consistency between agencies.
- **Ground surface elevation surveys –** High-resolution LiDAR is the basis for the DRCOG DEM mentioned above. In cases where substantial construction has modified the ground surface after the flyover used for the DEM, modelers should resample the regional DEM with more recent LiDAR flyover information and/or post-construction finished grade elevations.
- **Supplemental field measurements –** Spot elevation checks, inlet and manhole rim verification, pipe size confirmation, and documentation of atypical or unmapped features can substantially improve confidence in the model setup, particularly in areas where the GIS or DEM shows inconsistencies.

Taken together, these datasets provide a flexible but complete framework for building a reliable ICM model. Modelers are encouraged to use professional judgment when integrating or substituting data sources, especially in locations where terrain, infrastructure, or system connectivity is complex. The intent is to develop a consistent, defensible model without imposing rigid or overly prescriptive data requirements.

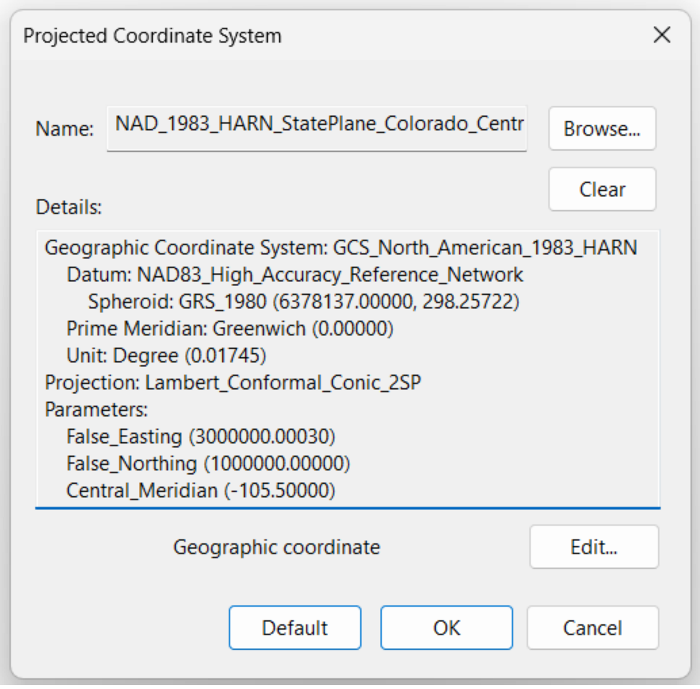
2.3. Governing Assumptions

The development of any ICM model relies on a set of governing assumptions and baseline parameters that guide how terrain, hydrology, hydraulics, and numerical controls are represented. These assumptions do not function as strict requirements; rather, they establish a consistent technical foundation that supports model stability, defensibility, and comparability across studies. The following statements summarize the key assumptions and parameters commonly applied in CCD stormwater modeling efforts. Each item is presented as a standalone guideline so modelers can understand its role within the ICM framework and adapt it as needed based on project-specific conditions, engineering judgment, and available data.

Horizontal Datum

All models should be built in the NAD83 Colorado Central State Plane coordinate system using units of US Survey Feet (Colorado [FIPS] 0502, Central Zone (1983 HARN, US Survey feet) [EPSG 2877]) as illustrated in Figure 2.

Note: ICM can display any units desired but saves and calculates all data in metric units. The difference between ‘US Survey Feet’ and ‘International Feet’ has non-negligible influences on model build and post-processing and modelers should be cognizant of influences of this setting.



Name: NAD_1983_HARN_StatePlane_Colorado_Centr

Details:

Geographic Coordinate System: GCS_North_American_1983_HARN
Datum: NAD83_High_Accuracy_Reference_Network
Spheroid: GRS_1980 (6378137.00000, 298.25722)
Prime Meridian: Greenwich (0.00000)
Unit: Degree (0.01745)
Projection: Lambert_Conformal_Conic_2SP
Parameters:
False_Easting (3000000.00030)
False_Northing (1000000.00000)
Central_Meridian (-105.50000)

Geographic coordinate

Figure 2 ICM Projected Coordinate System Settings

Vertical Datum

All models should be built in the NAVD88 vertical datum so that models can be stitched together easily and regional boundary conditions may be applied without transformation.

Topographic and Bathymetric Data

Accurate terrain representation is a fundamental assumption underlying all RoM modeling including ICM. The DEM should be reviewed for fitness and accuracy before it is used to populate elevations within the model. This review typically includes checking for areas where recent construction may have altered the ground surface, locations where construction activity was underway during the LiDAR flyover, and instances where perennial water bodies prevented LiDAR from capturing the true bed elevation. In addition, modelers should confirm whether the DEM has removed or modified features such as bridges, buildings, or other structures, as these edits can influence how ground elevations are assigned to 1D and 2D elements. The intent of this review is not to require exhaustive verification of every feature, but to ensure that modelers recognize where DEM limitations may influence results and apply engineering judgment when supplementing or adjusting terrain data.

Upstream Boundary Inflows

Upstream boundary inflows should be applied at the open channel water bodies located along the outer limits of the CCD modeling domain. These inflows represent the discharge entering the modeled drainage system from upstream watersheds and are a required component of establishing realistic riverine and gulch conditions at the model boundary.

To ensure consistency with regional hydrology, upstream inflow values should be extracted from MHFD–administered HEC-RAS riverine models. These models provide standardized hydrologic and hydraulic conditions for major waterways and should be used as the authoritative source for boundary inflow information.

MHFD riverine models are the preferred basis for defining upstream boundary inflows. However, model availability and quality may vary by location. Models and supporting documentation should be requested from MHFD staff who can also confirm that the model is up to date and reliable for the intended use(s). Where no model exists or where the available model is considered unreliable, upstream boundary inflows should be developed using engineering judgment and defensible hydrologic methods (e.g., prior CUHP version 1.4–derived inflows, CUHP version 2.0 calculations, or other industry accepted approaches), with all assumptions, data sources, and methods clearly documented.

Typical applications include:

- Constant inflow rates which represent a specified return period (e.g., 2-, 10-, 100-year events) when a steady inflow boundary is appropriate for the study.
- Temporally varying hydrographs, applied as a dynamic inflow time series, to model historical events or design storms where peak flow timing and shape of the hydrograph influence water levels and flood behavior.

The chosen inflow type should align with the study’s objectives and the availability of supporting hydrologic information. Regardless of approach, upstream inflow boundary conditions should be clearly documented in both the flow file properties description and any accompanying reports, including their source, return period (if applicable), and any modifications applied to ensure seamless integration at the CCD boundary.

Downstream Boundary Tailwater

A downstream tailwater condition should be applied at the downstream end of the ICM model to account for the influence of major waterways (such as the South Platte River) without requiring the model to dynamically simulate the full extent of the regional river system. Applying a water surface elevation boundary at these downstream locations ensures that backwater effects, water surface controls, and stage driven interactions with the local drainage system are represented accurately and consistently.

Downstream water surface elevations should be extracted from MHFD–administered HEC-RAS riverine models and Flood Insurance Study (FIS) reports. These models provide standardized stage information for major waterways and should serve as the authoritative source for defining tailwater conditions.

Typical applications include:

- *Constant water surface elevations* representing a specified return period (e.g., 2-, 10-, 100-year events) are appropriate when a steady tailwater condition is sufficient for the study. These are typically derived from FIS reports.

- *Temporally varying stage hydrographs*, applied as a dynamic time series, should be used when modeling historical storms or design events where the timing and magnitude of downstream stages influence system performance.

The selected tailwater approach should reflect the study objectives and the availability of supporting hydrologic and hydraulic information. It should be noted that these boundary conditions can be applied to both 1D elements (such as an outfall) or as a linear boundary along the edge of the 2D mesh. All downstream boundary conditions should be clearly documented, including their source, return period (if applicable), and any adjustments made to ensure smooth integration with the modeled drainage system.

Simulation Duration

The duration of a simulation should be set using engineering judgment to ensure that all pertinent storm influences are fully captured. The appropriate simulation duration will depend on the objectives of the analysis and the hydrologic and hydraulic processes most relevant to the study.

In some cases, it may be sufficient to run the model through the rising limb and peak of the storm. This is often appropriate for alternatives analyses focused only on peak flow rates. However, evaluations involving storage performance, drawdown behavior, or recession limb hydraulics will require longer simulation durations. Extended runtimes allow the model to capture drain-out timing, storage recovery, and the return of system conditions to pre-storm levels.

Because the required duration varies by watershed, storm type, and analytical goals, no single prescriptive simulation duration is recommended. Instead, modelers should select a duration that ensures the full hydrologic response of interest is represented while avoiding unnecessary runtime beyond what is needed for defensible results.

Mesh Specifications

The 2D mesh plays a central role in determining how accurately terrain features, flow patterns, and water surface gradients are represented within the model. While finer mesh elements can improve resolution and hydraulic detail, they also increase computational effort. Therefore, mesh specifications should be selected using engineering judgment to balance accuracy, model stability, and project schedule.

Element sizes in ICM are governed by the meshing parameters assigned to the 2D Zone (see Section 4.1) and any supplemental mesh refinement polygons. For production simulations (simulations intended for final mapping and publication to CCD’s GIS), modelers should use the standardized meshing parameters described in Section 4.0 to ensure consistent resolution and comparability across all CCD study areas. These production settings provide a uniform foundation for generating Urban Flood Risk Area (UFRA) layers and other deliverables that rely on consistency across study areas.

During model development or alternatives analysis, however, modelers may apply coarser mesh parameterization to improve computational efficiency. A less granular mesh can be appropriate for preliminary screening, rough design assessments, or sensitivity testing where the goal is to compare alternatives rather than produce publishable outputs. Coarser meshes should still capture major topographic controls and flow paths, but do not need the full refinement of the production configuration.

Ultimately, the mesh resolution should be tailored to the needs of the task at hand—granular enough to represent key hydraulic processes but not so detailed that run times become burdensome or delay project delivery. Engineering judgment remains essential in determining when increased resolution provides meaningful benefit and when a streamlined mesh is sufficient.

Representation of Surface Features

ICM provides multiple ways to represent surface features, either through 1D hydraulic elements or as part of the 2D mesh. The appropriate approach should be selected using engineering judgment, based on project objectives, available data, and the need to balance accuracy with computational efficiency.

In general, creeks, gulches, and other open channel waterways are preferred to be represented as 1D river reach elements, similar to their treatment in HEC-RAS. This approach offers several advantages:

- 1D elements allow for more stable and efficient initialization, particularly because river reaches can be initialized using boundary conditions rather than requiring a warmup period in the 2D domain.
- Base DEM data typically cannot capture underwater channel geometry, meaning 2D only representations may misrepresent bed elevations or inadvertently introduce artificial storage.
- Modeling gulches and ponds as 1D elements reduces unnecessary computational burden without sacrificing hydraulic fidelity.

Because of these benefits and the importance of runtime efficiency for alternatives analysis representing these features as 1D components should be considered the default approach for CCD modeling. However, modelers retain the flexibility to represent certain surface features within the 2D mesh where appropriate. In some cases, local topography, project needs, or unique infrastructure conditions may make a 2D representation acceptable or preferable. When doing so, modelers should ensure that the chosen approach still accurately conveys expected flow paths, storage behavior, and hydraulic connectivity.

Regardless of representation, care must be taken to avoid “double counting” storage or conveyance capacity. If a gulch or channel is modeled using 1D river reach elements, its area is removed from the 2D mesh, meaning it will not receive rainfall unless subcatchments are explicitly added to represent that contribution. Likewise, when surface features are modeled in 2D, modelers must confirm that no parallel 1D representation duplicates the same physical storage or conveyance.

Ultimately, the selection of 1D versus 2D representation should reflect the specific objectives of the analysis, terrain conditions, data availability, and the need to maintain efficient yet defensible model performance. These guidelines are intended to support consistent practice while allowing the flexibility necessary to accommodate the diverse conditions present across CCD watersheds.

Calibration and Verification

All hydraulic and hydrologic models are approximations of real-world conditions. As such, calibration and verification are essential steps in increasing confidence that the model parameters, assumptions, and resulting predictions reflect actual system behavior as closely as practical. Calibration allows the modeler to refine the mathematical parameterization of individual assets and hydrologic inputs so that simulated performance more closely aligns with measured or observed field conditions.

Where data is available, calibration should be performed using reliable quantitative measurements, such as temporary flow meters installed in the collection system, water surface level gages installed in open channel water bodies, high water marks, or other hydraulic monitoring data. These records help modelers evaluate how well the system responds during storm events and provide a basis for adjusting parameters such as roughness, infiltration rates, storage characteristics, and/or operational assumptions.

Model verification can also be supported by historical storm events, using information such as observed flooding locations, depth estimates, or qualitative field observations. Maintenance records, DOTI flooding service request logs, and other documented events can offer valuable insight into where flooding has historically occurred and the severity of those conditions. Comparing these real-world observations to simulated results helps confirm whether the model is capturing key system behaviors, particularly in areas where instrumentation may be limited.

Although CCD has not historically performed this level of model calibration for past stormwater studies, incorporating calibration and verification into the unified modeling framework is a crucial step toward ensuring that model outputs are both reliable and defensible. Calibrated models improve confidence in alternatives analyses, risk assessment, and recommended improvements, ultimately strengthening the quality and credibility of planning-level and design-level decisions informed by these simulations.

Software Version

All testing and the first nine basins developed for the 2025 SDMP under this unified modeling framework were completed using ICM version 2024.5. As with any actively maintained software, continuous improvements are made to enhance functionality, improve stability, and streamline user experience. Because of this ongoing development, these guidelines do not prescribe a single required software version for future studies, other than the recommendation that no version older than 2024.5 should be used.

In general, it is advantageous for project teams to adopt the most recent stable version available at the onset of a study, then maintain that version consistently through project completion. This approach minimizes unexpected discrepancies in results, avoids complications introduced by mid-project version changes, and helps ensure compatibility across model components.

However, modelers should apply professional judgment when selecting a version for their study, particularly when considering factors such as project timelines, other ongoing CCD modeling efforts, team-wide software availability, and version stability. The intent of these guidelines is not to impose rigid constraints but to promote consistency and reliability while ensuring that all studies are conducted using a modern and fully supported version of the modeling software.

To support reproducibility, the ICM software version used for model development and for each final simulation run should be documented in the deliverable. If a model is advanced to a newer software version during a study, the version change and rationale should be documented, and key results should be spot-checked to confirm that differences (if any) are understood and acceptable. When a model or study area is revisited in the future, the existing model version should be retained where practicable and only updated when necessary (e.g., to address compatibility, stability, or required functionality), to avoid introducing version-related variability and associated re-checks.

Data Source Flagging

One of the key advantages of ICM is its ability to cite data sources directly within individual model parameters, allowing modelers to track how each value was assigned and enabling future users to quickly understand the provenance of the information used during model development. To support this capability, CCD has established a preliminary set of standard data flags that should be used to identify the origin, method, or level of verification associated with specific model inputs. These flags provide a consistent shorthand for documenting assumptions and data lineage. Figure 3 illustrates CCD's preferred color symbology for each standard data flag. The CCD standard flag set (including names and colors) can be provided by CCD staff upon request in .csv format for import into project database(s). The application case for each flag is described below.

AS – Assumed Value

Description – Value assigned based on engineering judgment.
Uses – Data gaps or suspected erroneous data must be reconciled but no defensible external data source is available to reference.
Not applicable when – Value is interpolated from other data sources.
Example – A "dummy" node is created to represent the storage component of a green stormwater infrastructure facility underneath an artificial turf baseball field. The node ID for this asset and any parameters not extracted from drawings or other studies should use the AS flag.

ASB – As-Built

Description – Value assigned based on as-built drawings.
Uses – Exclusively for drawings labeled "as-built".
Not applicable when – Values come from design drawings or other record drawings not clearly marked "as-built".
Example – Pipe diameter not populated in GIS data and taken directly from as-built drawing set.

DEM – Digital Elevation Model

Description – Value assigned from LiDAR based digital elevation model using built-in ICM inference function.
Uses – Populating the "ground level" field for all nodes except where survey data is provided.
Not Applicable When – Source of ground level data is not from DEM.
Example – Node ground level.

DV – Digitized from Visual Verification

Description – Value assigned from visual verification using aerial imagery, google street view, etc.

Uses – Data gaps or suspected erroneous data are reconciled by visual verification.

Not Applicable When – Assumptions are made based on engineering judgment not aided by aerial imagery or google street view.

Example – An inlet is observed on Google Street View but missing from the GIS, the node ID and coordinates fields should be flagged as DV.

FHAD – Flood Hazard Area Delineation Study

Description – Values taken from Flood Hazard Area Delineation Study.

Uses – Hydraulic parameters and features of permanent water bodies and reservoirs

Not Applicable When – Values are extracted from drawings sets referenced by FHAD study

Example – Pond elevation vs area arrays.

FV – Field Verification

Description – Values assigned based on field measurement.

Uses – Information collection during field survey efforts.

Not applicable when – Values are based on as-built drawings or other record drawings.

Example – Manhole rim elevation and coordinates.

GIS – Geographic Information System

Description – Values imported from CCD hosted shapefiles.

Uses – Preliminary import of network information using Open Data Import Center.

Not Applicable When – Values have been changed from GIS-based on other sources.

Example – Node IDs and coordinates, pipe diameters, invert elevations, etc. that have been imported directly from CCD GIS datasets.

GOR – GIS Data Override

Description – Values changed from attribute information in CCD GIS data.

Uses – When imported GIS values are deemed unreliable or erroneous, this flag may be used in place of AS. The purpose is to document GIS assets that require updates.

Not Applicable When – GIS data is overridden by DV flag from visual inspection, or any other sources such as field survey, as-built drawings, etc.

Example – CCD GIS information indicates a 12-inch diameter pipe while both the incoming and outgoing pipe are 48-inch diameter. Update the diameter to 48-inches to match the size of the incoming and outgoing pipes and flag as GOR.

INF – Inference

Description – Value assigned from ICM built-in inference functions (except ground level inference, which uses a unique ‘DEM’ flag).

Uses – Data gaps or suspected erroneous data are reconciled by ICM inference functions.

Not applicable when – The value is assumed or manually changed by a user.

Example – Pipe invert elevations are populated using built-in inference functions that interpolate between known points.

INT – Interpolated

Description – Interpolated using GIS function prior to ICM import.

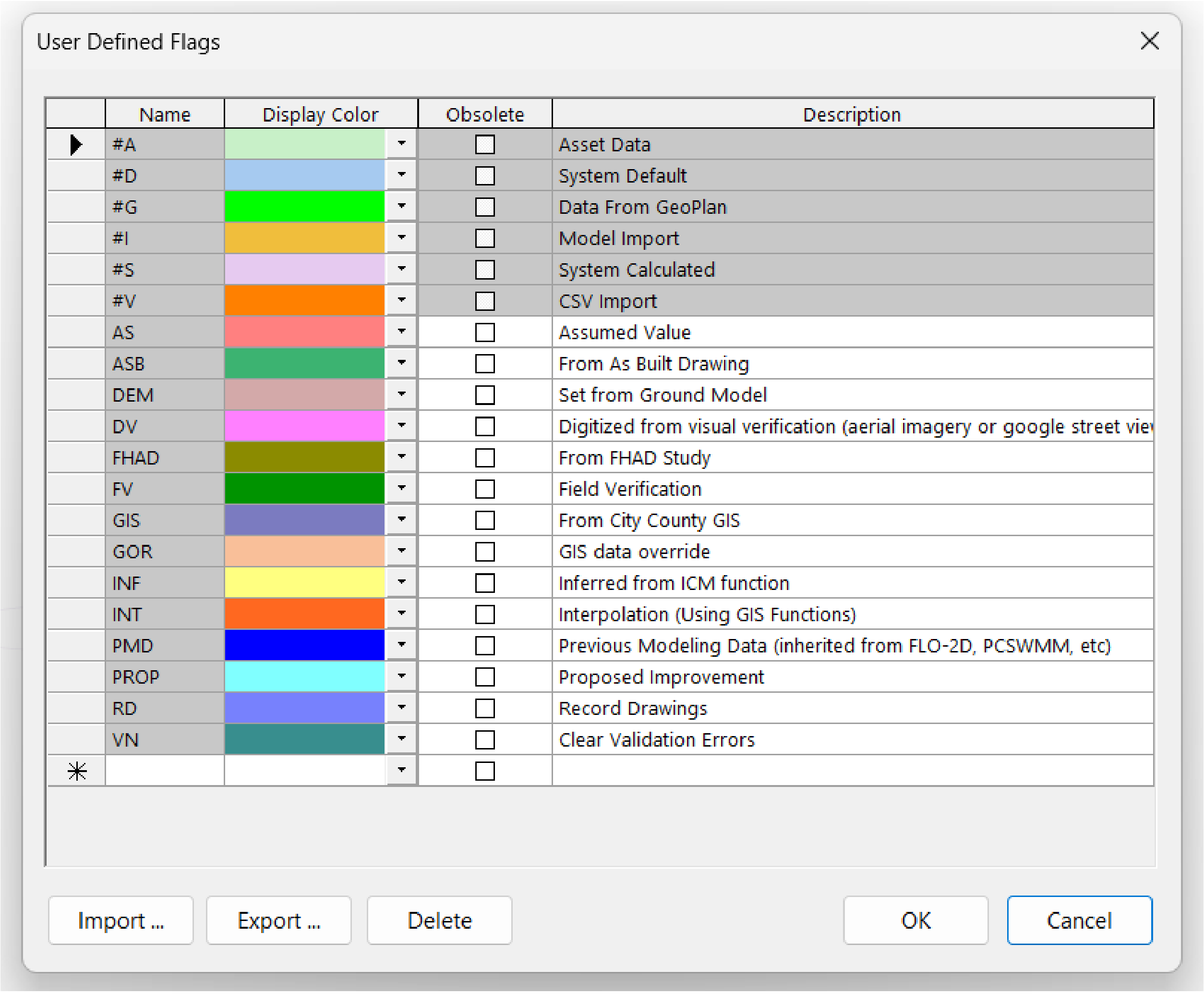
Uses – Data gaps and errors are so prevalent that data clean up, review, and modification is required before the initial import into ICM.
Not Applicable When – Values are interpolated using the built-in ICM inference functions.
Example – Pipe invert elevations missing from GIS are populated using excel spreadsheets or scripted functions in GIS prior to importing into the ICM software package.

PMD – Previous Modeling Data
Description – Modeling data inherited from previous modeling efforts such as from FLO-2D, PCSWMM, or HEC RAS models.
Not Applicable When – Previous models have simplified representations (for example: three short pipes consolidated into a single asset), and assets must be split apart for an explicit 1:1 representation.
Example – Representation of sub-surface storage facilities, such as storage arrays and drain-out rates, may be copied directly from previous model efforts.

PROP – Proposed
Description – Associated with recommended / proposed improvements.
Uses – New project alignments for alternatives analysis.
Not applicable when – Project is in 100% design phase or under construction (these should be flagged with RD or ASB).
Example – New project alignments should use this flag for Node IDs, pipe diameters, and invert elevations.

RD – Record Drawing
Description – Value assigned from record drawings.
Uses – Missing or erroneous value in GIS is replaced with value from drawings.
Not applicable when – The record drawings are specifically as-built drawings, in which case the ASB flag should be used.
Example – Missing pipe diameter from GIS data is updated using design drawing information.

VN – Validation Warning
Description – Value is adjusted from GIS, drawing, or default to remove warning message(s) encountered during network validation.
Uses – When a data field is updated solely for the purpose of clearing out validation messages.
Not applicable when –AS flag would be more appropriate.
Example – When node chamber or shaft plan area are set to default and the value is smaller than the simulation minimum plan area.



	Name	Display Color	Obsolete	Description
▶	#A	🟩	☐	Asset Data
	#D	🟦	☐	System Default
	#G	🟩	☐	Data From GeoPlan
	#I	🟨	☐	Model Import
	#S	🟪	☐	System Calculated
	#V	🟧	☐	CSV Import
	AS	🟥	☐	Assumed Value
	ASB	🟩	☐	From As Built Drawing
	DEM	🟫	☐	Set from Ground Model
	DV	🟪	☐	Digitized from visual verification (aerial imagery or google street vie
	FHAD	🟫	☐	From FHAD Study
	FV	🟩	☐	Field Verification
	GIS	🟦	☐	From City County GIS
	GOR	🟧	☐	GIS data override
	INF	🟨	☐	Inferred from ICM function
	INT	🟧	☐	Interpolation (Using GIS Functions)
	PMD	🟦	☐	Previous Modeling Data (inherited from FLO-2D, PCSWMM, etc)
	PROP	🟦	☐	Proposed Improvement
	RD	🟦	☐	Record Drawings
	VN	🟩	☐	Clear Validation Errors
✳			☐	

Figure 3 User Defined Flags

While the flags shown in the figure represent the standard set required for submissions to CCD, modelers may create and use temporary, project-specific flags during model construction. This set is preliminary, and additional CCD standard flags may be added in future updates, as agreed upon with CCD staff. These supplemental flags can help teams coordinate edits, track interim decisions, or manage workflows involving multiple contributors. Any such temporary flags should be replaced with the appropriate CCD standard flags before final delivery.

The intent of the flagging framework is not to constrain modeling workflows but to ensure a transparent, traceable record of how each parameter was assigned. Consistent application of data flags supports model defensibility, facilitates team-wide coordination, and provides future modelers with the context needed to understand and confidently build upon prior work.

Commenting and Notes

Effective documentation within an ICM model is essential for ensuring transparency, clarity, and continuity across project teams and future users. While these guidelines are not intended to require exhaustive narrative descriptions, modelers should provide concise, high-level notes that explain key data sources, assumptions, and adjustments made during model development. This practice helps prevent misinterpretation, supports defensible decision making, and allows subsequent users to quickly understand the provenance and intended use of critical model components.

Modelers should include brief but informative descriptions in the property fields of external files (ground models, inflow or level files, and initial conditions) summarizing where the data originated and how it is intended to be used. Where applicable, these descriptions should also note the spatial reference information (vertical datum and coordinate system/projection) for the dataset, particularly for ground model grids, to support model portability and future reuse. These entries allow future users to identify data lineage without having to retrace sourcing steps or decipher undocumented assumptions. Maintaining this level of transparency is consistent with the intent of the model development checklist and documentation expectations included elsewhere in the guidelines.

In addition, when modelers modify or adjust specific components within the model to address data gaps, inconsistencies, or inaccuracies, they should leave a concise explanation in the element's "Notes" field. These notes should briefly describe the rationale for the modification. For example: correcting an elevation anomaly, adjusting a roughness value based on field conditions, or applying engineering judgment to resolve missing GIS attributes. The goal is not to provide exhaustive justification, but to leave a clear reference that helps future modelers understand why a change was made and avoid misapplication of the model structure.

This level of documentation ensures that the model remains a transparent, traceable, and defensible engineering product. It also supports CCD's broader objectives of consistent, high-quality model development across study areas and provides future teams with the context needed to maintain or refine the model effectively.

2.4. Recommended Workflow

The sequence in which model components are built has a significant influence on efficiency, clarity, and the ability to resolve data gaps without becoming overwhelmed by simultaneous validation issues. Based on experience developing the initial study area models under CCD's unified modeling framework as part of the 2025 SDMP, the following high-level workflow, as depicted in Figure 4, is recommended to streamline model construction, review, and results production.

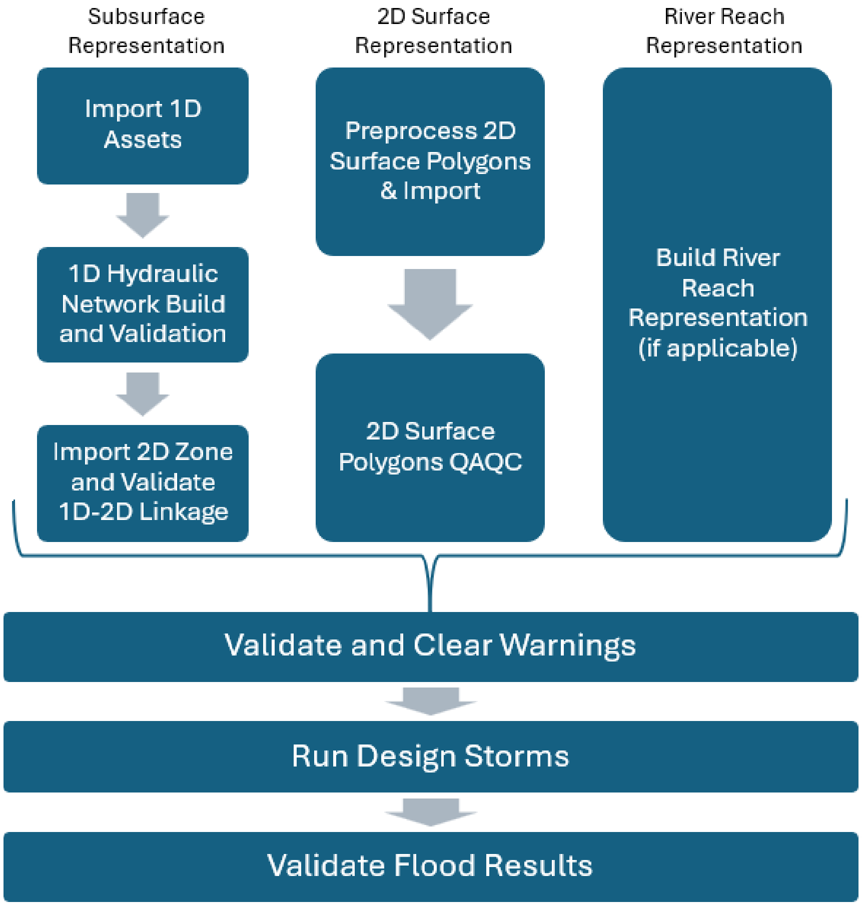


Figure 4 Workflow Chart

The most efficient starting point is to build the 1D hydraulic network first, as described in Section 3.0. During this phase, all nodes should be temporarily assigned a default ‘Flood Type’ of Stored to facilitate an efficient model build and prevent premature surface–subsurface interaction. This setting will be updated in the subsequent step once the 2D zone has been created and the model is ready for more detailed configuration. Establishing manholes, inlets, pipes, and initial connectivity early allows modelers to resolve errors using ICM’s built-in validation tools before additional layers of complexity are introduced. Addressing issues in this stage prevents situations where validation messages from multiple components overlap, making it difficult to isolate the source of discrepancies. When using this approach, modelers should note that imported outfall nodes may later require removal or rerouting if the project includes explicit 1D representation of major open channel drainage features such as gulches or creeks.

After the 1D network is validated, the next step is to define the 2D Zone boundaries, switch the manhole settings from *Stored* to ‘*Gully 2D*’, and create an initial mesh without adding roughness zones, infiltration zones, mesh zones, or other surface feature polygons. At this stage, the intent is not to simulate the model but to run the built-in validation checks to confirm that the 1D and 2D components link correctly and that the mesh adequately represents the terrain.

Note: if significant data gaps exist, it may be advantageous to set the manhole flooding type to ‘2D’ before ‘Gully 2D’ to complete validation checks.

Once 1D–2D connectivity is verified and validation checks pass, the modeler should import the remaining 2D surface feature polygons, following the guidance in Section 4.0. This includes infiltration zones, roughness zones, mesh zones, buildings, walls, and other 2D modifiers needed to accurately represent surface hydrology and hydraulics.

With these elements in place, the final major structural component is the representation of the primary stormwater drainageway (the gulch or creek) constructed using the procedures described in Section 5.0. During this step, modelers will incorporate river reaches, bank lines, and storage elements as needed and will also revise the preliminary 1D outfalls created earlier so that all components form a fully connected, contiguous network.

After the major structural components of the model have been assembled, the next step is to test the completed model build using design storms. These test simulations help confirm that the model runs efficiently, that numerical behavior is stable, and that the hydraulic response is defensible before alternatives analysis or detailed scenario evaluations begin. Running representative storm events at this stage provides an opportunity to identify missing connectivity, inconsistent parameterization, or unintended flow behavior, ensuring that any issues are addressed early and that the model is ready to support reliable decision making.

CCD requires all warning messages to be cleared in finalized model submissions. This expectation helps prevent the masking of important issues, reduces the potential for misapplication of parameters, and ensures that project teams and future users can trust that the model has been constructed and reviewed with a high-level of technical rigor.

3.0. Hydraulic Modeling – 1D Subsurface Network

The construction of the 1D subsurface collection system network forms one of the core foundations of CCD's unified stormwater modeling approach. While Section 2.0 introduced the overarching framework and data sources that support model development, this section focuses on how those inputs are translated into the hydraulic components that represent the underground collection system. Together, these elements (manholes, inlets, fittings, pipes, outfalls, and related structures) define how runoff is conveyed below the surface and how it interacts with the 2D domain.

A core principle of this modeling framework is to develop a 1:1 representation of publicly owned subsurface stormwater infrastructure, preserving individual assets wherever feasible and minimizing simplification. This level of fidelity ensures that the collection system functions hydraulically in the model in a manner consistent with how it operates in the field, supports clear traceability between GIS datasets and modeled features, and facilitates defensible alternatives analyses.

Developing a reliable subsurface network requires translating diverse datasets into a coherent hydraulic system, reconciling differences in GIS completeness, addressing known data gaps, and applying engineering judgment where field information or as-built documentation is limited. The intent of this section is to outline the recommended practices for representing these assets within ICM so that the resulting model behaves consistently, remains defensible, and supports both planning and design-level analyses.

The following subsections describe each major 1D asset type, the key fields that govern its hydraulic behavior, and the preferred practices for assigning or adjusting these attributes. Each subsection is designed to stand on its own, allowing readers to focus on specific elements as needed, while contributing to an integrated and consistent representation of the overall stormwater collection system.

3.1. Manholes, Surface Inlets, and other Nodes

Manholes, surface inlets, fittings, and similar structures function as the fundamental node elements of the 1D subsurface network, analogous to junctions in EPA SWMM, FLO-2D, or HEC-RAS models. In ICM, these nodes establish the connection points between pipes, surface inflows, and the 2D domain, forming the backbone of how runoff moves into and through the underground system. GIS-based asset locations serve as the starting point for defining these nodes, while subsequent adjustments reflect data gaps, field conditions, or modeling needs. The subsections that follow describe how each node type should be represented, the key attributes that govern its hydraulic behavior, and the considerations that support a consistent, defensible treatment of these assets across all CCD study areas.

3.1.1. Importing GIS Assets

All manholes, surface inlets, outfalls, fittings, structures, and cleanouts should be imported directly from the CCD GIS data, using the asset locations and attributes provided in the City's geospatial datasets. These GIS-based x/y coordinates form the starting point for defining node locations within ICM, and the imported model asset names should match the naming conventions used in the original GIS layers to maintain traceability.

GIS assets should be brought into the ICM model using the Open Data Import Center, which automatically assigns the correct spatial coordinates during import and applies the configured field mapping relationships. This ensures consistent placement of nodes and supports alignment with data quality review and data flagging requirements.

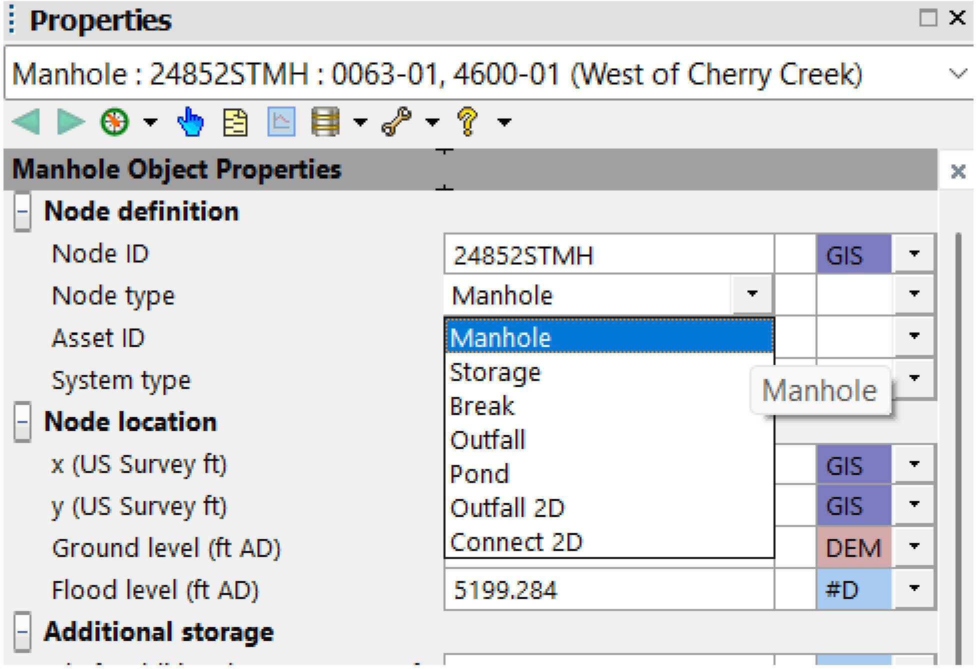
In some cases, GIS linework may imply connectivity without an explicit node feature in the initially imported datasets. Before creating a node manually, modelers should review other available stormwater GIS datasets such as fittings, structure, and cleanout layers, to determine if the point asset already exists. If no corresponding feature is available, a node may be manually generated to maintain proper pipe routing and connectivity. In these cases, it is recommended to create a node ID that is identical to the corresponding 'UPSTREAMNODEID' or 'DOWNSTREAMNODEID' field in the 'UTIL_STMMAIN_L' feature class.

All imports completed through the Open Data Import Center should follow the data source flagging protocols described in Section 2.0 to document the origin and level of verification associated with each asset attribute.

3.1.2. Node Type

Assigning the appropriate node type is essential to ensuring that each element of the subsurface network behaves consistently within the overall hydraulic framework. In ICM, node types define how individual structures interact with connected pipes, the 2D surface, and other parts of the system. The following options as shown in Figure 5 may be assigned for this parameter:

- **Manhole –** Used for nearly all model nodes, including manholes, surface inlets, and fittings. Manhole type nodes serve as the primary junctions of the subsurface collection system and are necessary for enabling exchange between the 1D network and the 2D surface mesh when appropriate flood type settings are applied.
- **Outfall –** Applied where flow is intended to leave the modeled network, typically along the outer boundary of the study area. Outfall nodes are also used in special cases to support construction of *inline banks* associated with 1D representations of major open channel drainage features.
- **Outfall 2D –** Used when discharge occurs between the subsurface network and the 2D mesh, such as when a pipe discharges directly onto the surface or when surface flow must enter the underground system. This node type ensures proper hydraulic communication at these interfaces.
- **Connect 2D –** Used to maintain routing time step efficiency at locations where a 1D conduit interfaces with 2D mesh elements. These are typically placed at the ends of culverts to provide stable linkage while improving computational performance.
- **Storage –** Represents non-standard manholes or intentional storage within a 1D node—such as underground detention tanks, subsurface vaults, or surface retention ponds. Storage nodes are configured using an elevation-versus-area curve, similar to EPA SWMM's storage treatment. Additional guidance on developing storage nodes for ponds is provided in Section 5.3.
- **Pond –** Represents a storage node with additional parameters to support infiltration losses from the bottom and sides of the unit. Because permanent water bodies are assumed to have negligible infiltration capacity, this node type is not typically used for CCD's event-based design storm simulations.
- **Break –** A node type with no internal volume, used primarily along river reaches. Break nodes act as geometric anchors for the 1D open channel system, while the actual channel volume is represented within the river reach links themselves. This node type is generally reserved for gulches, creeks, and other open channel elements.



Properties

Manhole : 24852STMH : 0063-01, 4600-01 (West of Cherry Creek)

Manhole Object Properties

Node definition

Node ID	24852STMH	GIS
Node type	Manhole	
Asset ID		
System type		

Node location

x (US Survey ft)		GIS
y (US Survey ft)		GIS
Ground level (ft AD)		DEM
Flood level (ft AD)	5199.284	#D

Additional storage

Figure 5 Node Type Drop-Down Menu

3.1.3. 1D-2D Interaction

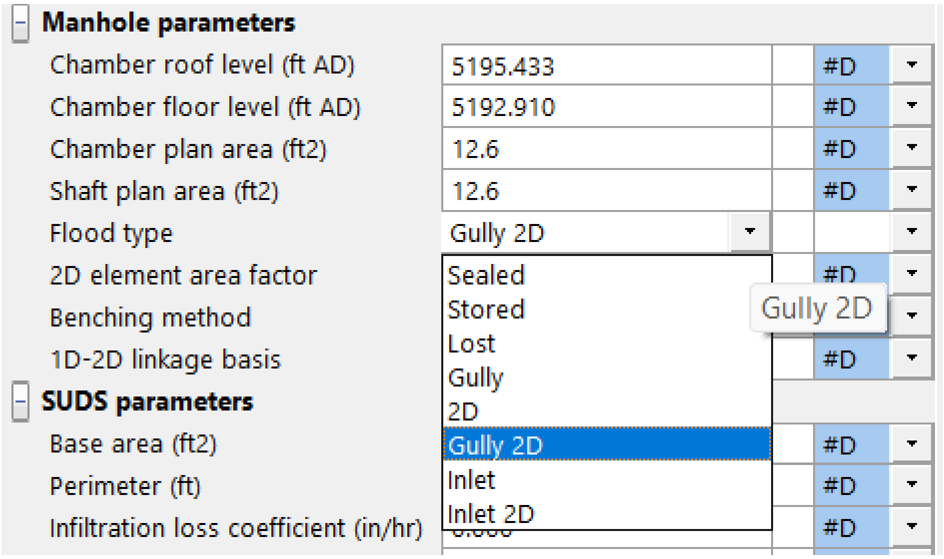
This section provides guidance for populating the model parameters which control how 1D subsurface elements interact with the 2D surface domain. The subsections which follow outline the recommended approaches for assigning these fields so the exchange of flow between the 1D network and 2D mesh is represented consistently and appropriately across CCD models.

3.1.3.1. Flood Type

The Flood Type setting defines how a 1D node exchanges flow with the 2D surface. Within the CCD modeling framework, this parameter is assigned based on the intended hydraulic behavior of the asset and the level of interaction expected between the subsurface system and the 2D mesh. Since most modeled nodes use the ‘Manhole’ node type, the applicable flood type options in CCD models are 2D, Gully 2D, and Sealed. Figure 6 shows a drop-down menu of all available flood types. The following guidance summarizes how each option is applied.

- **Gully 2D –** This is the default flood type for most manholes and surface inlets. It enables hydraulic exchange between the 1D node and the 2D mesh through an assigned head–discharge curve, allowing surface flow to enter the subsurface system or surcharge to return to the surface in a physically realistic manner. This setting should be used for the majority of nodes mapped from CCD’s inlet and manhole GIS datasets.
- **Sealed –** Used when no interaction between the 1D system and the 2D surface is intended. This flood type is appropriate for fittings, buried junctions, bolted manholes, and locations where pipes change size and no surface connection exists. Sealed nodes prevent unintended exchange with the 2D mesh and should be applied wherever structures do not have a surface opening.

- **2D –** Represents a simplified inflow mechanism for directing surface runoff into the 1D network. This option is not recommended to represent typical surface inlets within the CCD collection system, as it lacks the detailed hydraulic control provided by Gully 2D and does not align with CCD's desired representation of inlet performance. However, nodes draining detention areas may use a 2D flood type if the outgoing drainage structure takes the form of bottom orifices rather than above ground culverts.
- **Stored (Not to be used in CCD deliverables) –** Although *Stored* may be used temporarily during early model build phases to simplify validation, it must not be used in finalized CCD models because the stored volume behavior would double count surface storage, which is already represented explicitly through the 2D mesh.



Manhole parameters

Chamber roof level (ft AD)	5195.433	#D
Chamber floor level (ft AD)	5192.910	#D
Chamber plan area (ft2)	12.6	#D
Shaft plan area (ft2)	12.6	#D
Flood type	Gully 2D	
2D element area factor		#D
Benching method		
1D-2D linkage basis		#D

SUDS parameters

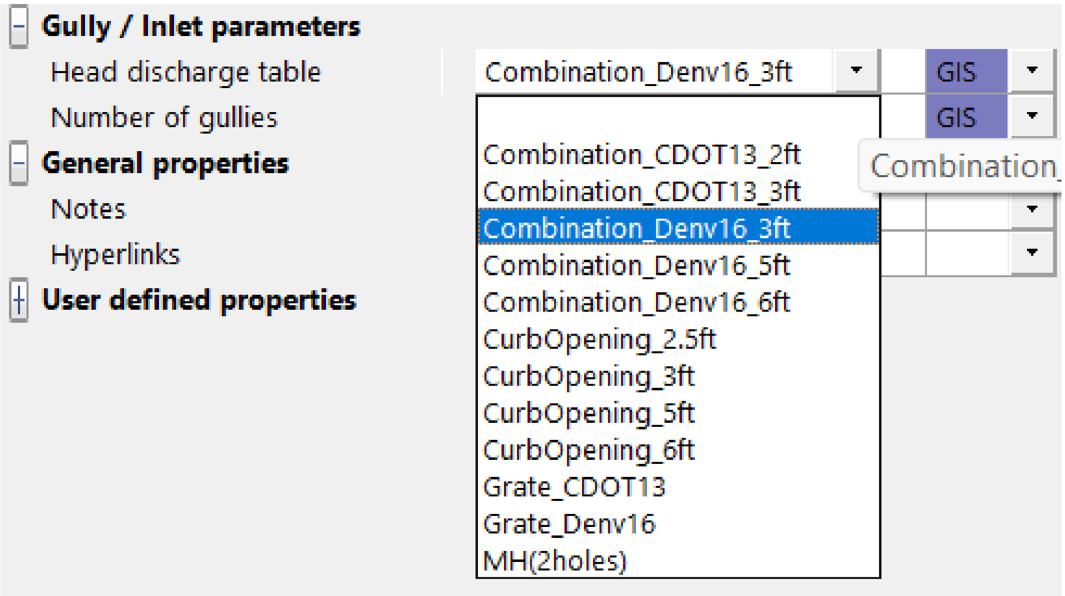
Base area (ft2)		#D
Perimeter (ft)		#D
Infiltration loss coefficient (in/hr)		#D

Figure 6 Flood Type Drop-Down Menu

These flood type selections ensure consistent treatment of surface–subsurface interaction across CCD models while preserving model stability and alignment with the City's preferred representation of its collection system.

3.1.3.2. Head-Discharge Curve and Number of Gullies

Nodes assigned "Gully 2D" flood type may represent either surface inlets or standard manholes. The appropriate head-discharge relationship must be selected so that each node reflects how it is intended to interact with the 2D surface. Figure 7 shows the drop-down menu for defined head-discharge curves, which can be defined under the Links table. Where needed, inlet types and counts may be verified using aerial imagery or Google Street View, and any such verification should be documented using the "DV" (digitized from visual verification) data source flag.



Gully / Inlet parameters

Head discharge table: Combination_Denv16_3ft — GIS

Number of gullies — GIS

General properties

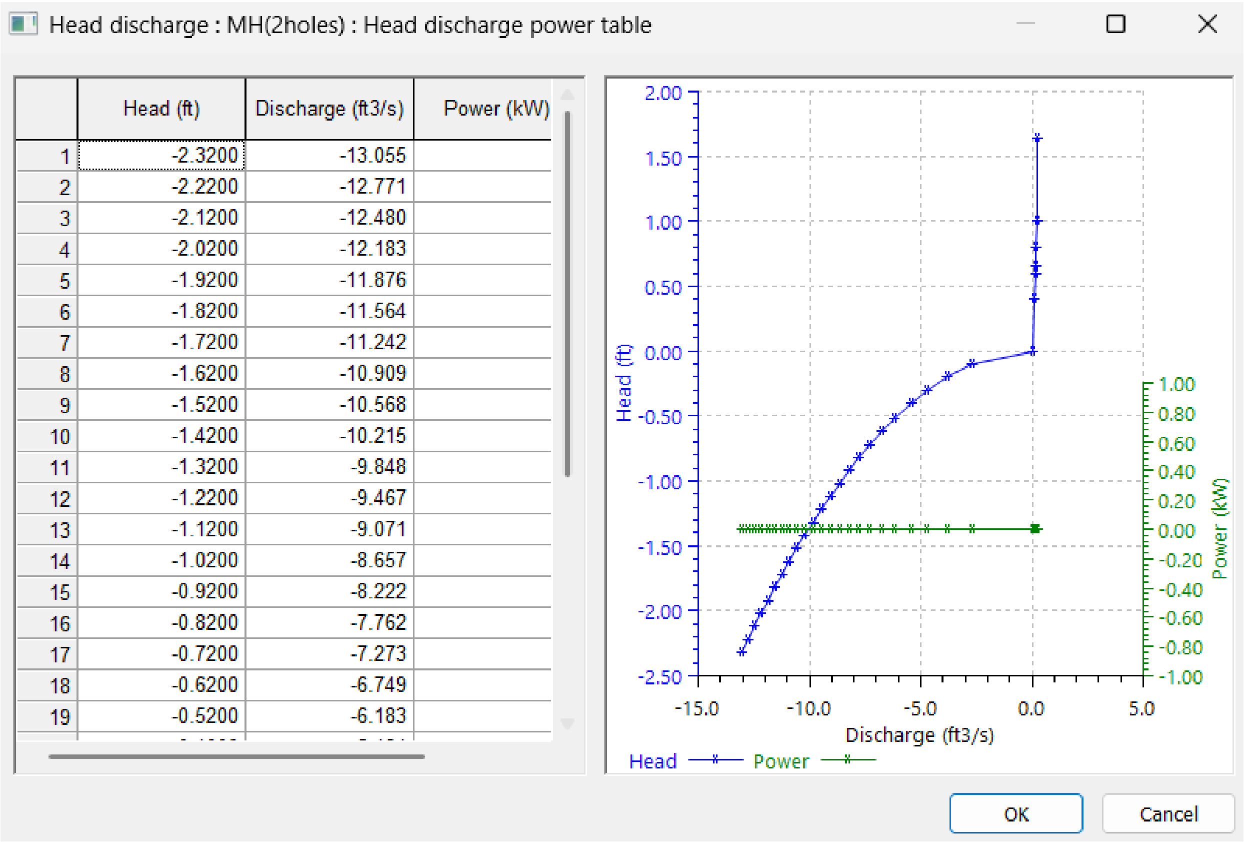
Notes

Hyperlinks

User defined properties

Figure 7 Head-Discharge Table Drop-Down Menu

Manholes with solid lids should be assigned the "MH(2holes)" head-discharge curve, illustrated in Figure 8. This rating curve reflects the behavior of a manhole that can relieve sub-surface pressure but does not collect overland runoff.



Head discharge : MH(2holes) : Head discharge power table

	Head (ft)	Discharge (ft3/s)	Power (kW)
1	-2.3200	-13.055	
2	-2.2200	-12.771	
3	-2.1200	-12.480	
4	-2.0200	-12.183	
5	-1.9200	-11.876	
6	-1.8200	-11.564	
7	-1.7200	-11.242	
8	-1.6200	-10.909	
9	-1.5200	-10.568	
10	-1.4200	-10.215	
11	-1.3200	-9.848	
12	-1.2200	-9.467	
13	-1.1200	-9.071	
14	-1.0200	-8.657	
15	-0.9200	-8.222	
16	-0.8200	-7.762	
17	-0.7200	-7.273	
18	-0.6200	-6.749	
19	-0.5200	-6.183	

Figure 8 Head-Discharge Curve Example: MH(2holes)

Surface inlets should be assigned a head-discharge curve corresponding to the inlet type based on the ’Asset type’, ‘Unit Kind’, and ’Length’ fields of the ‘UTIL_STMINLET_P’ GIS layer. The following guidance explains how the inlet head-discharge curves are indexed and assigned in ICM:

- ‘Asset type’ may be ‘Grate’, ‘CurbOpening’, ‘Combination’, ‘Other’, or ‘Unknown’. For ‘Other’ or ‘Unknown’ subtype, the inlet type is assumed to be ‘Combination_Denver16_3ft”.
- ‘Unit Kind’ may be ‘UNKN’, ‘C’, ‘D’, ‘R’, ‘NO13’, ‘NO14’, or ‘NO16’. ‘NO13’ and ‘R’ are assigned ‘CDOT13’, while the rest are assigned ‘Denv16’. This excludes ‘Grate’ and ‘CurbOpening’ subtypes where neither ‘CDOT13’ nor ‘Denv16’ is assigned.
- ‘Length’ is appended to the end of the inlet type. Where ‘Length’ is blank or 0, assume inlet length to be 3 ft.
- Examples of head-discharge curve IDs are ‘Combination_CDOT13_2ft’ or ‘CurbOpening_6ft’. Head-discharge curves have been included in the ‘Basis for Development’ InfoWorks network and transportable database, available upon request from the CCD project manager, for most of the commonly referenced inlet types.

The CCD ‘Basis for Development’ model includes the following head-discharge curves as published by the MHFD:

- Colorado Department of Transportation (CDOT) “Type 13” Grate
- Denver “No. 16” Grate
- CDOT “Type R” curb opening
- CDOT “Type 13” combination curb opening and grate
- Denver “No. 16” combination curb opening and grate

Source: https://www.mhfd.org/files/08a85afd2/UDFCD-Street-Inlet-Capacity.pdf

In ICM, the ‘Number of Gullies’ parameter functions as a multiplier on the selected head–discharge curve. This setting is intended for locations where multiple inlet castings of the same type exist at a single asset location—a configuration that reflects how CCD stores these assets in its GIS and how Asset IDs are assigned for maintenance and management. The count of identical inlet openings is recorded in the MULTIINLETCOUNT field of the UTIL_STMINLET_P feature class, and this value should be imported directly into the Number of Gullies field in ICM. Using this parameter consistently ensures that inlet capacity is represented accurately without requiring the creation of multiple separate nodes for a single mapped inlet location.

The list above includes castings that are considered “standard” design. Additional inlet types may be added as needed. When inlet information is not available in the GIS or cannot be confirmed through visual verification, modelers should apply a Denver “No. 16” grate head–discharge curve with one gully as the default representation. This provides a consistent, conservative basis for inlet performance while ensuring that missing attribute data does not introduce unintended variation into the model.

3.1.3.3. 1D-2D Linkage Basis

The 1D-2D linkage basis of a node can be set to either "depth" or "elevation". The default value for manholes and inlets can be set to "depth" to improve computational stability. Connect 2D and Outfall 2D nodes are typically left at the default "depth" setting to support computational performance. However, where differences in water surface elevation may be introduced by depth-based linkage, the setting should be changed to "elevation".

3.1.4. Storage Nodes

Storage nodes are used sparingly within CCD's unified modeling framework, as few subsurface assets function as enclosed storage structures without direct interaction with the ground surface. In ICM, a storage node represents a volume–elevation relationship contained entirely within a 1D element, making it appropriate only in situations where no 2D surface exchange is expected.

Storage nodes should be applied in the following limited cases:

- Subsurface detention facilities with a ceiling where all inflow and outflow occur through connected sub-surface pipes rather than overland runoff. These facilities have no physical mechanism for direct interaction with the 2D mesh and therefore will remain strictly within the 1D domain. In these applications, the highest elevation in the storage array should be below the node ground level. Examples include storage vaults or cisterns, below parking garages, within apartment complexes, and adjacent to large industrial or institutional buildings.
- Representation of open channel waterbody reservoirs or retention ponds when they are modeled strictly as 1D storage elements. This approach is typically used for permanent waterbodies or retention features whose surface geometry and storage characteristics are better defined through elevation–area curves than through the underlying DEM. In these applications, the highest elevation in the storage array should be above the node ground level. Examples include Sloan's Lake, Barnum Park Lake Reservoir, and Heron Pond.

When a storage node is used to represent surface storage, additional 2D integration steps are required. In these cases, the storage node must be paired with a storage area polygon and associated bank lines to ensure correct hydraulic exchange between the 1D waterbody and the surrounding 2D mesh. These procedures (described in Section 5.0) create a seamless 1D–2D interface and prevent double counting of storage or unintended hydraulic isolation.

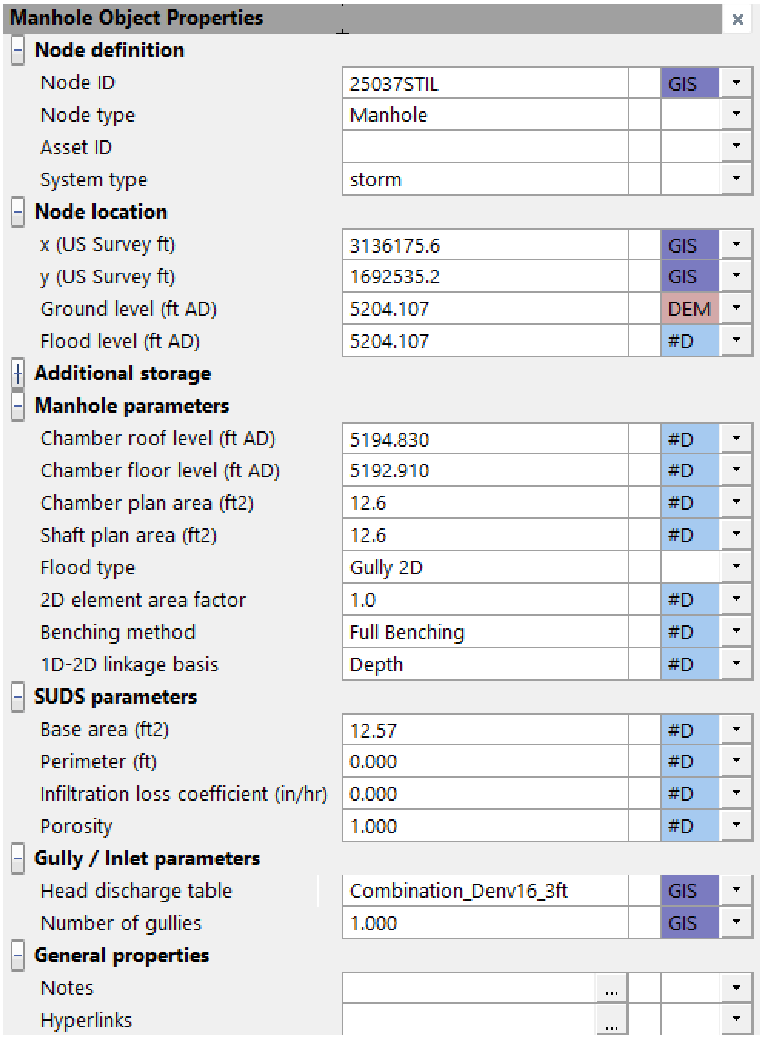
Because of their limited applicability, storage nodes should be included only where they reflect a physical, enclosed storage volume or where a simplified 1D representation of a waterbody is appropriate for study goals.

3.1.5. Other Fields

The following additional node fields should be populated consistently to support stable, defensible model behavior:

- **Ground Elevation –** Populate using the DEM-based ground model through ICM's built-in inference functions.
- **Flood Elevation –** Typically assigned using the default flag unless project-specific conditions warrant modification.
- **Additional Shaft Area/Additional Storage Area –** Set to **zero** for all manhole type nodes to prevent unintended volume.
- **Chamber Roof Level –** Set using the default flag.
- **Chamber Floor Level –** May be set using the default flag or inferred to match the outgoing pipe invert (both approaches yield equivalent elevations in practice).
- **Chamber Plan Area –** Should ideally match the physical manhole chimney area.
    - Where available, calculate using the manhole diameter stored in the *DIAMETER_FT* field of the *UTIL_STMMANHOLE_P* feature class.
    - Where this information is unavailable, the default flag value may be used.
    - No value smaller than 12.56 sq ft (equivalent to a standard 4-ft diameter manhole) should be used; smaller values can negatively affect computational stability and simulation runtimes.
- **Shaft Plan Area –** set depending on the flood type of the node.
    - Where the node flood type is set to '2D', the shaft plan area should be set to the area of the grate opening. This area may be based on GIS attribute data, drawings, or estimated based on aerial imagery where not available.
    - Where the node flood type is set to 'Gully 2D' or 'sealed', the shaft plan area should be set to 12.56 square feet (equivalent to a 4-foot diameter manhole chimney).
- **Benching Method –** Use the default Full Benching method for all nodes.
- **2D Element Area Factor –** Maintain default value of 1.

Figure 9 illustrates a typical manhole parameter configuration. While these parameters should be assigned as described above, conceptual testing used default plan area values that represent the volume that can be stored in manhole elements. The results of those analyses indicated that this assumption did not significantly influence overall system behavior or the interpretation of model outputs. However, adopting a more realistic representation of node storage volume (particularly by using GIS-derived manhole diameters, where available) will improve both model accuracy and the perceived defensibility of the modeling approach. As with all parameter adjustments, any changes to these fields should follow the standard data flagging protocols described in Section 2.3 to ensure transparency and traceability of assumptions.



Manhole Object Properties

Node definition		
Node ID	25037STIL	GIS
Node type	Manhole	
Asset ID		
System type	storm	
Node location		
x (US Survey ft)	3136175.6	GIS
y (US Survey ft)	1692535.2	GIS
Ground level (ft AD)	5204.107	DEM
Flood level (ft AD)	5204.107	#D
Additional storage		
Manhole parameters		
Chamber roof level (ft AD)	5194.830	#D
Chamber floor level (ft AD)	5192.910	#D
Chamber plan area (ft2)	12.6	#D
Shaft plan area (ft2)	12.6	#D
Flood type	Gully 2D	
2D element area factor	1.0	#D
Benching method	Full Benching	#D
1D-2D linkage basis	Depth	#D
SUDS parameters		
Base area (ft2)	12.57	#D
Perimeter (ft)	0.000	#D
Infiltration loss coefficient (in/hr)	0.000	#D
Porosity	1.000	#D
Gully / Inlet parameters		
Head discharge table	Combination_Denv16_3ft	GIS
Number of gullies	1.000	GIS
General properties		
Notes		
Hyperlinks		

Figure 9 Manhole Object Properties

3.2. Sub-surface Pipes

Sub-surface pipes form the primary conveyance pathways within the underground collection system and operate in tandem with the node elements described in the previous section. While nodes represent hydraulic junctions (such as manholes, inlets, fittings, and outfalls) the pipes define the physical links between them, routing flow through the network and transmitting hydraulic conditions from one node to the next. Together, these components establish the 1D backbone of the stormwater system, enabling ICM to simulate how runoff captured at the surface moves through the subsurface infrastructure.

The following subsections provide guidance on assigning pipe attributes such as length, invert elevations, roughness, and headloss coefficients. These parameters govern how efficiently flow is conveyed, how energy is lost through the system, and how subsurface conditions interact with upstream and downstream hydraulic constraints. The subsequent subsections focus on the specific parameter guidance needed for consistent and defensible model development within CCD's unified framework.

3.2.1. Lengths

Pipe lengths should, generally, be auto-calculated by the software using the conduit line geometry within the model. Allowing the software to compute these distances is preferred (even when the resulting values differ from GIS-reported lengths) because it avoids simulation issues that can arise when above ground and below ground distances diverge during flooding conditions.

A noteworthy exception is when a subsurface pipe discharges directly into a modeled gulch or creek and must be snapped to the nearest break node along the 1D river reach. In this case, manually overwriting the pipe length is appropriate, as no 1D–2D interaction occurs at the break node and consistency with the GIS discharge point can be maintained without introducing surface routing complications.

3.2.2. Pipe Shape / Geometry

Pipe shapes and geometric definitions should be taken directly from CCD's GIS datasets wherever available. The *PIPESHAPE* field within the *UTIL_STMMAIN_L* feature class provides the preferred source for identifying these attributes.

Where non-circular or special shapes exist (e.g., egg, arch, or oval), geometry should be imported from previously developed SWMM or FLO-2D models when available, as these models typically include more explicit or vetted cross-sectional definitions than what is stored in the GIS attributes.

When no pipe shape information exists, pipes should be assumed to be circular by default. An exception is when both the upstream and downstream connected pipes are known to be non-circular. In these cases, the pipe shape should match the geometry of the adjacent pipes.

3.2.3. Inverts

Invert elevations should be populated primarily using the GIS attributes provided in the UPSTREAMINVERT and DOWNSTREAMINVERT fields of the *UTIL_STMMAIN_L* feature class. Where these values are available and consistent with surrounding system conditions, they should serve as the basis for assigning pipe inverts.

When GIS attributes are missing or produce suspect elevation profiles—such as adversely sloped pipes, abrupt vertical discontinuities, or cases where a large diameter pipe discharges into a smaller diameter pipe—the GIS values may be replaced using one of the following approaches:

- As-built drawings, where available
- Linear interpolation between known upstream and downstream elevations
- Reasonable engineering assumptions necessary to complete subsurface connectivity

A general overriding assumption is that all pipes should maintain at least 3 ft of ground cover above the pipe crown, and invert adjustments should remain consistent with this expectation.

3.2.4. Roughness

ICM allows users to specify separate bottom and top roughness coefficients for each pipe link. For stormwater applications within CCD's unified modeling framework, these values should be identical, as stormwater pipes are assumed to have uniform internal surface characteristics.

All pipes should use the roughness type "N", corresponding to a standard Manning's roughness coefficient input. For consistency with previous CCD modeling efforts, a Manning's *n* value of 0.013 should be used as the default roughness parameter for both the pipe invert and crown surfaces.

While this uniform value has performed well in testing, CCD may consider developing an indexed set of Manning's *n* coefficients for different pipe materials in future updates to these guidelines. This would allow for more nuanced representation of conveyance conditions while maintaining the overall consistency desired in the unified modeling framework.

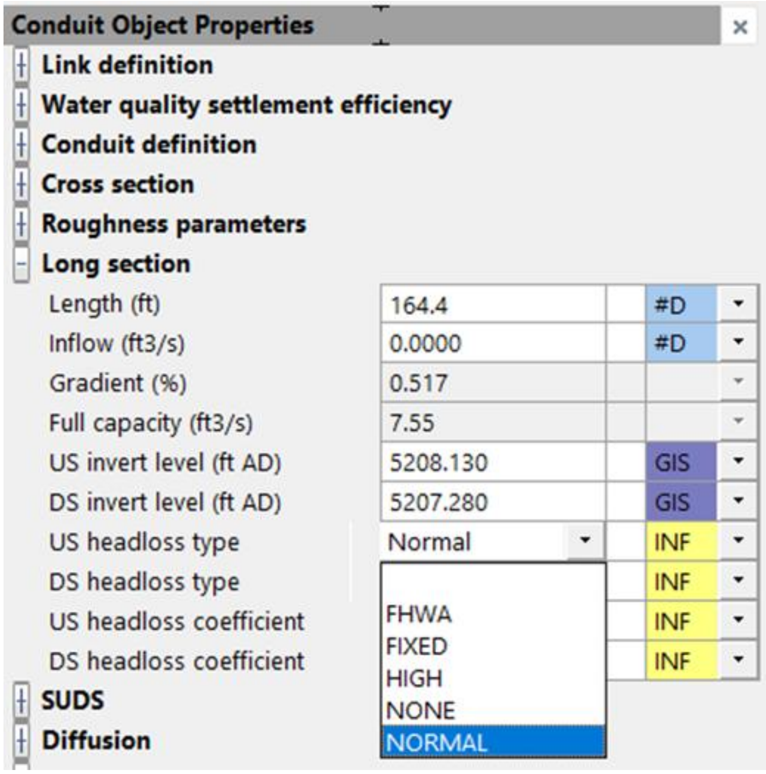
3.2.5. Headloss

ICM provides the option to dynamically calculate hydraulic headloss at both the upstream and downstream ends of a pipe. These point loss calculations are controlled through the headloss type and coefficient fields associated with each conduit. Users seeking additional detail on the underlying equations and implementation can refer to the 'Headloss Curves' section of the ICM user manual.

For CCD models, the recommended approach is to populate the US Headloss Type, DS Headloss Type, and their associated coefficient fields using the built-in headloss inference function. These fields should carry the "INF" data flag to document that they were assigned automatically. The inference tool provides consistent, defensible values, but it does not operate correctly when a pipe transitions between different shapes. In those cases, a temporary workaround is recommended: set all pipes to a uniform shape (e.g., circular), apply the inference function, and then restore the original shape and size information from the model table.

There are several situations where headloss parameters should be assigned manually rather than using the inference function (see Figure 10 for headloss type drop-down menu options):

- **Large box culverts** – Set headloss to None (AS flag) unless the culvert transitions to a pipe of different size, in which case the downstream pipe's upstream headloss should be Fixed = 0.15. This reflects the assumption that large boxes are not connected by typical manholes.
  Note: Incoming laterals do not constitute a pipe size transition.



Length (ft)	164.4	#D
Inflow (ft3/s)	0.0000	#D
Gradient (%)	0.517	
Full capacity (ft3/s)	7.55	
US invert level (ft AD)	5208.130	GIS
DS invert level (ft AD)	5207.280	GIS
US headloss type	Normal	INF
DS headloss type		INF
US headloss coefficient		INF
DS headloss coefficient		INF

Figure 10 Headloss Type Drop-Down Menu Options

- **Pipes representing the gulch under a bridge –** Assign the upstream headloss as Fixed = 0.2 and set the downstream headloss to None. See Figure 11 below.

- **Gulch discharge pipes –** All pipes discharging to a gulch should have their downstream headloss set to Fixed = 0.05, except for the large box culverts that may constitute the gulch itself.

- **Connections to storage nodes –** For pipes leaving a storage area, assign the upstream headloss as Fixed = 0.1. For pipes entering a storage area, the downstream headloss should be set to None.

Figure 11 Representation of Gulch with Conduit Example

These conventions ensure that headloss values remain consistent across CCD models, reflect expected hydraulic behavior, and avoid unintended instability during simulation.

4.0. 2D Surface and Hydrology

Accurate representation of the ground surface is fundamental to any RoM model, because in ICM the 2D hydraulic routing and the hydrologic response are solved together as a single, integrated process. Unlike traditional hydrologic methods where runoff generation and flow routing may occur in separate model components, RoM directly applies rainfall to the 2D mesh—meaning that overland flow paths, ponding behavior, infiltration, and imperviousness are all computed within the same spatial framework. As a result, the configuration of the 2D mesh (called a “mesh” in ICM or a “grid” in FLO-2D) is not just a hydraulic representation of ground topography; it also embodies the hydrologic characteristics of the watershed.

Because hydrology and hydraulics are inextricably linked in this modeling approach, the 2D surface must explicitly distinguish impervious and pervious areas and assign infiltration and roughness parameters accordingly. Impervious features—such as pavement, rooftops, and other hard surfaces—govern how quickly rainfall becomes runoff, while pervious areas rely on soil-specific infiltration parameters to simulate losses. Similarly, buildings, ditches, walls, and other surface features influence both runoff generation and routing, shaping the patterns of shallow flow and local ponding captured by the model.

This section provides the overarching framework for how these surface components are represented in the unified modeling approach. The subsections that follow describe each polygon or line feature in detail, and outline recommended practices for parameterization:

- 2D Zone
- Infiltration Zones
- Roughness Zones
- Buildings
- Mesh Zones
- Walls
- Mesh Level Zone
- Breaklines

Together, these elements ensure that the 2D surface realistically reflects both the physical terrain and the hydrologic behavior needed for a stable and defensible ICM RoM model.

4.1. 2D Zone

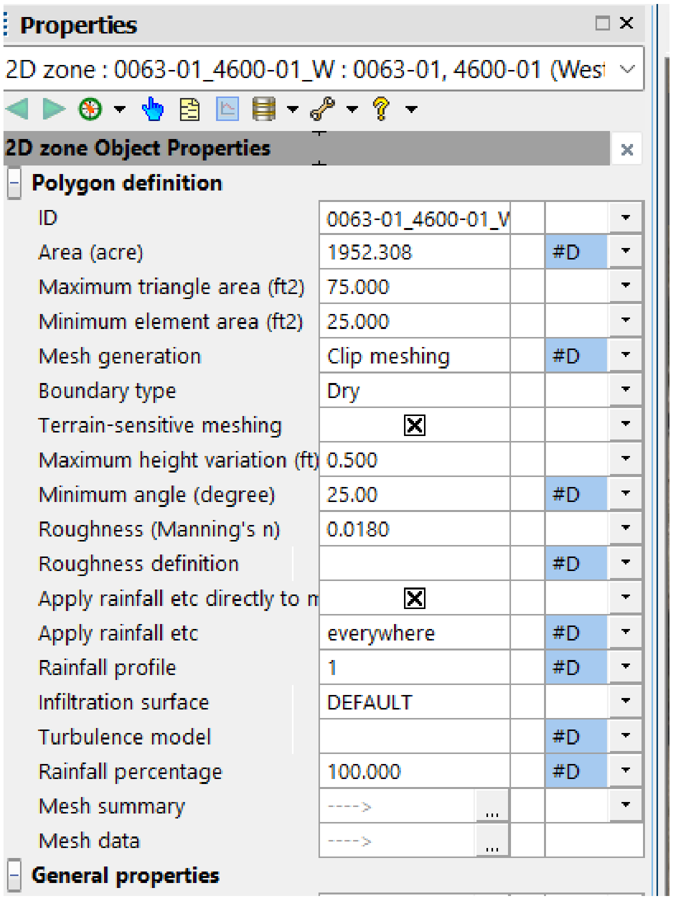
A 2D Zone is a polygon that defines the full spatial extent over which the 2D surface hydraulic and hydrologic calculations will be performed. In RoM modeling, this polygon establishes where rainfall is applied, where mesh elements are generated, and ultimately the full area in which surface flow, ponding, and infiltration will be simulated. The 2D Zone should therefore encompass the entire study area and any adjacent terrain necessary to support realistic overland flow routing.

For CCD studies, the 2D Zone extents are typically derived from the Storm Collection System Boundaries dataset. However, because basin delineations do not always perfectly capture contributing tributary areas or shallow flow paths near the edges of a watershed, CCD recommends buffering the study area boundary by approximately 50–100 feet. This buffer ensures that the modeled domain captures all relevant topography influencing surface flow patterns. CCD has a “Topographical Basin Boundary” GIS layer which should be used as a basis for the model 2D domain definition.

In CCD’s unified modeling approach, the 2D Zone also serves as the parent layer that defines the default hydraulic and hydrologic characteristics for impervious surfaces. These defaults include the baseline roughness, infiltration behavior, and rainfall application settings used in RoM modeling. Parameters for pervious surfaces, however, are not defined within the 2D Zone. Instead, infiltration zones and roughness zones are used to explicitly represent pervious areas and assign soil-specific infiltration and surface roughness values. These polygons override the parent 2D Zone settings wherever they are present, allowing the model to distinguish pervious and impervious areas with appropriate spatial fidelity.

Figure 12 illustrates the recommended 2D Zone parameters for production simulations. The following standard parameterization of the 2D Zone should be used to ensure consistency in mesh generation, stability, and mapping outputs across all study areas:

- **Mesh generation method –** *Clip meshing*
- **Maximum triangle area –** *75 square feet*
- **Minimum triangle area –** *25 square feet*
- **Boundary type –** *Dry*
- **Terrain-sensitive meshing –** *Enabled, with a maximum height variation of 0.5 feet*
- **Minimum internal triangle angle –** *25 degrees (ICM default)*
- **Default Manning's roughness –** *0.018 (impervious surface)*
- **Rainfall application**
  - *Apply rainfall directly to mesh (engages RoM)*
  - Apply rainfall *everywhere*
  - Rainfall percentage = *100%*
- **Infiltration surface –** *DEFAULT (representing impervious conditions with no infiltration)*
- **Turbulence model –** *May be ignored (left blank) for standard CCD planning level analyses.*



Properties

2D zone : 0063-01_4600-01_W : 0063-01, 4600-01 (Wes

2D zone Object Properties

Polygon definition

ID	0063-01_4600-01_V	
Area (acre)	1952.308	#D
Maximum triangle area (ft2)	75.000	
Minimum element area (ft2)	25.000	
Mesh generation	Clip meshing	#D
Boundary type	Dry	
Terrain-sensitive meshing	☒	
Maximum height variation (ft)	0.500	
Minimum angle (degree)	25.00	#D
Roughness (Manning's n)	0.0180	
Roughness definition		#D
Apply rainfall etc directly to m	☒	
Apply rainfall etc	everywhere	#D
Rainfall profile	1	#D
Infiltration surface	DEFAULT	
Turbulence model		#D
Rainfall percentage	100.000	#D
Mesh summary	---->	
Mesh data	---->	

General properties

Figure 12 Typical 2D Zone Properties

These settings provide a consistent foundation for all model builds, ensuring that surface routing, runoff generation, and mesh behavior remain comparable across study areas while allowing subsequent surface feature polygons (infiltration zones, roughness zones, buildings, mesh zones, etc.) to refine local parameters as needed. While the parameterizations listed above are required for production simulations to ensure study-to-study consistency, modelers may apply engineering judgment to temporarily increase mesh element sizes or relax meshing constraints during intermediate model building and validation steps, provided these adjustments are returned to CCD-standard values prior to final deliverables. For example: a 300 square foot maximum triangle area and 60 square foot minimum element area may be used during earlier stages of model validation or conceptual alternatives analysis to improve run time.

4.2. Infiltration Zone

Infiltration Zones are polygons that define the infiltration characteristics of 2D mesh elements and are used to explicitly represent pervious surfaces within the model. These zones override the default impervious surface parameters defined in the 2D Zone and play a central role in establishing the hydrologic response of the watershed under the RoM modeling approach.

To determine pervious surfaces within the study area, modelers should begin with the two CCD GIS datasets that represent all mapped impervious features:

- Comprehensive Citywide Impervious Surfaces
- Building Outlines (2022 or later)

Before importing into ICM, these two layers should be merged then dissolved to form a single, impervious surface polygon layer using GIS tools. It should be noted that the ‘Comprehensive Citywide Impervious Surfaces’ dataset includes features classified as ‘Building’ in the ‘IMPERVIOUS_TYPE’ field. However, this category and the ‘Building Outlines’ dataset, while both intended to represent building footprints, may exhibit notable differences in representation of existing conditions and spatial accuracy. Modelers should review both datasets and determine which appears more reliable for the study area, recognizing that a combination of these sources may be necessary to achieve an accurate representation of existing building footprints. Once merged, the ‘*Pairwise Erase*’ tool is used with the 2D Zone polygon to remove all impervious features, resulting in a polygon layer that represents only pervious areas within the study boundary. These pervious polygons should then be converted to single part polygons using the *Multipart to Singlepart* tool to ensure each discrete pervious area is carried into the model independently.

Once pervious areas are defined, the next step is to categorize each polygon based on its underlying soil characteristics. Modelers should use the USDA SSURGO soil classification spatial dataset to assign an NRCS hydrologic soil group (A, B, C, or D) to each pervious polygon. This soil group forms the basis for applying Horton infiltration parameters. Horton infiltration values should follow the parameters carried forward from CUHP and adopted for CCD modeling efforts. These values are summarized in Table 1. It should be noted that, in ICM, the infiltration parameters themselves are defined in a separate configuration table called Infiltration Surfaces. Each Infiltration Zone polygon acts as a spatial index that points to the appropriate Infiltration Surface entry rather than storing the parameters directly.

Table 1 Horton Infiltration Parameters for USDA Soil Groups

Soil Group	***Horton Initial Infiltration (in/hr)***	***Horton Final Infiltration (in/hr)***	***Decay Coefficient (1/hr)***
A	5.0	1.0	2.52
B	4.5	0.6	6.48
C & D	3.0	0.5	6.48

Modelers may adjust infiltration parameters where reliable stream gage, flow monitoring data, or well-documented field observations support modification, provided changes remain within acceptable engineering practice.

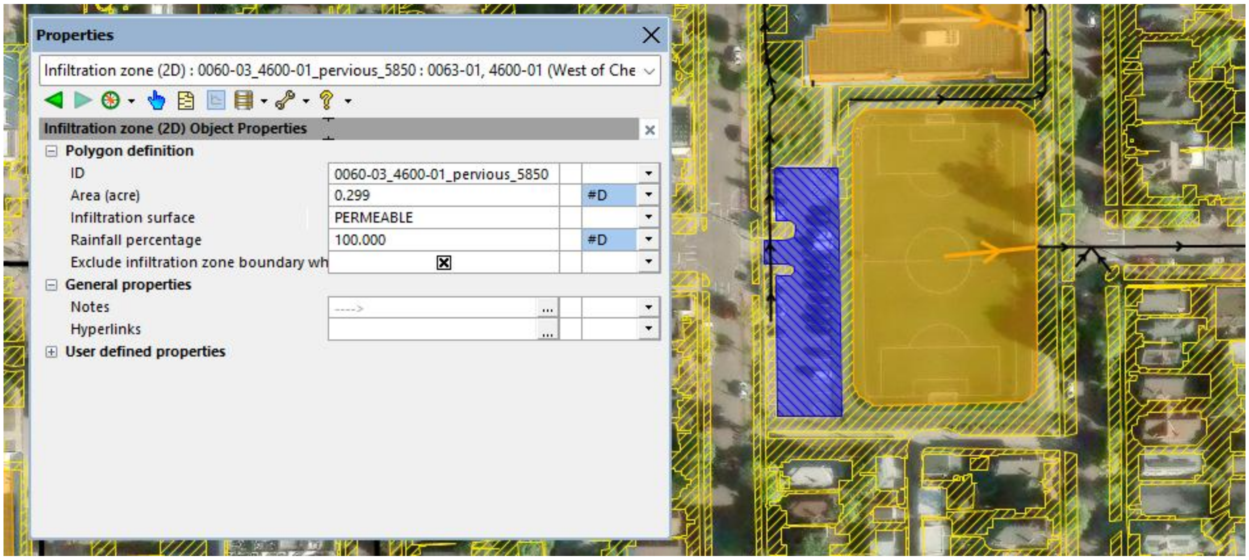
After soil types and infiltration parameters are assigned in GIS, each pervious area polygon (now attributed with its associated NRCS soil group) should be imported into ICM as individual infiltration zones using the Open Data Import Center. This ensures that all polygons are indexed correctly and linked to the appropriate infiltration surface definition. Where not available, users should assume Group D soils.

Note: some of the 2025 SDMP ICM modeling basins (4800-01, 4801-01, 4900-01, 5100-01, 4500-01, 4500-03, 4500-04, 0060-01, and 0060-02) used a slightly different approach that has been updated for these guidelines. In these models, impervious areas such as roads, building footprints, and paved surfaces were represented by Infiltration Zones and Roughness Zones. All other areas were defaulted to 2D Zone settings, which was defined as a pervious surface with the manning's n (0.06) and Horton infiltration settings. The Central Platte Basin model (0063-01, 4600-01) and all future modeling efforts should use the guidance enumerated above to allow for more flexibility and options in modeling different soil types.

4.2.1. Special Case: Permeable Pavement

Permeable pavement areas are typically mapped as polygons in the Storm Detention and Water Quality Facilities feature class (a Denver GIS Layer) and may be verified using aerial imagery or field review. Because these surfaces are intentionally designed to promote infiltration, they should be represented in the model using Infiltration Zones so that their enhanced hydrologic function is captured, see Figure 13 below.

For permeable pavement installations connected to the CCD stormwater system, the Horton infiltration parameters summarized in Table 2 should be applied to permeable pavement systems with or without underdrains. These parameters include a very high initial infiltration rate (reflecting the fact that permeable pavement systems commonly infiltrate water at rates significantly greater than the underlying native soils) and are intended to capture the substantial infiltration capacity of installed pavers.



Infiltration zone (2D) : 0060-03_4600-01_pervious_5850 : 0063-01, 4600-01 (West of Che

ID	0060-03_4600-01_pervious_5850	
Area (acre)	0.299	#D
Infiltration surface	PERMEABLE	
Rainfall percentage	100.000	#D
Exclude infiltration zone boundary wh	☒	
Notes	---->	
Hyperlinks		

Figure 13 Example of Infiltration Zone Representing Permeable Pavement

Table 2 Infiltration Parameters for Permeable Pavement

ID	PERMEABLE
Infiltration type	Horton
Horton initial (in/hr)	80
Horton limiting (in/hr)	0.01
Horton decay (1/hr)	80

Modelers may adjust the Horton parameters where appropriate to reflect variations in permeable pavement type or design. In particular, the initial infiltration rate may be reduced for systems with lower hydraulic conductivity, and the decay coefficient may be modified to limit the total volume of water that can infiltrate into the pavement structure when warranted by site-specific information or design documentation.

4.3. Roughness Zone

Roughness Zones will utilize the same pervious area polygons developed for the Infiltration Zone step above and provide a means to override the default impervious surface parameters defined in the 2D Zone. These polygons allow the model to represent the variability of ground surfaces across an urban environment with greater spatial fidelity. By assigning Manning's roughness values at a finer resolution, modelers can better capture differences in vegetation cover, land use, and surface texture that influence overland flow routing.

For CCD's unified modeling approach, a default Manning's n value of 0.060 has been applied to most pervious surfaces. This value aligns with industry standards and software vendor recommendations for general vegetated ground conditions. Where flow monitoring data or field observations are available and real storm calibration is desired, these roughness values may be adjusted to better reflect the localized surface characteristics. Values may be reduced to approximately 0.030 for well-manicured lawns or sparsely vegetated surfaces with smooth topography or increased to as high as 0.100 for densely vegetated, wooded, or rough overland areas. Any deviations from the default value should be documented by the modeler, noting the rationale and data source that informed the adjustment.

For impervious surfaces, the roughness value is defined in the 2D Zone and should default to 0.018. Where appropriate (such as in areas with surface texture that differs significantly from typical pavement) values may be reduced to 0.013 or increased to 0.025, provided such adjustments are supported by flow monitoring data or clear real-world observations. In these cases, users will likely need to manually create roughness zone polygons.

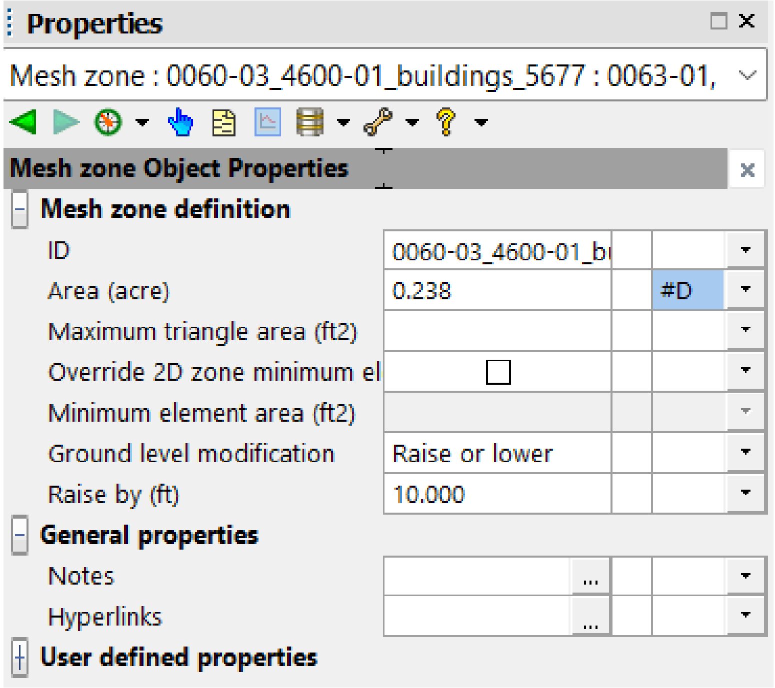
The 2D Zone, and the Roughness Zone polygons, paired with the infiltration parameters assigned through the Infiltration Zone workflow, allow the model to represent both hydrologic and hydraulic surface characteristics at a consistent and defensible level of detail.

4.4. Mesh Zone and Building

Mesh Zones and Buildings are polygon features used in ICM to represent structures within the 2D modeling environment. Figure 14 shows an example near the Metropolitan State University Denver campus, where building polygons are shown in orange and mesh zone polygons are shown in blue. Although they are both derived from the Building Outlines 2022 dataset, they serve fundamentally different hydraulic and hydrologic purposes in a RoM model.

Figure 14 Building Polygons (Orange) and Mesh Zone Polygons (Blue)

A Mesh Zone modifies underlying ground surface elevations during mesh generation and forces 2D elements edges along the mesh zone polygon boundary. This means that 2D mesh elements are formed either fully within the polygon or fully outside of it and elements do not cross over Mesh Zone boundaries. All 2D elements within a Mesh Zone polygon are raised or lowered by a defined amount (typically, raised 10 feet for buildings so that surface runoff flows around the structure, see Figure 15). Rain falling on top of the elevated mesh elements drains along the slope of the modified surface, mimicking runoff from pitched roofs and similar features represented directly in the DEM.


Properties

Mesh zone : 0060-03_4600-01_buildings_5677 : 0063-01,

Mesh zone Object Properties

Mesh zone definition

ID	0060-03_4600-01_bı	
Area (acre)	0.238	#D
Maximum triangle area (ft2)		
Override 2D zone minimum el	☐	
Minimum element area (ft2)		
Ground level modification	Raise or lower	
Raise by (ft)	10.000	

General properties

Notes	...
Hyperlinks	...

User defined properties

Figure 15 Mesh Zone Properties

A Building polygon, by contrast, removes the roof area from the 2D mesh entirely and represents its hydrologic contribution using a calculated hydrograph. (See Building properties in Figure 16.) This hydrograph is routed into the system similarly to a traditional subcatchment in EPA SWMM, allowing roof runoff to be directed to a specific node, link, or 2D inflow location. This representation is appropriate for buildings with flat roofs and internal drainage, where roof discharge would not be captured by the DEM or standard 2D surface routing.

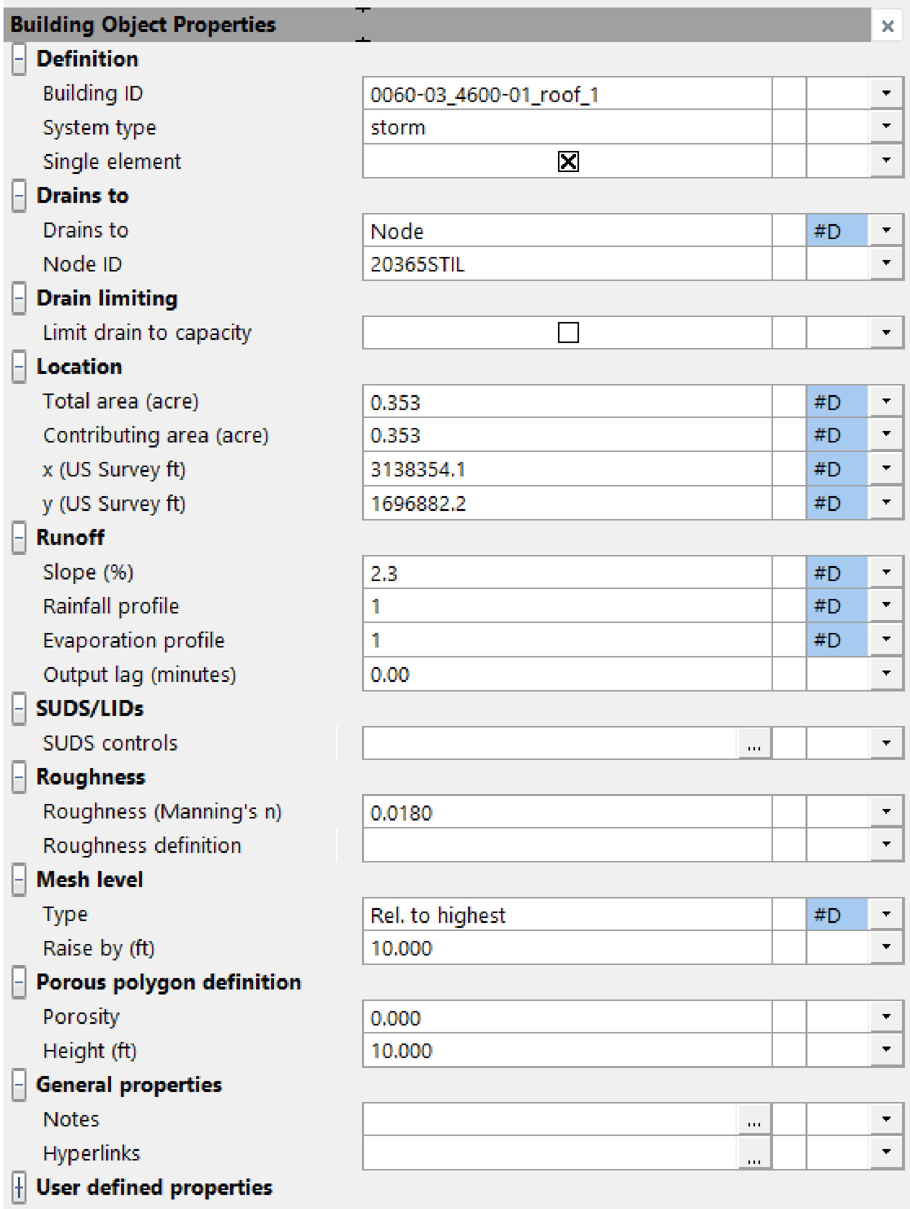
For most small-scale or residential structures with pitched roofs, a Mesh Zone is appropriate. These buildings typically shed runoff directly to adjacent ground surfaces, and raising the surface by 10 feet ensures that stormwater is routed around the building footprint while preserving realistic overland flow paths.

A Building polygon should be used when a structure has internal roof drainage, such as commercial or multifamily buildings with flat roofs. These structures often convey roof runoff through 4- to 6-inch internal roof drains, which can be identified in GIS stormwater datasets. Because this drainage path is not represented in the DEM, a Building polygon ensures proper routing of roof runoff into the subsurface or surface system at the correct discharge point.

When importing into ICM:

- Building features represented by mesh zone polygons should be configured to raise the ground surface by 10 feet so that rain falling on the building is shed outward and surface flow is routed around the footprint.
- Building features represented by Building polygons should be assigned parameters that reflect roof characteristics:

- A slope matching the actual roof slope
- A roughness value representative of the roof material
- A mesh level increase of 10 feet (with all other parameters left at default values)



Building Object Properties

Definition		
Building ID	0060-03_4600-01_roof_1	
System type	storm	
Single element	☒	
Drains to		
Drains to	Node	#D
Node ID	20365STIL	
Drain limiting		
Limit drain to capacity	☐	
Location		
Total area (acre)	0.353	#D
Contributing area (acre)	0.353	#D
x (US Survey ft)	3138354.1	#D
y (US Survey ft)	1696882.2	#D
Runoff		
Slope (%)	2.3	#D
Rainfall profile	1	#D
Evaporation profile	1	#D
Output lag (minutes)	0.00	
SUDS/LIDs		
SUDS controls		
Roughness		
Roughness (Manning's n)	0.0180	
Roughness definition		
Mesh level		
Type	Rel. to highest	#D
Raise by (ft)	10.000	
Porous polygon definition		
Porosity	0.000	
Height (ft)	10.000	
General properties		
Notes		
Hyperlinks		
User defined properties		

Figure 16 Building Properties

Building features imported as “Buildings” may also be meshed into a single computational element for simplicity and performance, with the resulting hydrograph routed to the most appropriate downstream node, conduit, or 2D point source.

In some areas, adjacent buildings share common walls or are tightly clustered. This can create artificial depressions or “sinks” in the mesh when represented as separate polygons. In such cases, building polygons may be dissolved into a single feature to prevent unintended ponding and ensure realistic overland flow behavior.

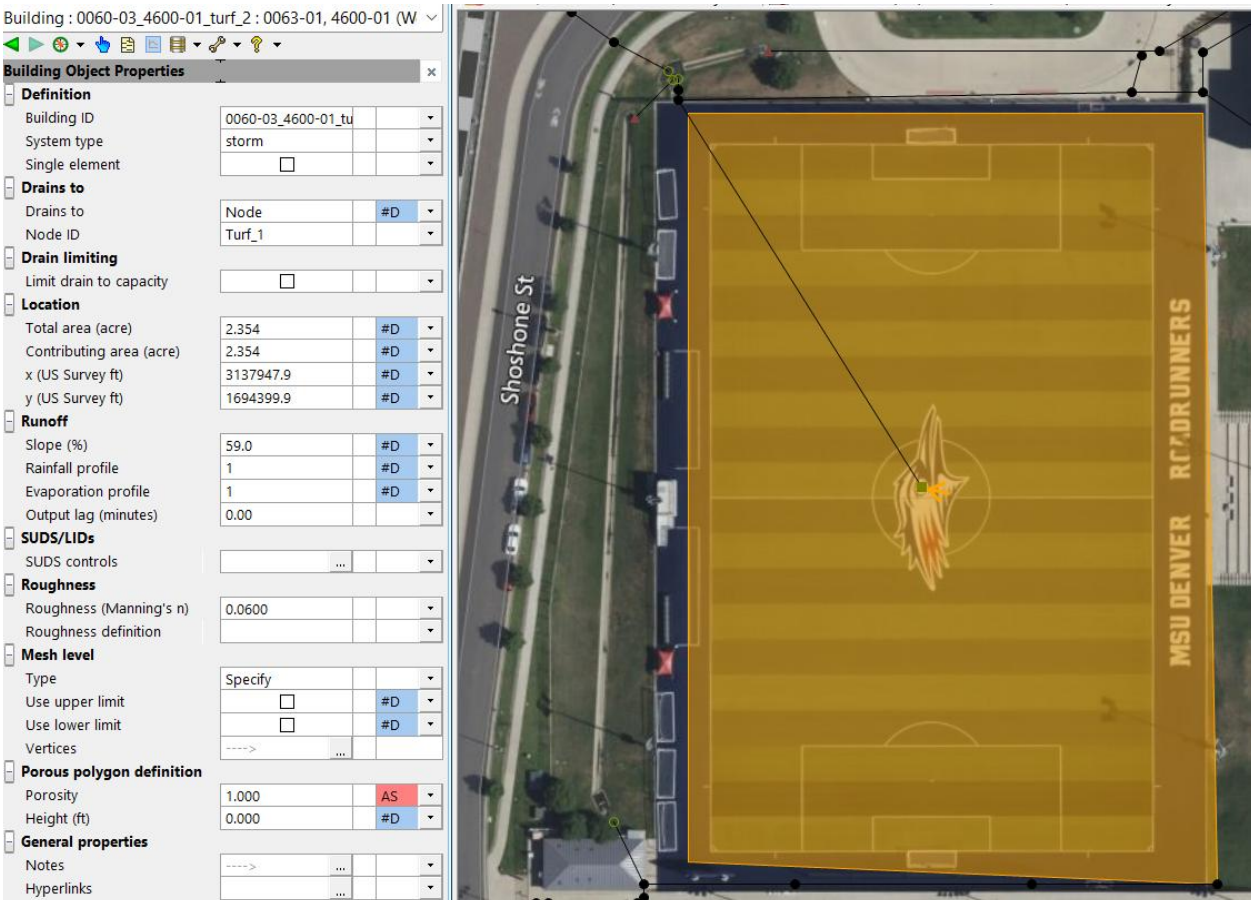
Note: Dissolving building polygons may be necessary when adjacent structures share walls that would otherwise create false low spots in the 2D mesh.

4.4.1. Other Use of Mesh Zone

Mesh Zones can be applied in a variety of ways beyond representing buildings. There are countless potential uses, and these guidelines are not intended to limit future innovation or modeling approaches. One practical application is modifying the local mesh resolution in areas where additional detail is beneficial or where reduced resolution is sufficient. For example, a modeler may choose to increase resolution in an intersection where flow can split along multiple paths or decrease resolution in a dry detention area with minimal hydraulic activity.

4.4.2. Other Use of Building

Buildings can also be used in a variety of innovative ways beyond representing structures with internal roof drainage. One practical application is modeling the hydrologic influence of artificial turf athletic fields. Because these systems typically include underdrains that function similarly to roof drains (collecting runoff and conveying it through a defined outlet) they can be effectively represented using a Building feature paired with a dummy storage node. The parameters used for a building object representing turf are shown in Figure 17.

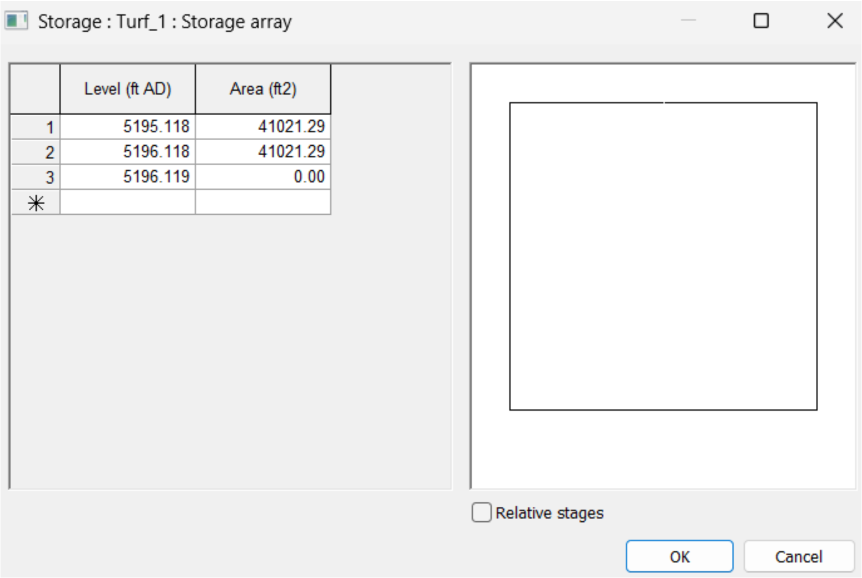

Building : 0060-03_4600-01_turf_2 : 0063-01, 4600-01 (W

Building Object Properties

Definition		
Building ID	0060-03_4600-01_tu	
System type	storm	
Single element	☐	
Drains to		
Drains to	Node	#D
Node ID	Turf_1	
Drain limiting		
Limit drain to capacity	☐	
Location		
Total area (acre)	2.354	#D
Contributing area (acre)	2.354	#D
x (US Survey ft)	3137947.9	#D
y (US Survey ft)	1694399.9	#D
Runoff		
Slope (%)	59.0	#D
Rainfall profile	1	#D
Evaporation profile	1	#D
Output lag (minutes)	0.00	
SUDS/LIDs		
SUDS controls		
Roughness		
Roughness (Manning's n)	0.0600	
Roughness definition		
Mesh level		
Type	Specify	
Use upper limit	☐	#D
Use lower limit	☐	#D
Vertices	---->	
Porous polygon definition		
Porosity	1.000	AS
Height (ft)	0.000	#D
General properties		
Notes	---->	
Hyperlinks		

Figure 17 Modeling Turf with Building Polygon and Storage Node

The storage node should represent the volume within the underdrain layer. Where design information is available, the documented storage volume should be used. Where such documentation is not available, modelers should assume a storage volume equal to 12 inches of underdrain #2 stone with a porosity of 0.4, multiplied by the turf polygon area. The top of the storage array may be set to be 1 foot below ground elevation. This storage node is then connected to the public storm sewer system to reflect how these facilities drain in the real world. An example of this application is shown in Figure 18.



	Level (ft AD)	Area (ft2)
1	5195.118	41021.29
2	5196.118	41021.29
3	5196.119	0.00
✳		

☐ Relative stages

Figure 18 Storage Array Associated with Turf

4.5. Walls

Walls are used in ICM to represent constructed features that restrict or redirect overland flow but may not be fully captured in the underlying DEM. These features help ensure that flood routing and shallow flow behavior accurately reflect real-world topographic constraints wherever retaining walls, sound barriers, floodwalls, or similar structures influence surface hydraulics. An example application is shown in Figure 19, where a wall is used to represent a retaining wall along a roadway tunnel approach.

Walls may be represented using either ‘Porous Wall’ features or ‘Base Linear Structure (2D)’ features:

- Porous Walls are linear features that can be modeled either as a fixed height above the DEM or as a fixed absolute elevation. They can also incorporate a porosity value to allow some water to pass through the structure, representing partial blockage or flow through gaps, fences, or slotted barriers.
- Base Linear Structure (2D) features support a more detailed representation, including variable elevations along the feature and additional head loss related parameters. These can be useful for complex structures where hydraulic behavior cannot be captured by a simple height or porosity alone.

Modelers should use engineering judgment when selecting the appropriate feature type and populating the associated parameters. The intent is not to constrain workflows but to provide flexible tools for representing constructed barriers that meaningfully influence surface flow and ponding.

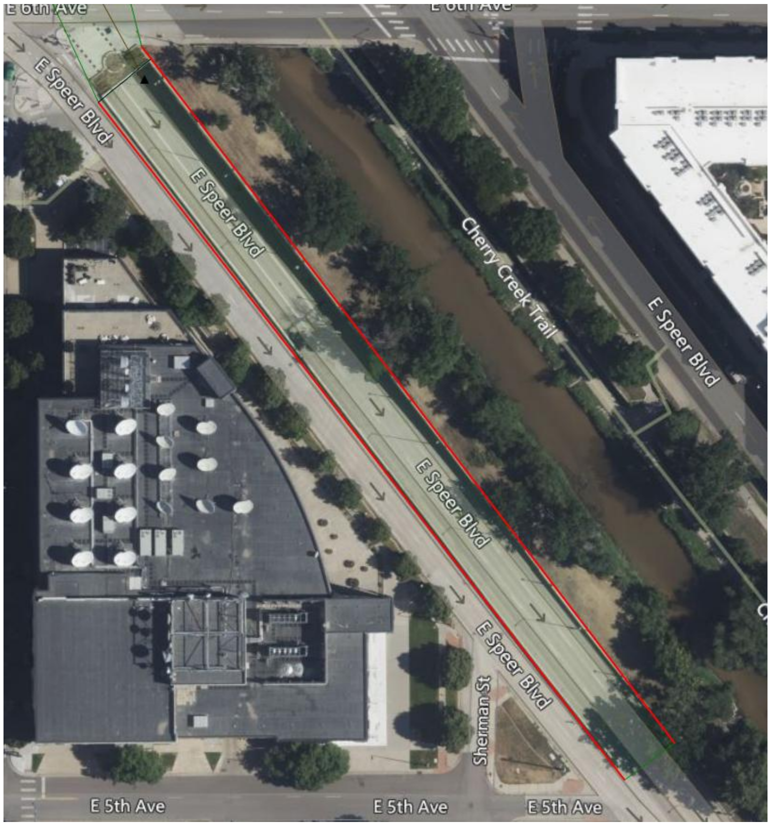


Figure 19 Example of a Wall along a Roadway Tunnel Approach

4.6. Mesh Level Zone

Mesh Level Zones provide capabilities distinct from standard Mesh Zones by allowing modelers to directly set ground elevations for the individual vertices within the polygon. This feature enables users to manually override the underlying DEM in locations where the terrain is inaccurately represented or where small-scale features are too narrow or subtle to be captured by the LiDAR-derived surface.

Mesh Level Zones are particularly useful for representing narrow ditches, small channels, or pitched roofs where the true topography cannot be reliably inferred from the DEM alone. By explicitly defining elevations along the polygon boundary or within the polygon interior, modelers can more accurately reflect the intended hydraulic behavior in areas where the DEM may smooth, omit, or incorrectly generalize terrain features.

These cases are often identified during preliminary results validation steps, when unexpected ponding, unnatural flow paths, or missing conveyance features reveal where supplemental elevation adjustments are needed. Applying Mesh Level Zones in these targeted locations allows the modeler to correct local terrain inaccuracies without modifying the broader DEM.

4.7. Breaklines

Breaklines may be applied within the 2D mesh to enforce elevation transitions or preserve linear topographic features; however, their use in CCD study area models should be approached with caution. Although software vendor tutorials often demonstrate workflows that incorporate curb lines as breaklines, testing this application in the CCD system identified several drawbacks, including impacts on simulation times, associated with this practice in Denver's steep, highly variable street network.

When curb lines were imported directly as breaklines, inconsistencies between the underlying DEM, impervious surface polygons, and curb location geometry frequently produced unintended depressions within individual 2D elements. These localized low points tended to trap water that should otherwise drain along the street surface, resulting in persistent (but incorrect) ponding that drew attention to locations that are not representative of true hydraulic concerns. In addition, the density of curb line features in urban corridors often forced the mesh generator to create narrow or highly skewed elements, which increased computational effort and extended runtimes without providing meaningful improvements to model fidelity.

Comparative tests performed without curb lines as breaklines generally produced more hydraulically coherent surface routing and visually more reliable overland flow patterns. For these reasons, breaklines are not recommended as a default requirement for curb representation.

That said, breaklines remain a useful tool when applied selectively. Modelers may incorporate breaklines where they are judged to add value, provided they do not create mesh instability or excessive runtimes. Engineering judgment should guide their use, with an emphasis on avoiding unnecessary geometric complexity and ensuring that breaklines reinforce, rather than distort, the intended surface flow behavior.

5.0. Hydraulic Modeling – Waterway Drainage Features as 1D Components

Major regional drainage features (such as gulches, creeks, streams, and rivers) are represented in the CCD unified modeling framework using 1D hydraulic components rather than 2D mesh elements. These waterways are typically administered in coordination with MHFD and serve as the primary conveyance paths for regional runoff. Because these features form the backbone of the overland drainage system but are not the primary focus of CCD's local stormwater planning efforts, they are most efficiently and appropriately represented using ICM's 1D riverine tools.

Modeling these major waterways as 1D river reaches provides several advantages. First, 1D elements can be initialized directly during the pre-simulation warmup period using the assigned inflow and tailwater boundary conditions. This avoids the need for a full 2D dynamic simulation to "wet" the channel system, substantially reducing computational effort. Second, the direction of flow in channelized systems is already known, meaning that solving these areas in 2D provides limited additional value but significantly increases computational demand. Third, in reaches with perennial flow, the DEM cannot accurately represent the ground surface beneath the water surface, since LiDAR cannot penetrate the water column. Correcting this would require DEM resampling or manual elevation replacement—adding unnecessary effort and introducing opportunities for discontinuities in the resulting terrain. Representing gulches and creeks with 1D transects therefore improves model runtimes while still maintaining the necessary hydraulic interaction between the major overland drainage system and the subsurface storm sewer network. This balance of efficiency and fidelity is a key component of CCD's unified modeling approach.

This strategy is also well aligned with regional modeling practices. The areas represented using 1D elements typically fall within the floodplain of the major waterway and are not the primary focus of CCD's local planning level studies. By using ICM's 1D river reach and bridge modeling tools, CCD can import MHFD-developed HEC-RAS cross sections, bridge definitions, and hydraulic geometry directly into the ICM model. This avoids duplicating work already completed by MHFD and preserves consistency across regional modeling efforts.

The sections that follow describe the workflow and model components used to represent these features, including cross section development, bank line creation, 1D–2D interfacing, representation of convergences, and modeling approaches for bridges and ponds. Together, these elements ensure that major drainageways are captured efficiently, consistently, and with the appropriate hydraulic detail needed to support CCD's unified modeling framework.

5.1. Gulches, Creeks, and Rivers

Major regional drainageways (such as gulches, creeks, streams, and rivers) should be represented in the model using 1D open channel elements based on cross section (transect) geometry, similar to the approach used in HEC-RAS. These features constitute the primary conveyance corridors for regional runoff and form the backbone of the surface drainage system within CCD. Because these waterways are large, channelized, and typically studied in coordination with MHFD, representing them as 1D riverine elements provides the appropriate level of hydraulic detail while maintaining model efficiency and consistency across study areas.

In ICM, these 1D systems are constructed using cross section lines, river reach links, and bank lines, which together define the channel geometry and the interface between the 1D watercourse and the surrounding 2D mesh. The procedures for establishing this connection differ from a traditional standalone HEC-RAS model and are documented in detail below. These steps include creating cross sections, building river reach links, generating bank lines, voiding the channel area from the 2D mesh, and establishing the 1D–2D hydraulic exchange.

Wherever possible, HEC-RAS transect information developed by MHFD can be imported directly into ICM. However, importing the transects is only the first step. Additional steps are required to fully integrate the channel with the 2D mesh domain, including establishing bank lines, building boundaries, and assigning rainfall-driven subcatchments over the voided channel area.

The steps below provide the recommended workflow for constructing these 1D channel features in ICM and ensuring that they interact correctly with the broader 2D surface. The River Reach build tools referenced in Steps 1–8 are accessed from the River Reach functions menu shown in Figure 20.

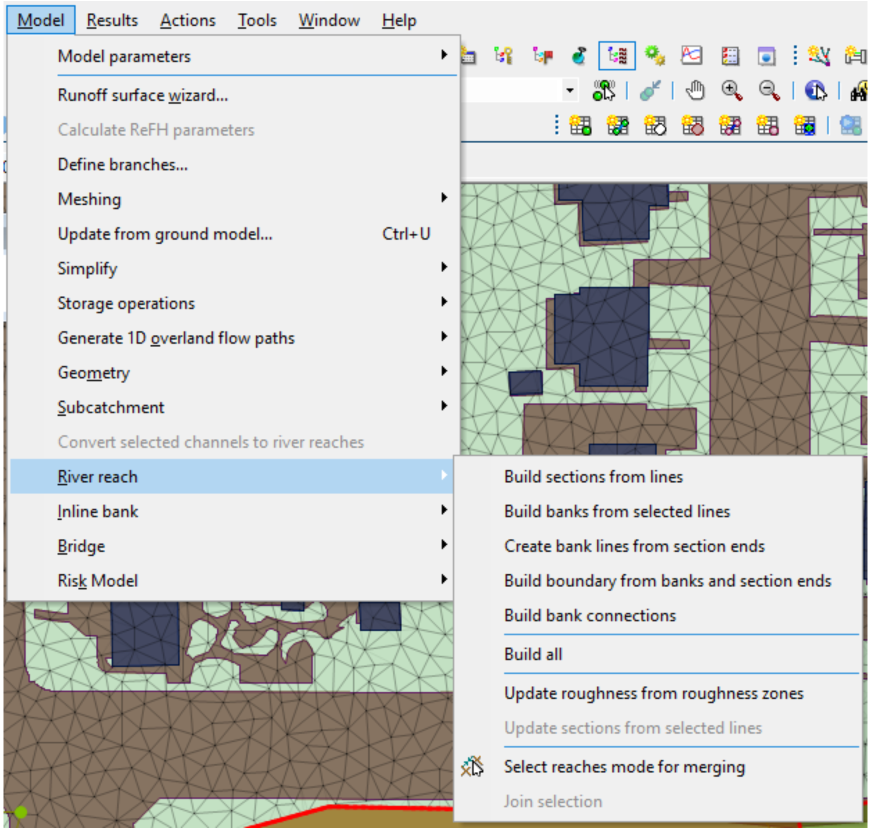


Figure 20 River Reach Functions

Step 1 - Create cross section lines

Cross section lines should be perpendicular to the flow path and extend to the edge of the overbank. Cross section lines should exist near each outfall or where there is a noticeable change in channel shape or slope.

If importing from a HEC-RAS model:

Use the network import function to import the HEC-RAS model information directly to a InfoWorks network as shown in Figure 21 below. It should be noted that some transects may need to be “trimmed” to the overbank to maintain consistency throughout the study areas.

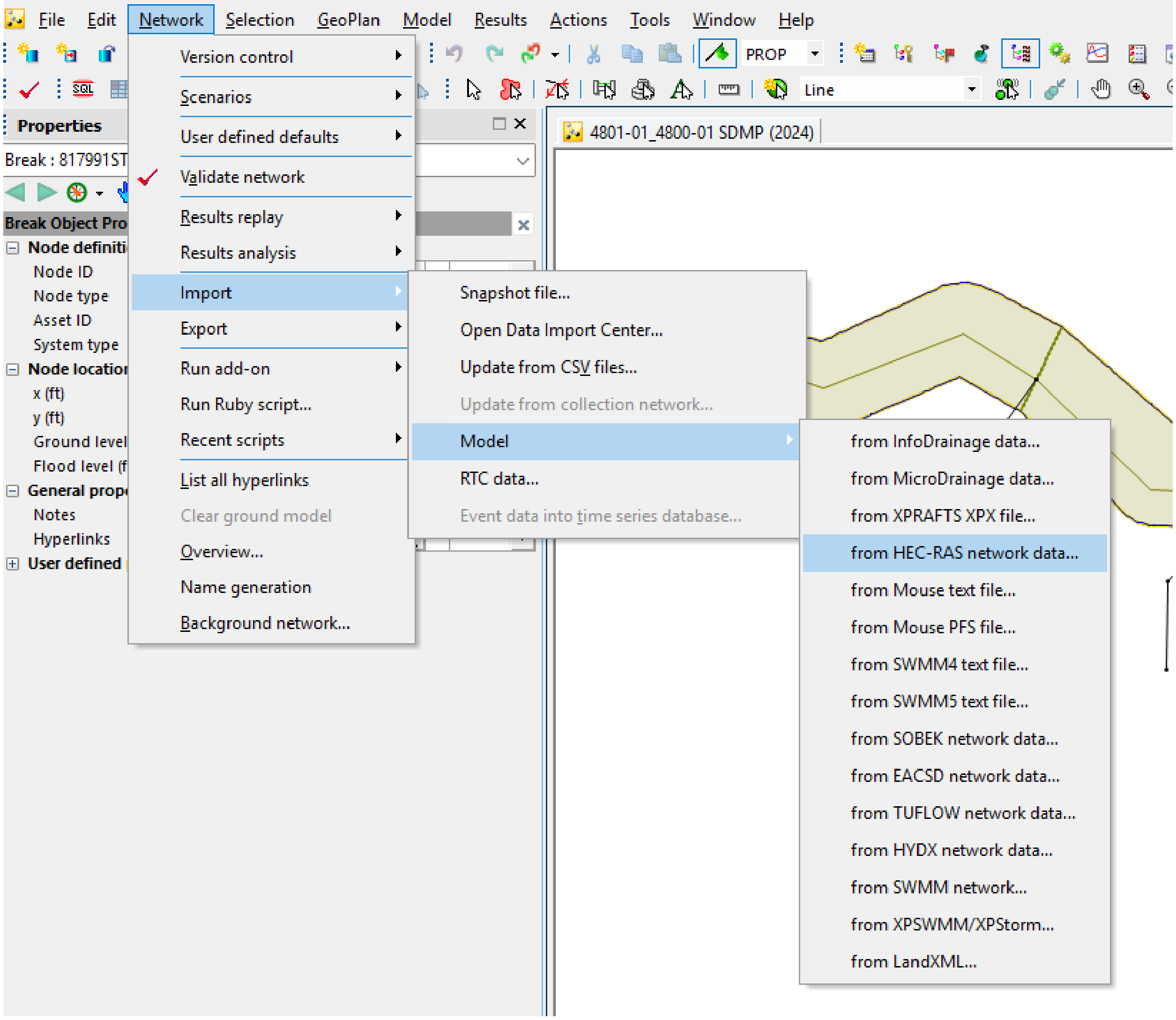


Figure 21 Importing HEC-RAS Model Network Data

If creating new transects:

Manually draw new transect lines directly in ICM using ‘cross section’ features. Select cross section lines and use the “Update from Ground Model” function to populate the “Section data” field. Different Manning’s roughness may be set for different parts of the riverbed.

Step 2 - Create break nodes near outfalls

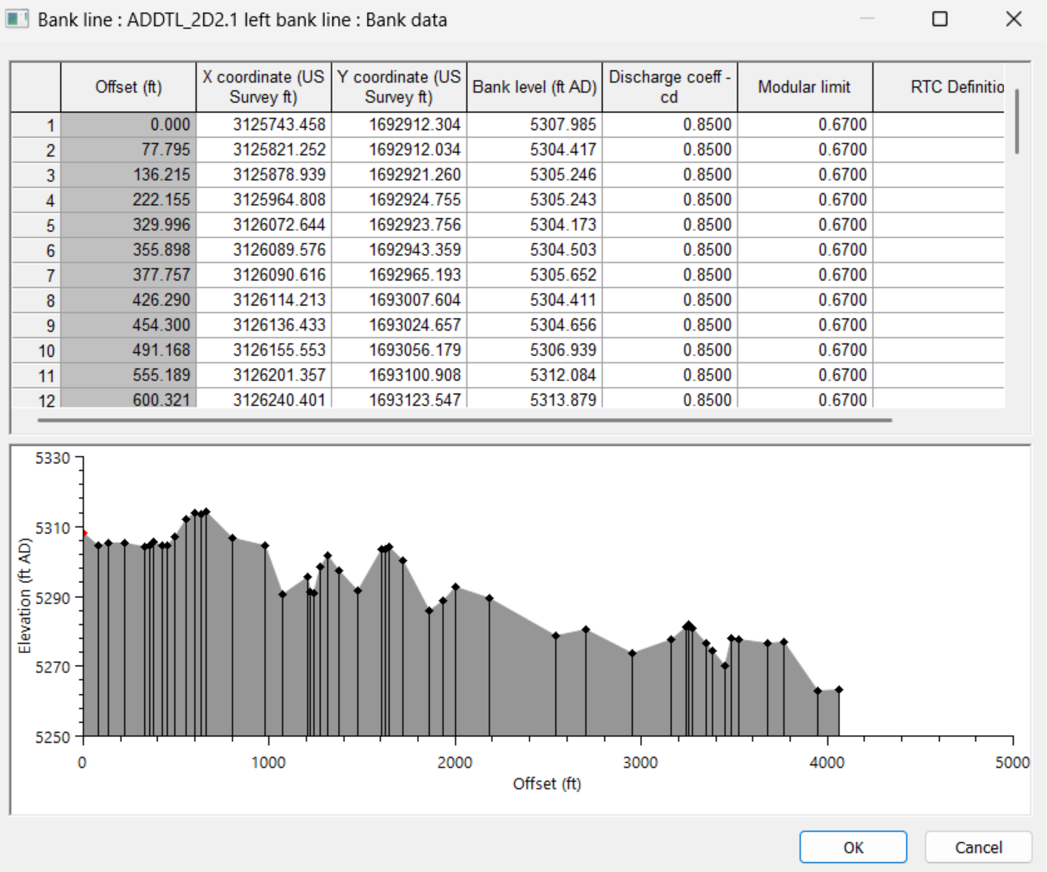
Create break nodes at critical cross section lines created in Step 1 where the 1D sub-surface networks can connect. These should all be snapped to a vertex on the cross-section line, and the name of the node should match the name of the cross-section line.

Step 3 - Create a river reach link

Connect the nodes defined in Step 2 with River reach links. These links should follow the thalweg of the drainageway. Select the river reach links and run the “Build sections from lines” function to populate the river sections table with section data from step 1. The data between the cross sections are linearly interpolated to populate the length of the river reach link, similar to the HEC-RAS solver.

Step 4 – Create and edit bank lines

Select the river reaches and run the “Create bank lines from section ends” function. This creates a left bank line and a right bank line for each selected line. The bank lines act as the interface between the 1D river reach and 2D mesh element. Additional vertices should be added to the bank lines to ensure there are no major disjoints between the 2D mesh element elevations and the linearly interpolated bank line vertex elevations. Once the bank lines have been edited, run the “Update from Ground Model” function to populate the bank data. The Discharge Coefficient and Modular limit should also be set to 0.85 and 0.67, respectively, based on recommendations from the software vendor. These values may be changed based on the modeler’s discretion. After populating the bank line parameters, confirm the updated attributes appear as expected. Figure 22 provides a reference screenshot of the expected bank line information.



Bank line : ADDTL_2D2.1 left bank line : Bank data

	Offset (ft)	X coordinate (US Survey ft)	Y coordinate (US Survey ft)	Bank level (ft AD)	Discharge coeff - cd	Modular limit	RTC Definitio
1	0.000	3125743.458	1692912.304	5307.985	0.8500	0.6700	
2	77.795	3125821.252	1692912.034	5304.417	0.8500	0.6700	
3	136.215	3125878.939	1692921.260	5305.246	0.8500	0.6700	
4	222.155	3125964.808	1692924.755	5305.243	0.8500	0.6700	
5	329.996	3126072.644	1692923.756	5304.173	0.8500	0.6700	
6	355.898	3126089.576	1692943.359	5304.503	0.8500	0.6700	
7	377.757	3126090.616	1692965.193	5305.652	0.8500	0.6700	
8	426.290	3126114.213	1693007.604	5304.411	0.8500	0.6700	
9	454.300	3126136.433	1693024.657	5304.656	0.8500	0.6700	
10	491.168	3126155.553	1693056.179	5306.939	0.8500	0.6700	
11	555.189	3126201.357	1693100.908	5312.084	0.8500	0.6700	
12	600.321	3126240.401	1693123.547	5313.879	0.8500	0.6700	

Figure 22 Bank Line Data

Step 5 – Build banks

Select the bank lines and river reaches and run the “Build banks from selected lines” function. This function imports the bank line table from step 4 into the river reach section.

Step 6 – Build reach boundary

Select the river reach section and run the “Build boundary from banks and section ends” function. This step voids the river reach area from the 2D mesh to avoid double counting.

Step 7 – Connect to 2D zone

Select river reaches and the 2D zone, run the “Build bank connections” function. This step connects the banks to the 2D zone and establishes the 1D-2D interface.

Step 8 – Create subcatchments

Since the river reach area is voided out from the 2D mesh in Step 6, it receives no rainfall. The solution to this problem is adding subcatchments that exactly overlay the river reach areas. These subcatchments drain to the break nodes on river cross section lines.

5.1.1. Convergence Locations

At locations where multiple river reaches converge, a cross-section line should be created at the termination or start of each channel. The area between the cross-section lines should be covered by a storage area, as shown in the triangular area in Figure 23. Instead of creating a break node on each cross-section line, a break node is created in the middle of the storage area, and the three river reaches all connect to this point. This way, the gulch capacity covered by the storage area is accounted for in the overrun of the river reach links.

Figure 23 Multiple River Convergence Example

5.2. Bridges and Crossings

Bridges and roadway crossings can be represented in different ways within ICM, and the appropriate method depends on how the underlying DEM captures these structures. If the DEM reflects the road deck elevation, the bridge can typically be handled through 2D mesh treatment. If the DEM instead exposes the channel beneath the structure (such as when a roadway surface has been removed or not captured), a 1D bridge feature similar to HEC-RAS is required to represent the crossing accurately. The following subsections outline the recommended workflows for each scenario.

5.2.1. 1D Bridge Representation

In some locations, the DEM does not capture the roadway deck and instead reflects the underlying channel, requiring the use of a 1D Bridge feature to represent the crossing accurately. This method is also appropriate when importing HEC-RAS–based bridge geometry, as the setup closely parallels the HEC-RAS workflow and can be imported directly into ICM. In addition, modelers may choose this approach in cases where a 2D-only representation of bridge overtopping is not preferred due to stability, runtime, or analytical considerations. The step-by-step procedure for constructing a Bridge object is detailed below.

Note: it is assumed that upstream and downstream river reaches will have been built before the bridge structure is created.

Step 1 – Create cross section lines

Five cross section lines perpendicular to the direction of flow are required for any bridge object. From upstream to downstream, the 5 cross section lines represent the contraction reach, start of US bridge opening, the bridge deck for overtopping, end of bridge opening, and expansion reach as shown in Figure 24. Similar to river reaches, run the "Update from ground model" function on the cross section lines to populate elevations. It should be noted that the cross section for the bridge deck will likely require manual definition of elevations where the DEM has been modified to represent the streambed.

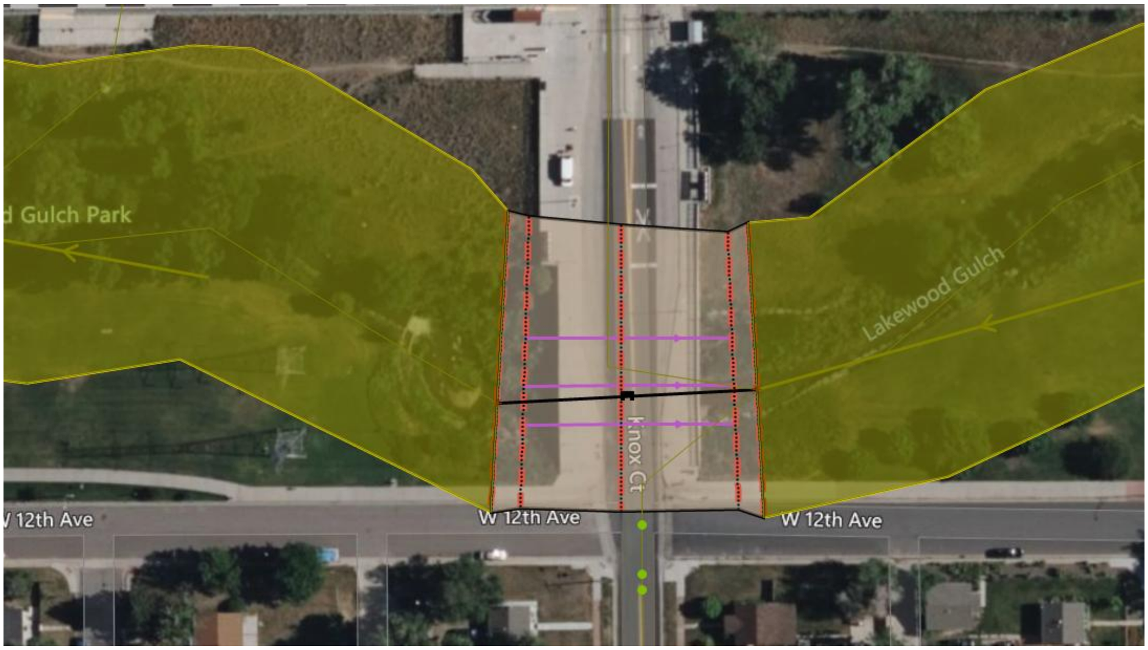


Figure 24 Bridge Object

Step 2 – Create bridge object

Connect the break nodes between the upstream and downstream river reaches with a Bridge link. Select all cross-section lines and the bridge link, run the "Build sections from lines" function as shown in Figure 25. This step populates the Bridge object table with the section data.

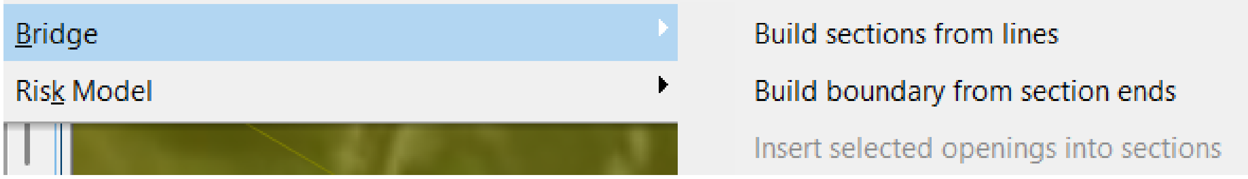
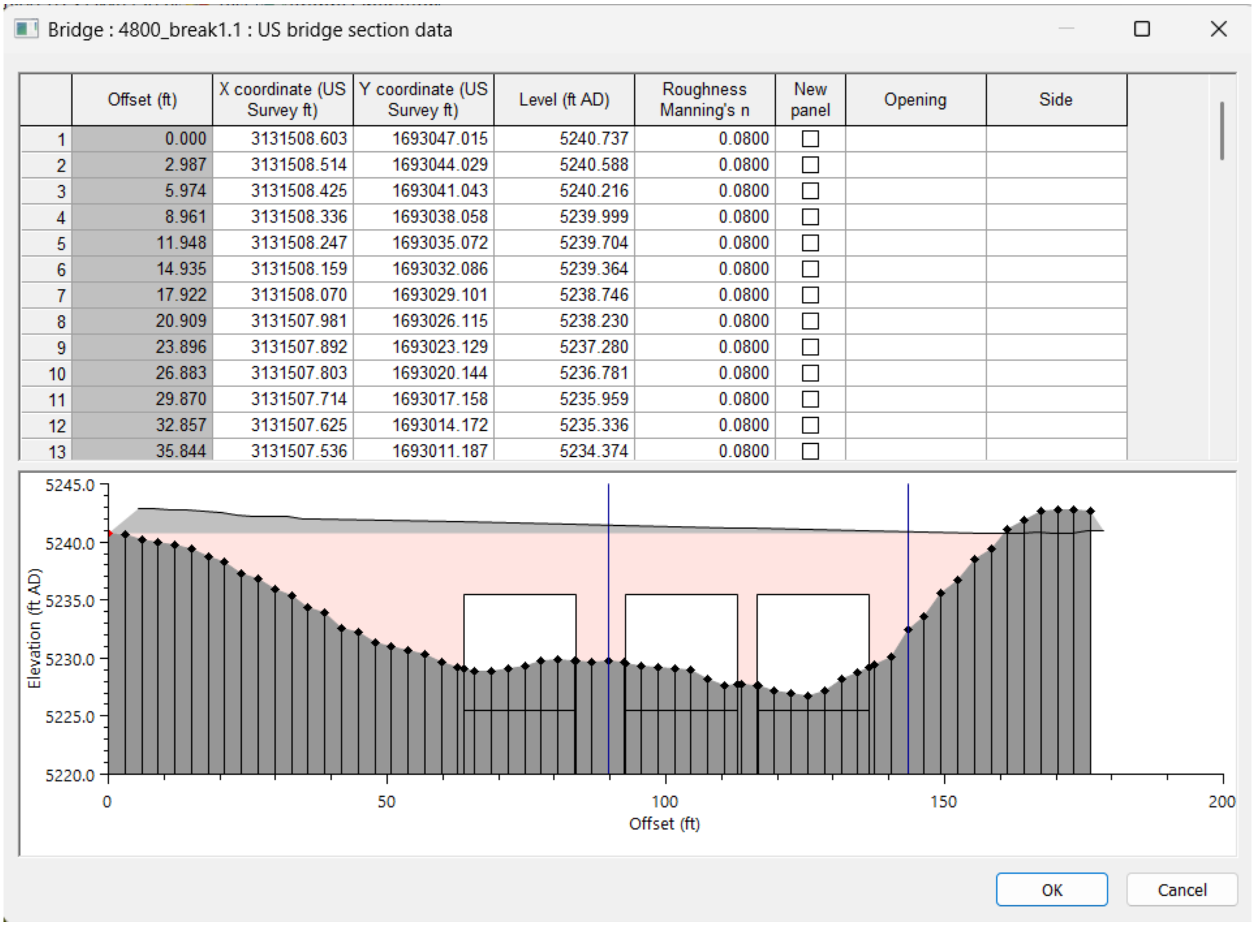


Figure 25 Bridge Functions

Step 3 – Create bridge opening lines

‘Bridge Opening’ features are lines in the direction of the flow, representing the culvert, pipe, or opening under the roadway. Figure 26 includes 3 bridge openings, shown as the pink arrows in the direction of the gulch. Shape, size, and invert elevations of each Bridge Opening need to be defined. Select the Bridge openings and the Bridge object, then run “Insert selected openings into sections” to populate the Bridge object with Bridge opening data.


Bridge : 4800_break1.1 : US bridge section data

	Offset (ft)	X coordinate (US Survey ft)	Y coordinate (US Survey ft)	Level (ft AD)	Roughness Manning's n	New panel	Opening	Side
1	0.000	3131508.603	1693047.015	5240.737	0.0800	☐		
2	2.987	3131508.514	1693044.029	5240.588	0.0800	☐		
3	5.974	3131508.425	1693041.043	5240.216	0.0800	☐		
4	8.961	3131508.336	1693038.058	5239.999	0.0800	☐		
5	11.948	3131508.247	1693035.072	5239.704	0.0800	☐		
6	14.935	3131508.159	1693032.086	5239.364	0.0800	☐		
7	17.922	3131508.070	1693029.101	5238.746	0.0800	☐		
8	20.909	3131507.981	1693026.115	5238.230	0.0800	☐		
9	23.896	3131507.892	1693023.129	5237.280	0.0800	☐		
10	26.883	3131507.803	1693020.144	5236.781	0.0800	☐		
11	29.870	3131507.714	1693017.158	5235.959	0.0800	☐		
12	32.857	3131507.625	1693014.172	5235.336	0.0800	☐		
13	35.844	3131507.536	1693011.187	5234.374	0.0800	☐		

Figure 26 Bridge Object – US bridge section data table showing ground elevation, openings, and deck elevation.

Because Bridge objects do not support bank lines along their upstream or downstream edges, they cannot interface directly with the 2D mesh in the same manner as river reach features. This distinction is intentional; the bridge opening hydraulics are handled entirely within the 1D Bridge object, and no lateral exchange with the 2D domain occurs at the object boundaries. As a result, connectivity to the surrounding 2D surface must be established through the adjacent river reach sections rather than through the bridge object itself.

5.2.2. 2D Bridge Representation

A 2D bridge representation may be used when the DEM reliably captures the roadway surface, including the deck elevation and any meaningful topographic detail across the crossing. When this condition is met, the bridge can be modeled directly within the 2D mesh, albeit with additional treatment at the ends of the 1D river reaches. This approach is often advantageous for crossings that are skewed relative to the channel, where overtopping flow paths may deviate from the culvert alignment, or where roadway crown and lateral grade significantly influence how overflow spreads across the street network or re-enters the storm system. When these geometric or hydraulic considerations are important, a 2D treatment provides greater flexibility and realism than a 1D bridge object, which assumes overtopping and culvert conveyance occur along the same path. Figure 27. illustrates a representative model setup for the 2D bridge approach described in Steps 1-6 below.

Figure 27 2D Bridge Example

Step 1 – Create Storage area polygon

Storage area polygons are used to intentionally exclude certain regions from 2D mesh generation. By voiding these areas from the mesh, the model ensures they are not solved within the 2D domain and are instead represented using a corresponding 1D hydraulic element—similar in concept to the voided channel created by a river reach boundary. This avoids double counting and preserves the intended 1D–2D interface.

A storage area polygon should be drawn around the end of the river reach so that the left and right bank lines will form a contiguous boundary around the river reach. This area should be drawn so as to exclude low spots, preferably staying at a constant elevation between the two bank lines. It should also be noted that the break node should be inside the polygon and there should not be any gaps between the storage area and the river reach cross section.

Step 2 – Create Bank line

Create a bank line along the outside edge of the storage polygon, snapping to each vertex. Then, run the "Update from ground model" function to populate the Bank data table.

Step 3 – Create a Dummy Outfall Node and Inline Bank link

Create a dummy 1D outfall outside the storage area polygon (a ground surface elevation will need to be populated, but it is not referenced), then create an Inline bank link from the break node to the 1D outfall (the inline bank must intersect the bank line from Step 2). Then, select both the inline bank and the bank line, and run the "Build section data from selected bank line" function shown in Figure 28. This will populate the inline bank object table with the bank data.

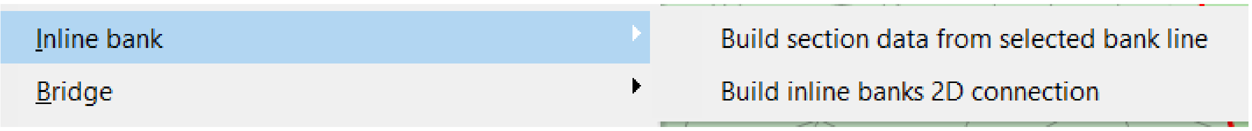


Figure 28 Inline Bank Build Functions

Step 4 – Connect to 2D Zone

Select the inline bank and the 2D zone, run "Build inline banks 2D connection".

Step 5 – Create Subcatchment

Create a subcatchment that overlaps the storage area, so the area that is voided out of the 2D domain still receives rainfall. Because the storage area represents the same contributing corridor as the adjacent river reach boundary/subcatchment, it is recommended to extend the subcatchment that covers the adjacent river reach boundary so that it also overlaps the storage area polygon. This ensures rainfall is applied to the voided storage area footprint (which does not have mesh elements to receive rain) without creating a separate subcatchment. Confirm the edited subcatchment fully covers the storage area, is snapped to all vertices of the storage area, and continues to drain to the appropriate break node.

Step 6 – Connect sections across the bridge

Connect break nodes with a 1D conduit link of the appropriate size. Ex. 10 ft wide x 10 ft tall.

5.3. Ponds and Reservoirs

Permanent ponds and reservoirs are modeled using an approach similar to the 2D bridge representation workflow, relying on storage areas and inline banks to define the 1D–2D interface. In this method, the pond water surface is not solved within the 2D mesh; instead, a storage area polygon is used to exclude the pond footprint from 2D meshing, and a corresponding 1D storage node represents the volume–elevation relationship of the waterbody. This approach is appropriate for ponds and reservoirs where internal water circulation is less important than accurately capturing the storage capacity and its hydraulic connection to the surrounding system. Inline banks built along the storage area perimeter then establish the required linkage between the 1D pond representation and the adjacent 2D mesh, consistent with the steps described for bridge treatments. Figure 29 shows an example (Garfield Lake) where a 1D storage node is used to represent storage/retention volume within a permanent water body. The steps to implement this approach are detailed below.

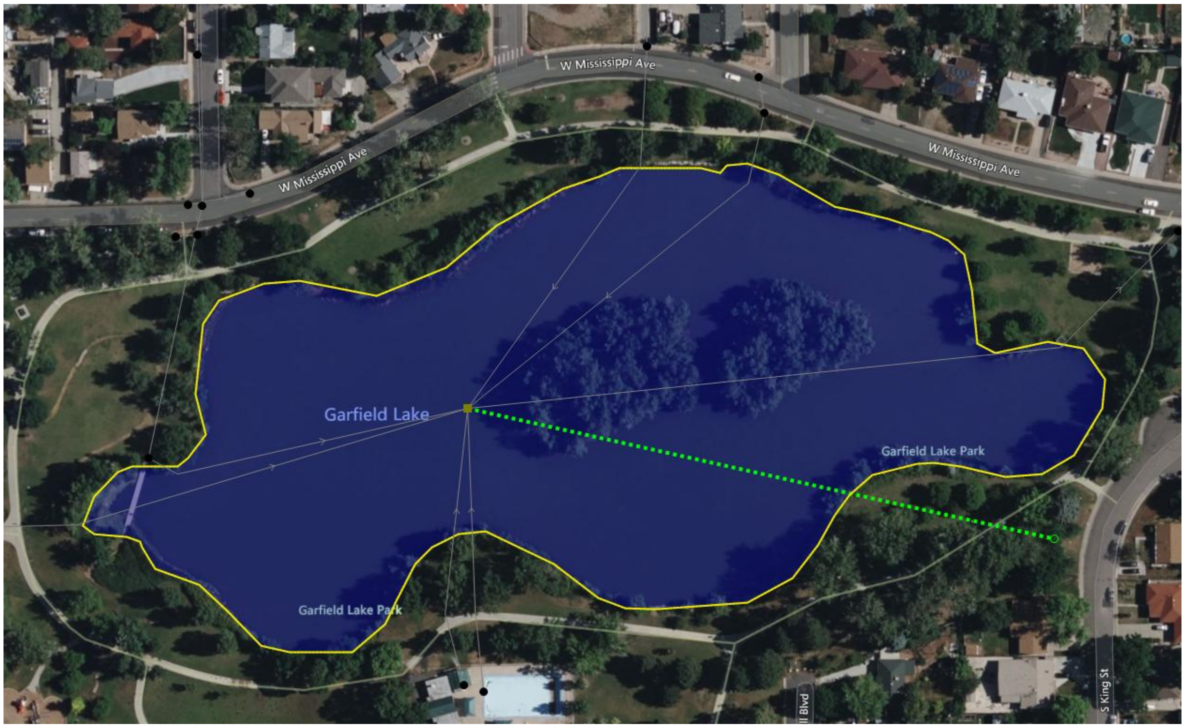


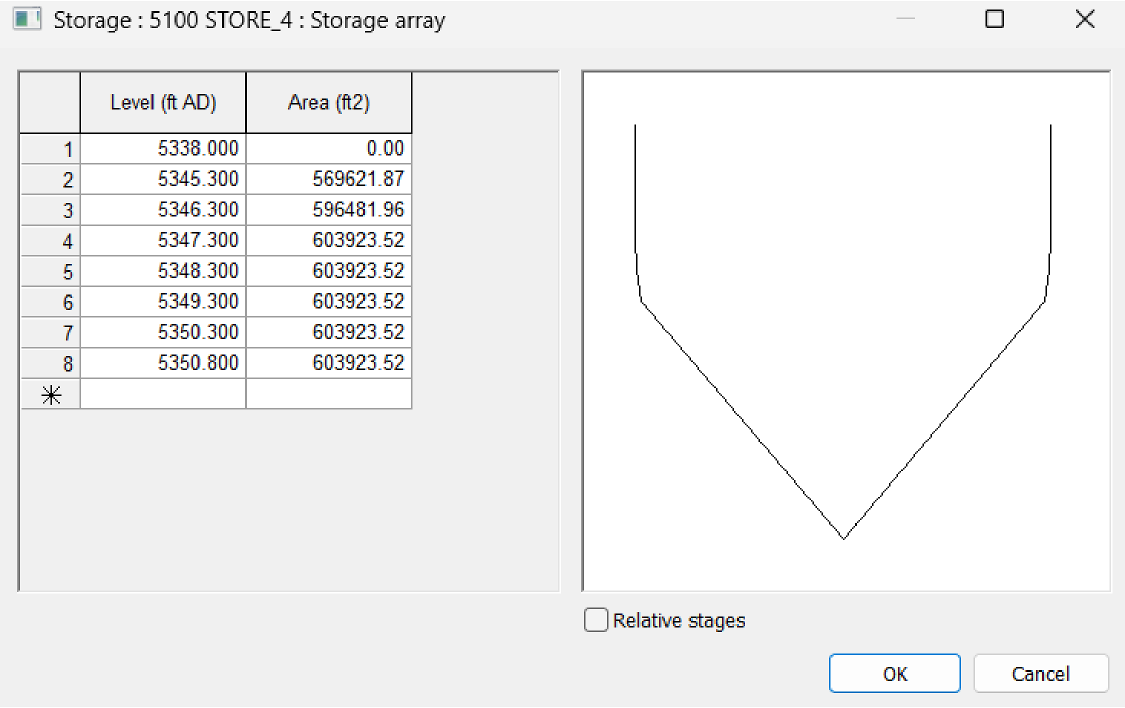
Figure 29 Retention Pond Example

Step 1 – Create Storage Area Polygon

Draw a storage area polygon by tracing the pond outline.

Step 2 – Create Storage Node

Create a storage node in the center of the storage area, then redirect the nearby pipe networks that terminate at outfalls into the storage node. Create an elevation vs area array for the pond, ensuring that the lowest elevation of the array is lower than the lowest connected pipe and that the highest elevation is greater than the ground level of the storage node. It is recommended to remove the flood level for these nodes. An example storage array is illustrated in Figure 30. Surface areas below the minimum water surface elevation (sometimes referred to as “dead storage”) do not have to match real-world conditions as they are inconsequential to model calculations but can be populated based on best available information.



Storage : 5100 STORE_4 : Storage array

	Level (ft AD)	Area (ft2)
1	5338.000	0.00
2	5345.300	569621.87
3	5346.300	596481.96
4	5347.300	603923.52
5	5348.300	603923.52
6	5349.300	603923.52
7	5350.300	603923.52
8	5350.800	603923.52
*		

☐ Relative stages

Figure 30 Storage Elevation Array Example

Step 3 – Create Bank line

Create a bank line around the perimeter of the storage area, making sure to snap to all vertices of the polygon. Run “Update from ground model” function to populate ground surface elevations.

Step 4 – Create Dummy Outfall Node and Inline Bank

Create a dummy 1D outfall outside the storage area polygon (a ground surface elevation will need to be populated, but it is not referenced), then create an Inline bank link from the break node to the 1D outfall (the inline bank must intersect the bank line from Step 2). Then, select both the inline bank and the bank line, and run the “Build section data from selected bank line” function. This will populate the inline bank object table with the bank data.

Step 5 – Connect to 2D Zone

Select the inline bank and the 2D zone, run the “Build inline banks 2D connection” function.

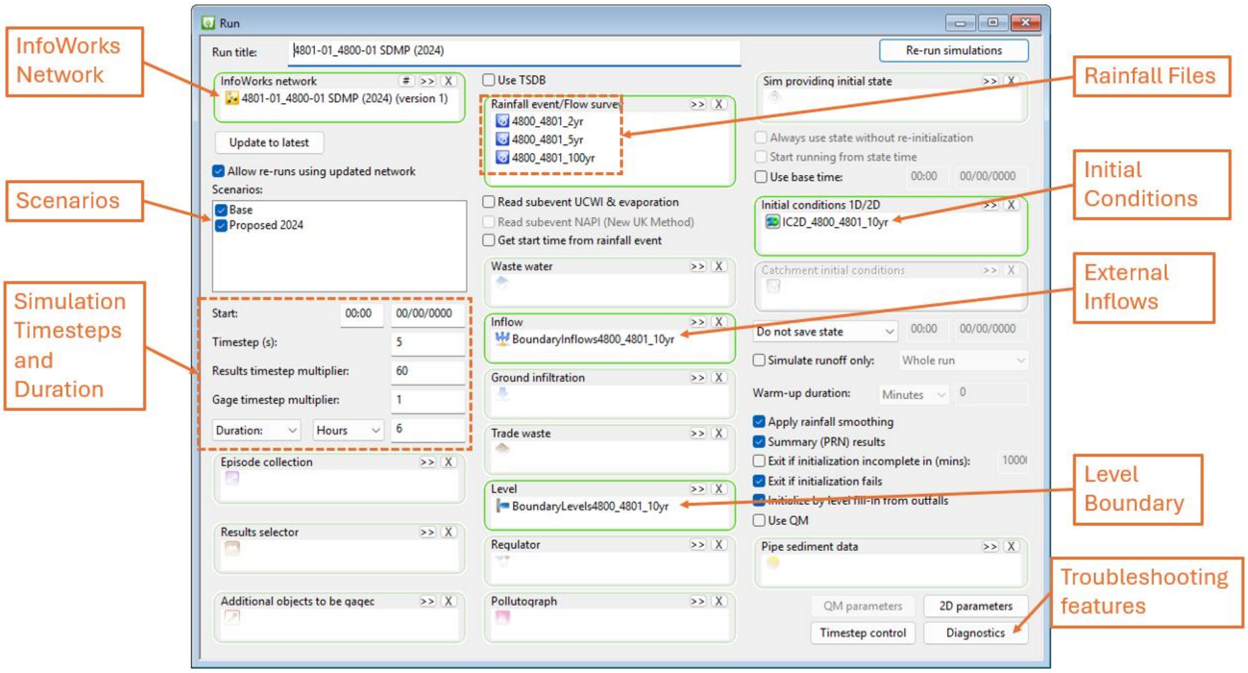
Step 6 – Create Subcatchment

Create a subcatchment over the Storage area to accurately simulate precipitation falling on the waterbody itself.

6.0. Simulation Inputs

In ICM, the simulation run setup is stored as a dedicated run file, which functions as a container that references all components needed to execute a hydraulic and hydrologic simulation. Unlike

EPA SWMM where rainfall inputs, boundary conditions, hydraulic elements, and time step controls are all embedded within a single input file, the ICM framework separates these elements into modular datasets. The run file pairs the project's InfoWorks network (which contains the hydraulic and hydrologic network), with rainfall hyetographs, inflow and tailwater boundary files, initial conditions datasets, and all simulation settings such as routing time steps, reporting intervals, and solution controls. An example run setup, with two scenarios and three rainfall inputs, is shown in Figure 31. This structure allows modelers to maintain a clear separation between models, boundary conditions, and computational parameters.


Run title: 4801-01_4800-01 SDMP (2024)

InfoWorks network: 4801-01_4800-01 SDMP (2024) (version 1)

☑ Allow re-runs using updated network

Scenarios:
☑ Base
☑ Proposed 2024

Start: 00:00 00/00/0000
Timestep (s): 5
Results timestep multiplier: 60
Gage timestep multiplier: 1
Duration: Hours 6

☐ Use TSDB

Rainfall event/Flow survey:
4800_4801_2yr
4800_4801_5yr
4800_4801_100yr

☐ Read subevent UCWI & evaporation
☐ Read subevent NAPI (New UK Method)
☐ Get start time from rainfall event

Inflow: BoundaryInflows4800_4801_10yr

Level: BoundaryLevels4800_4801_10yr

☐ Always use state without re-initialization
☐ Start running from state time
☐ Use base time: 00:00 00/00/0000

Initial conditions 1D/2D: IC2D_4800_4801_10yr

Do not save state 00:00 00/00/0000
☐ Simulate runoff only: Whole run
Warm-up duration: Minutes 0
☑ Apply rainfall smoothing
☑ Summary (PRN) results
☐ Exit if initialization incomplete in (mins): 1000
☑ Exit if initialization fails
☑ Initialize by level fill-in from outfalls
☐ Use QM

Figure 31 Sample Simulation Run Configuration

The subsections that follow provide guidance on configuring these simulation inputs, including recommended time step selections, rainfall definitions, and boundary condition treatments used in CCD's unified modeling approach. Each subsection highlights considerations that support model stability, efficiency, and consistency across basin-wide studies.

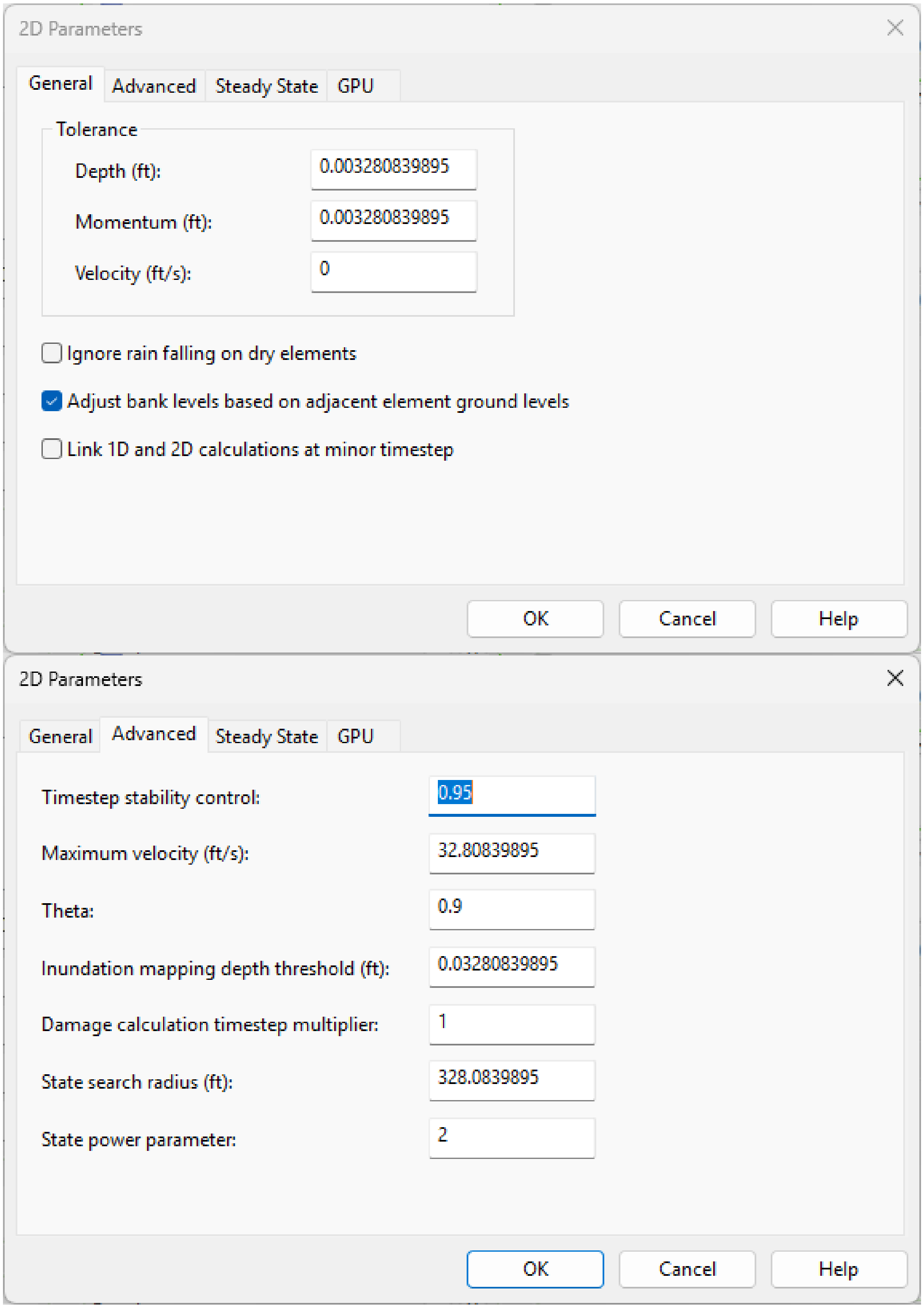
6.1. Time Steps & Global Parameters

The following guidance outlines how key time step and simulation parameters should be defined:

- Start: Stormwater simulations may be set with a dateless simulation start time (00:00 00/00/000), as there are no diurnal patterns to be affected by the day of week nor seasonal groundwater representation to affect the time of year.
- Time step: 5 seconds (or smaller).
- Results time step multiplier: 60 if time step is 5 seconds (otherwise adjust to record every 5 minutes).
- Duration: See Section 2.3. Note that SDMP studies default to 2-hour duration design storm events as these have been deemed more representative of conditions within the CCD study

area limits and historically applied for CUHP analyses. Coordination with CCD is required if other storm durations are used.

- 2D parameters should be set using the vendor defaults shown in Figure 32 below:



Tolerance

Depth (ft): 0.003280839895

Momentum (ft): 0.003280839895

Velocity (ft/s): 0

☐ Ignore rain falling on dry elements

☑ Adjust bank levels based on adjacent element ground levels

☐ Link 1D and 2D calculations at minor timestep

Timestep stability control: 0.95

Maximum velocity (ft/s): 32.80839895

Theta: 0.9

Inundation mapping depth threshold (ft): 0.03280839895

Damage calculation timestep multiplier: 1

State search radius (ft): 328.0839895

State power parameter: 2

Figure 32 Simulation 2D Parameter Settings

- Initial conditions may be applied for 2D zones, where warranted, but care should be taken when applying initial conditions to 1D elements as this will cause issues with the initialization routines.
- Exit if initialization fails should be checked.
- Initialize by level fill-in from outfalls should be checked.
- Apply rainfall smoothing should be checked.

6.2. Rainfall

Rainfall inputs in ICM are stored in rainfall files, which are part of the model's database structure. Each rainfall file can contain the tabular hyetograph data for all rainfall events used within a simulation, allowing multiple storms or gauge records to be managed in a single, centralized dataset. Simulations then reference the appropriate rainfall event(s) within that file.

ICM supports three primary approaches for defining rainfall:

1. **Non-spatial rainfall (single ID method)**
   Rainfall may be defined without spatial variability by assigning a unique rainfall ID, similar to specifying a single rain gauge in an EPA SWMM model. This method applies the same hyetograph across the entire 2D domain, but subcatchments may reference different hyetographs within the dataset.
2. **Spatially varying rainfall using physical rain gauge data**
   When historical rainfall data from multiple physical gauges is available, ICM typically represents these records using Thiessen polygons generated through built-in tools. Each polygon is assigned its corresponding gauge hyetograph, allowing rainfall to vary across the study area based on proximity to each rain gauge.
3. **Spatially varying design storm rainfall (MHFD design hyetographs)**
   MHFD-developed design storm hyetographs are applied using a spatial grid representation, where each grid cell contains the corresponding hyetograph for that location. This approach mirrors the structure used for the Gauge-Adjusted Radar Rainfall (GARR)/Atlas 14 gridded rainfall products. Additional details on this method are provided in *Application of Mile High Flood District Gauge Adjusted Radar Rainfall Grid Cells with InfoWorks ICM* (Stantec, 2026).

6.3. Boundary Conditions

Boundary conditions define how flow enters and exits the modeled domain and are a critical component of establishing realistic hydraulic behavior at the limits of the 2D Zone and major drainageway network.

Upstream Boundary Conditions

Upstream boundaries should represent inflows generated outside of the 2D Zone but enter the study area through major drainageways. Given the nature of CCD's basins, these conditions are typically applied at the CCD jurisdictional limits, where the primary gulch or creek (represented in the model as 1D river reach elements) first enters the study area.

For consistent comparison of design storms across all CCD study areas, a constant inflow corresponding to the 10-year design storm is applied for the duration of the simulation. This same inflow rate is used regardless of the recurrence interval of the rainfall event applied to the 2D surface, ensuring that upstream boundary conditions remain standardized across studies.

Downstream Boundary Conditions

Downstream boundaries control how flows exit the modeled drainage system. These conditions are generally applied at the downstream end of the major drainageway, most often where the gulch or creek discharges into the South Platte River. This may require a time series for both the 1D outfall and a 2D linear boundary. To maintain consistency across design storm scenarios, CCD applies a constant stage boundary equal to the 10-year river stage for the full simulation period. This approach standardizes tailwater conditions and supports comparable hydraulic evaluations when assessing the set of synthetic design storms used for SDMP analyses. This approach provides insight into where CCD infrastructure risks exist independent of effects from adjacent jurisdictions. In cases where the downstream boundary condition appears overly conservative for design storms less than a 10-year recurrence frequency, additional evaluation may be necessary to refine recommended project prioritization.

Use of Historical Boundary Data

When simulating historical storms or performing hydrologic calibration, observed inflow and river stage data should be used in place of design storm values. Real-world measurements produce more representative system behavior and support validation of model hydrology and hydraulics.

7.0. Results and Mapping

Interpreting model outputs is a critical step in delivering reliable, defensible stormwater modeling results. While ICM provides robust numerical tools and supporting functions, engineering judgment and modeler experience remain essential for evaluating whether simulated flooding behavior, flow patterns, and system performance are realistic and consistent with field conditions. Automated outputs alone cannot account for data limitations, DEM artifacts, or localized drainage nuances; thoughtful review ensures that results are technically sound and that the model continues to perform efficiently as additional studies are performed. The subsections that follow provide a structured framework for validating model performance and identifying conditions that warrant closer inspection, as well as a standardized workflow for exporting and preparing results for seamless integration into CCD’s GIS environment as individual studies are finalized.

7.1. Results Validation

After the 1D and 2D components of the model have been assembled and initial simulations have been completed, a structured review of model results is essential to confirm that the predicted hydraulic behavior is reasonable and consistent with expectations. This validation step relies heavily on engineering judgment and modeler experience, as numerical results alone cannot account for data limitations, DEM artifacts, or localized drainage conditions. To help focus this review, the theme symbology within ICM can be configured to highlight areas where results warrant closer attention. For example, by emphasizing locations where modeled flood depths exceed approximately one foot.

During design storm simulations, instances where flooding depths exceed one foot are of particular importance. Because one foot of inundation during the 100-year design storm serves as a CCD planning threshold for identifying locations that may warrant capital improvement projects, these areas should be examined carefully to verify that the modeled flooding is both hydraulically reasonable and supported by field conditions. Shallow flooding encroaching building footprint is of high concern as well. This review helps ensure that improvement needs are neither overlooked nor overstated due to data gaps, DEM inaccuracies, or misrepresented drainage connectivity.

When evaluating areas of simulated flooding, engineers should consider whether the predicted behavior reflects known or expected conditions. For example, shallow or deeper ponding may be appropriate in natural low-lying areas where runoff typically collects. In other locations, apparent flooding may suggest gaps or inaccuracies in the underlying data, such as missing inlet capacity, outdated or incomplete drainage infrastructure in the GIS, or inlet features located on private properties that are not represented in CCD GIS database. These cases may warrant additional verification, though private property drainage issues should not be artificially corrected within the model if they cannot be reliably verified.

Some discrepancies may also result from limitations in the DEM. Recent construction, grading changes, or artifacts such as sky bridges (sometimes included within building footprint datasets) may introduce unrealistic depressions or obstructions that affect overland flow routing. These cases can typically be resolved by refining building representations or applying targeted elevation corrections through mesh editing tools.

Conversely, model validation should also identify locations where historically observed flooding is not reproduced. Records such as those captured in the Denver Service Request geodatabase can provide valuable context for comparing simulated and observed behavior. Reviewing active and past complaints helps ensure that the model appropriately reflects areas with documented drainage challenges and that unexpected absences of flooding are investigated and understood.

Overall, the goal of results validation is not to force models to conform perfectly to any single dataset, but to ensure that simulated conditions are technically defensible, hydraulically reasonable, and reflective of field conditions to the extent supported by available information. This combination of qualitative review, engineering judgment, and targeted use of visualization tools is essential for developing reliable basin-scale models and ensuring that CCD studies consistently support sound planning and decision making.

7.2. Results Export and Mapping

ICM produces results for 1D and 2D model components using separate export workflows, reflecting the differences in how point, line, and polygon elements are represented within the database. Because node-based results, link-based results, and 2D mesh element results serve distinct purposes within CCD's GIS environment, each requires its own export method to ensure that model outputs are processed consistently and integrated correctly.

For the 1D subsurface network, peak flow rate and water surface elevation results exports are required for the 2-year, 5-year, 100-year, and 2×100-year design storm simulations. These exports provide the information needed to populate CCD's stormwater GIS layers. All required node and link results can be generated in a single step using the Results → CSV Export functions within ICM, allowing modelers to efficiently produce standardized outputs across all design storms.

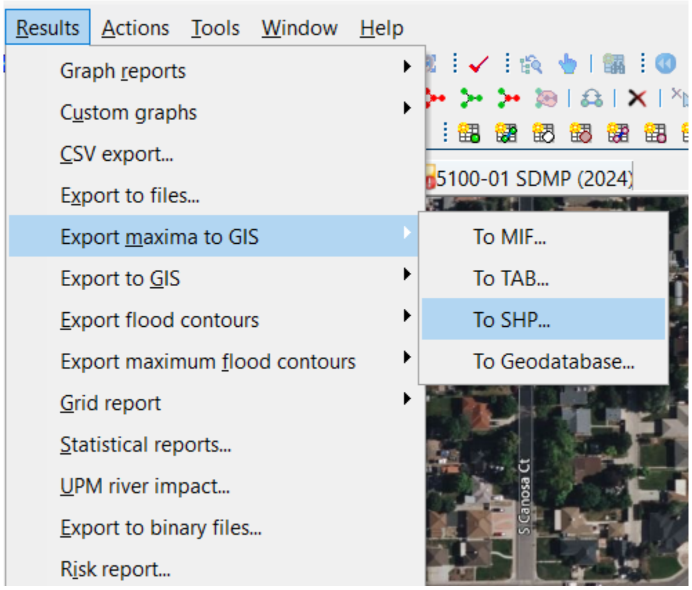
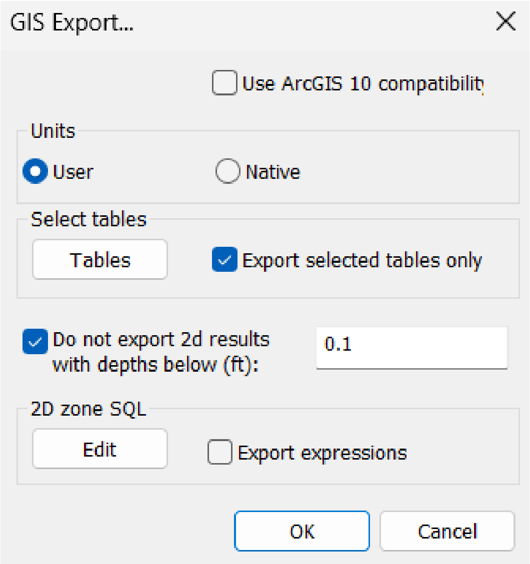


Figure 33 Exporting 2D Results

For the 2D domain, only the 100-year and 2×100-year design storms are required to generate the UFRA layers. The export should be completed using the Results → Export Maxima to GIS function illustrated in Figure 33. To keep file sizes manageable and ensure smooth visualization in GIS, the option "Do not export 2D results with depths below (ft)" should be selected, with a threshold of 0.1 ft as shown in Figure 34 below. Excluding depths less than 0.1 ft prevents the creation of excessively large files and eliminates noise that does not contribute meaningfully to flood risk interpretation. If 2D flood depth results are requested/required for other storms evaluated, the same export and post-processing workflow should be applied to maintain consistency.



GIS Export...

☐ Use ArcGIS 10 compatibilit

Units

● User ○ Native

Select tables

☑ Export selected tables only

☑ Do not export 2d results with depths below (ft): 0.1

2D zone SQL

☐ Export expressions

Figure 34 2D Results GIS Export Configuration Settings

Following export, the 2D results should be post-processed prior to incorporation into CCD's GIS datasets. The recommended ArcGIS Pro workflow is:

1. **Repair Geometry**
2. **Pairwise Erase** (using building footprints to remove rooftop areas)
3. **Clip** to the study area extents
4. **Calculate Field** to assign depth-based bins
5. **Dissolve** based on the assigned depth category

2D element depths should be classified into the following eight standard bins:

- 0.10–0.249 ft
- 0.25–0.499 ft
- 0.50–0.999 ft
- 1.00–1.499 ft
- 1.50–2.999 ft
- 3.00–4.499 ft
- 4.50–5.999 ft
- >6.0 ft

Note: The post-processing workflow should retain the full exported 2D results dataset initially, with areas subject to regulated floodplain delineations clipped out only in the final GIS deliverable. This approach is intended to reduce confusion and eliminate potential contradictions between the modeling approaches used for CCD drainage basin analyses and those used for MHFD FHAD or FEMA floodplain mapping.

These categories support consistent visualization and interpretation across all CCD study areas. Detailed 1D and 2D geodatabase instruction is provided in Guidance for 2D Storm Drainage Modeling and Deliverables (CCD, 2026) document. CCD's standard color scheme for these depth bins is shown in Figure 35 and should be used for all published mapping products to maintain uniformity across studies.

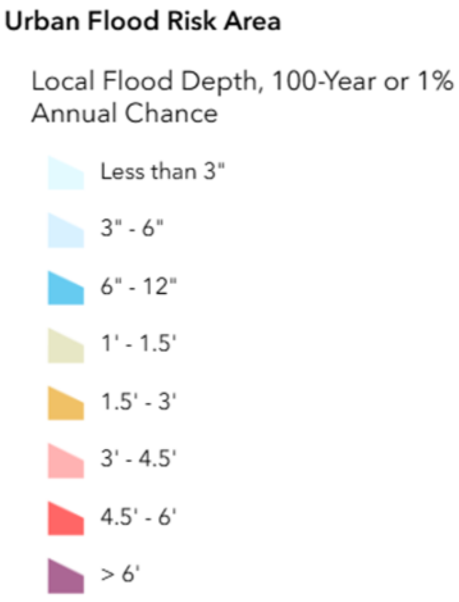


Figure 35 Urban Flood Risk Area (Previously known as Potential Inundation Area) Flood Risk Depth Classifications.

8.0. Deliverables: Transportable Databases and Submission Standards

The final step of any CCD study area model is the preparation of a transportable database. A transportable database is the packaged ICM model files required to open, review, and rerun the model exactly as delivered. Its purpose is to:

- Serve as the authoritative record of the model build, providing CCD staff and stakeholders with a consistent, transparent, and easily navigable structure.
- Support technical review and quality assurance, long-term maintenance, project design, and other future model reuse by standardizing the structure and content of submitted models.
- Help reviewers understand how the model was constructed, quickly locate key inputs, verify assumptions, trace data sources, and evaluate simulation behavior without having to reconstruct the modeling workflow.
- Provide a stable, self-contained dataset for future updates, study area stitching, results replication, or integration with other jurisdictional models.

These goals reflect CCD's emphasis on repeatability, defensibility, and ease of long-term model stewardship. The subsequent subsections summarize the preferred structure, required contents, and recommended practices for final submissions.

8.1. Required Contents

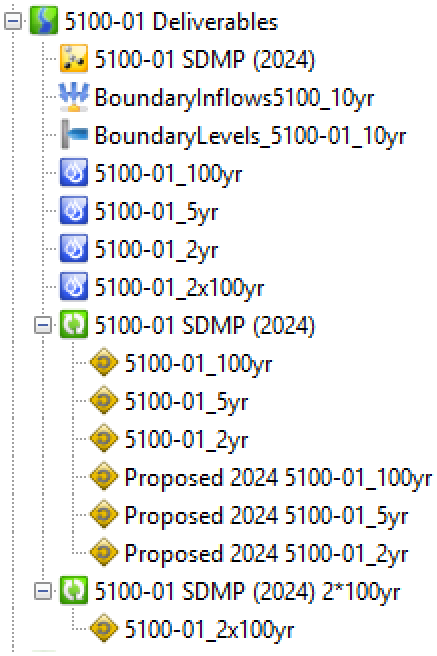
A complete transportable database should include all files needed to reproduce the model exactly as submitted. At minimum, the following components should be included:

- **InfoWorks network** containing all finalized 1D/2D assets, node/link attributes, data flags, notes, and validated configurations.
- **Ground model grid(s)** used for terrain assignment and mesh generation.
- **Rainfall files**, including all design storms and historical events referenced in the run files.
- **Inflow and level files** representing upstream and downstream boundary conditions.
- **Initial conditions** files, if used.
- **Simulation run files** for all required design storms (2-year, 5-year, 100-year, and 2×100-year) and any supplemental validation runs.
- **Exported results**, including 1D peak flows and water surface elevations for all design storms and 2D maxima for the 100-year event.
- **A brief metadata or model summary sheet**, documenting versioning, major assumptions, model extents, run descriptions, and any deviations from guidance.

These contents ensure that CCD reviewers can evaluate the model using the same datasets and configurations used by the modeling team.

8.2. Recommended Directory and Naming Structure

While some flexibility is acceptable, a consistent folder structure significantly improves review efficiency. The layout of the Sanderson Gulch model, illustrated in Figure 36 below, should be used as a reference:



- 5100-01 Deliverables
  - 5100-01 SDMP (2024)
  - BoundaryInflows5100_10yr
  - BoundaryLevels_5100-01_10yr
  - 5100-01_100yr
  - 5100-01_5yr
  - 5100-01_2yr
  - 5100-01_2x100yr
  - 5100-01 SDMP (2024)
    - 5100-01_100yr
    - 5100-01_5yr
    - 5100-01_2yr
    - Proposed 2024 5100-01_100yr
    - Proposed 2024 5100-01_5yr
    - Proposed 2024 5100-01_2yr
  - 5100-01 SDMP (2024) 2*100yr
    - 5100-01_2x100yr

Figure 36 Recommended Transportable Database File Structure

Modelers may expand this structure as needed, but the organization should remain intuitive, clearly labeled, and easy to navigate.

8.3. Final Validation Requirements Prior to Submission

Before packaging the transportable database, modelers should complete a final QA pass to ensure the model is fully ready for CCD review:

- All validation warnings cleared within the InfoWorks network.
- Mesh regenerated using CCD’s production meshing parameters.
- All temporary data flags removed or replaced with CCD standard flags.
- Results files tested to confirm they load correctly with no missing references.
- Note fields in nodes, links, storage areas, and external data files summarizing key adjustments or engineering judgment.
- Base scenario is representative of the existing conditions at the time of submission.
- Proposed conditions are included as a scenario, using ‘PROP’ as a data flag where assets have been added or changed from the base scenario.

These checks help ensure that reviewers evaluate the intended model configuration, not a partially completed or locally dependent version.

8.4. Packaging and Export Instructions

Once the model passes validation, the transportable database should be exported using ICM's built-in packaging tools. Recommended practices include:

- Existing conditions should be saved as the base scenario in the InfoWorks network and proposed conditions and/or alternatives analyses should be created as scenarios.
- Create the final .icmt transportable database from an InfoWorks network without any old versions. This reduces file size.
- Confirm that all referenced files (rainfall, ground models, hydrographs, level files) are contained within the exported package.
- Ensure the recycle bin of the transportable database is empty.
- Two transportable databases should be created: one with results and one without. Depending on the size of the model, it may be necessary to split the results deliverables into several transportable databases.

This ensures the delivered model is complete, portable, and immediately ready for CCD review without relinking or troubleshooting.

9.0. Troubleshooting

Like any hydrologic and hydraulic model build, challenges will inevitably arise during development of an ICM study area model. These issues are a normal part of the modeling process and should not discourage the modeler, call foundational assumptions into question, or detract from the broader goals of the study. Instead, they provide opportunities to refine inputs, confirm intended behavior, and strengthen confidence in the final model. This section offers a brief, non-exhaustive list of issues encountered during testing, along with examples of conditions that may warrant closer review, to help guide troubleshooting efforts and support efficient, consistent model development across study areas.

Validation Warning Messages:

It is recommended to clear all validation warning messages from the InfoWorks network. These comments offer valuable insights into model fidelity and should be rectified before effort is expended on other potential problems.

Addressing pipe invert discrepancies:

Users are encouraged to use SQL query tools within ICM to efficiently identify pipes and nodes with potentially incorrect or unrealistic geometric relationships such as adversely sloped pipes, larger conduits discharging into smaller ones, or manholes with unusually shallow or deep rim-to-invert distances. These conditions often indicate gaps or inconsistencies in the underlying GIS data and should be reviewed early to prevent stability and reliability issues. Once suspect assets are identified, the built-in invert inference functions can be used to quickly populate or correct invert elevations in a consistent manner. Applying these tools together allows modelers to resolve elevation discontinuities, maintain hydraulic coherence across the network, and reduce the time spent manually adjusting individual elements.

Polygon Drawing Errors:

ICM can struggle with importing multi-part polygon features. It is recommended to explode all polygons (particularly, roughness zones and infiltration zones) into single part features.

Courtyards:

Buildings with internal courtyards that are completely encircled by a building polygon can “trap” flow inside the building footprint. In these cases, it may be acceptable to assume a sub-surface drainage connection from the courtyard to the public storm sewer system.

Runtime Errors:

If the simulation runtime is extraordinarily slow, it is a good indication that something is not set up optimally. Convergence failures in the hydraulic engine are, typically, a product of 1D model assets. Modelers should use the simulation log files to identify model assets that are producing high convergence failure counts. The element that truly induces the failure may not be the element reported as the last element to fail convergence, but would stand out in the summary table of convergence failure counts.

Simulation Runtime:

The 2D algorithm in ICM has been optimized to work with the CUDA architecture of NVidia GPUs. Without a powerful PC that includes a graphics card with this architecture to simulate the rain on mesh conditions, simulations should be expected to take an order of magnitude longer than with a CPU-based simulation.

Bank lines active at the first time step of a simulation are computationally intensive and indicative of a model build issue. Attention should be given to ensure expected behavior outside of peak flow conditions.

As with any basin-scale H&H modeling effort, troubleshooting should be viewed as an expected and constructive part of the workflow. Ultimately, effective troubleshooting relies on a combination of modeler experience, thoughtful review of inputs and outputs, and steady adherence to the study’s goals. By approaching challenges with patience and a willingness to iterate, modelers can maintain confidence in the modeling framework and ensure that each study area model remains robust, defensible, and well-aligned with CCD’s unified approach.