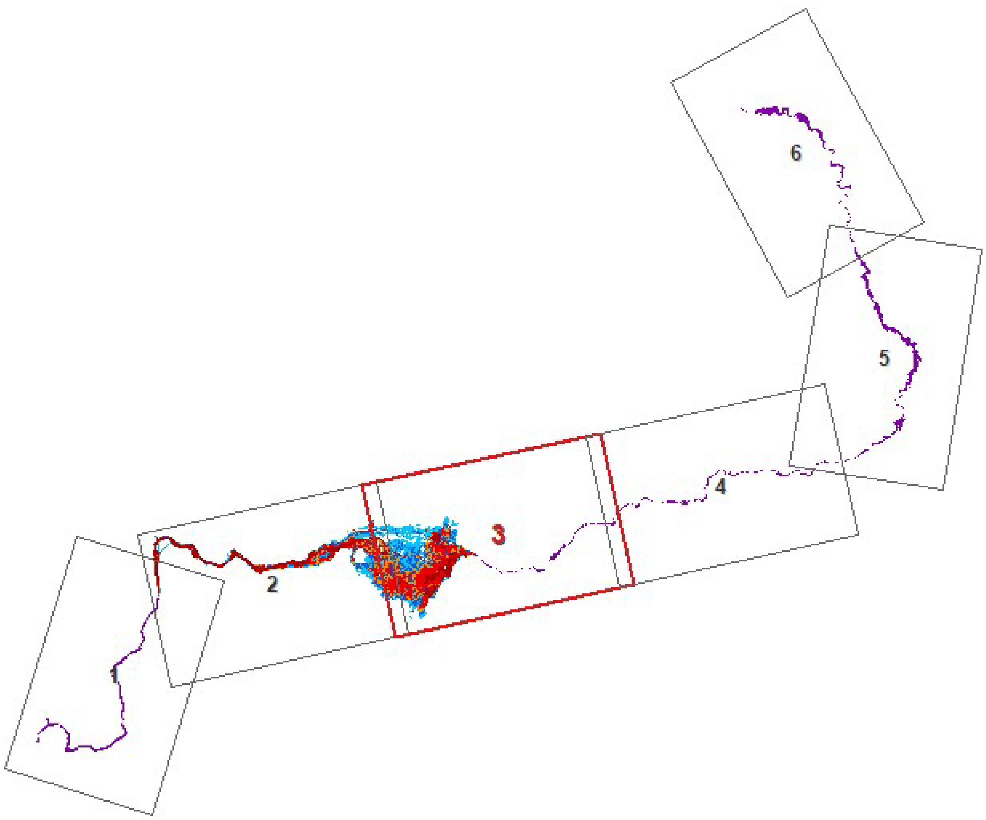
RECLAMATION
Managing Water in the West

Technical Service Center Manuals and Standards

Flood Inundation Mapping



U.S. Department of the Interior
Bureau of Reclamation

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Mission Statements

The Department of the Interior conserves and manages the Nation's natural resources and cultural heritage for the benefit and enjoyment of the American people, provides scientific and other information about natural resources and natural hazards to address societal challenges and create opportunities for the American people, and honors the Nation's trust responsibilities or special commitments to American Indians, Alaska Natives, and affiliated island communities to help them prosper.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

BUREAU OF RECLAMATION
Technical Service Center, Denver, Colorado
Geographic Applications & Analysis Group, 86-68260

Manuals and Standards

Flood Inundation Mapping

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Acronyms and Abbreviations

1D	one-dimensional
2D	two-dimensional
cfs	cubic feet per second
CUI	Controlled Unclassified Information
DV	depth times velocity
GIS	Geographic Information System
NAIP	National Agriculture Imagery Program
NHD	National Hydrography Dataset
QA/QC	quality assurance/quality control process
QMAX	maximum discharge
Reclamation	Bureau of Reclamation
T2LE	time to leading edge
T2QM	time to maximum discharge
TSC	Technical Service Center
USDA	U.S. Department of Agriculture

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1. Flood Inundation Map Overview

The Bureau of Reclamation (Reclamation) uses flood inundation maps to estimate dam failure life loss for dam safety risk analyses and to produce emergency action plans which aid emergency responders. These maps need to be clear and adhere to a standard so that they can be easily read and interpreted.

Inundation mapping data is the product of an engineering analysis, which involves numeric hydraulic modeling, dam breach analysis, and interpretation of a dam's potential failure modes. This document discusses the production of inundation maps from output data produced by the hydraulic modeling.

Mapping specialists use a data-driven approach (a standardized and accepted Geographic Information System [GIS] technological principle) to map out flood scenario extents via a series of custom map sheets. The clients and the hydraulic engineering analysts who conduct the inundation modeling determine the scenarios needed as well as the output information requirements. For example, inundation maps for emergency action planning may require a portrayal of maximum inundation flood depths, but a map which shows ranges of flooding intensity may be more useful for risk analysis. The hydraulic engineering analysts who complete the inundation modeling provide data from the model results to the mapping specialists.

The mapping specialists use output data from the hydraulic modeling to produce flood inundation maps. Mapping is completed with either one-dimensional (1D) or two-dimensional (2D) hydraulic modeling results, or via a combination of the two (1D & 2D), depending on the study. Standard products include mapping the maximum flooded extent in conjunction with discharge information, maximum depths, and flood leading edge/time to maximum flooding travel times. Note that 1D and 2D inundation maps have different formats and data requirements. Specialty maps include mapping flooding intensity, represented by the product of maximum depth and velocity (DV) values. Various ancillary data layers are added to the map sheets for context, including recent aerial imagery, rivers and streams, roads, and populated places.

Additionally, map elements are added (e.g., title box, scenario study notes, relevant data tables, legend, and an inset map showing the study area overview). The amount and type of information on inundation maps can be tailored to the client requirements.

While each map should be created based on these standard procedures, each map will require individual design decisions for layout and usability. Each set of inundation maps has a unique number and orientation of map sheets and data display requirements.

For specific guidelines and information regarding inundation modeling and mapping requirements, see U.S. Department of Interior, Reduce Dam Safety Risk Modernization Blueprint, Implementation Phase I, Inundation Mapping/Modeling Subproject Report, dated March 2011.

The standards in this manual from Reclamation's Technical Service Center (TSC) describe the cartographic elements (e.g., font size, color, and type, legend and table design, data layer display and symbology, and map scale and layout size) that each Reclamation inundation map should adhere to.

2. Project Estimates

The extent of the mapping requirements will determine the amount of time required to perform the work. To develop a project estimate, gather the following information:

- **Size of the area to map (distance downstream from the dam)** This will help determine how many map sheets will be needed for each scenario.

- **Type of modeling (1D, 2D, or combined).** This will determine the complexity of the maps.

- **Number of scenarios.** For all 2D, and for some 1D mapping projects, a separate set of maps is required for each scenario modeled.

- **Requirements for DV maps.** If DV maps are required, a separate set of maps showing DV values will be created.

- **End use to determine dimensions and map frame layout.** This will determine if any deviation from the standard dimensions will be needed.

- **Review process.** This will indicate the extent of potential changes and/or corrections that may be needed.

3. Security Requirements

All inundation data and inundation mapping products are controlled unclassified information. Follow all security requirements as noted in the Reclamation Manual Directives and Standards SLE 02-01, Identifying and Safeguarding Controlled Unclassified Information (CUI) https://www.usbr.gov/recman/sle/sle02-01.pdf.

4. Standards

4.1. Project Folder Storage and Naming

4.1.1. Folder Storage

Storage locations for project folders should be standardized to allow users to find datasets and inundation maps easily. Typically, project folders are stored in this network path convention:

> TSC > Jobs > *Region Folder* > *Dam* > *Inundation Study* > DWG > *GroupCode*_Inundation Mapping

For example, an inundation map folder for Green Mountain Dam would be stored at: TSC > Jobs > *GP* > *Green Mountain Dam* > *2018-DS-IE-Inundation Study and Population at Risk Analysis* > DWG > *8260*_InundationMapping

4.1.2. Sub-Folder Structure

Files should be stored according to TSC file structure conventions.

It is the responsibility of the mapping specialist to add all associated folders and data to the TSC network drive.

For a given inundation study, set up Folder Structure as shown in Figure 1 so that there are five subfolders containing their associated content: These folders will contain all data and map sheets related to the particular study:

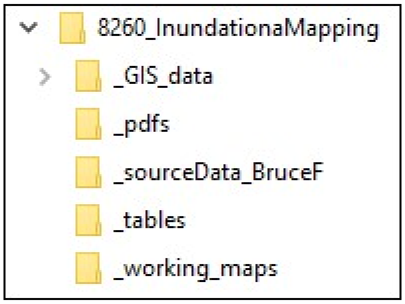


Figure 1. Folder structure for an inundation study.

1. **_GIS_data:** Geodatabases with all formatted GIS data used in the mapping project.

2. **_pdfs:** Final versioned map sheets in PDF format, output from the working map documents. These PDF maps are the final deliverable to the client.

3. **_sourceData_*HYDRAULIC ENGINEER NAME*:** All original data (.shp files, word documents, etc.) provided by the hydraulic engineer. Adding the name of the hydraulic engineer to the end of the folder name helps identify the original source of the data.

4. **_tables:** Spreadsheet populated with all tables that will appear on the map sheets. Use the spreadsheet to format the tables as necessary prior to adding them to the map sheets.
5. **_working_maps:** GIS software document files (i.e. ArcGIS .mxd files). These working map documents are where you create and manage your map production.

4.2. Map Scale, Dimensions, and Map Sheets

4.2.1. Print Size and Page Design

Standard maps are designed to fit a D-size paper sheet (34 x 22 inches), with a half-inch border.

4.2.2. Scale

The preferred map scale used for Reclamation inundation mapping is 1:24,000. This scale has shown to provide a good balance of detail for most inundation studies.

The second most used scale is 1:36,000, which is often used in cases where the inundation study reach is lengthy, has low detail levels (the inundation is confined to a relatively narrow area), and is located in a sparsely populated area. A benefit from using this smaller scale is that it saves on the number of required map sheets to cover the study.

Larger scales include:

- 1:6,000
- 1:12,000
- 1:18,000

Typically, these larger map scales would be used in cases where an inundation extent was very small, or, higher detail was required for display than the standard 1:24,000 scale. Work with the hydraulic engineer who completed the inundation modeling to determine the appropriate map scale.

Map Sheets

The number of map sheets in a study are determined by the number of index frames for that study. Index frames are designed as a series of consecutive polygons to “frame” the extent of the study inundation data (see cover for example). Each index frame serves as an individual map sheet in the overall map series for a given study.

4.3. Data Standards

This section describes the file naming and data attribute standards the hydraulic engineer should use when preparing inundation GIS data for delivery to the mapping specialist.

4.3.1. Data File Names

Inundation data file names should contain the dam name, model type (1D or 2D), model scenario, and data set type as listed in these subsections. For example, a maximum inundation flood polygon shapefile for a 1D seismic failure scenario of Boca Dam would be named: *Boca_1D_Seismic_MaxInunPoly.shp.*

4.3.2. 1D Study Standards

The Maximum Inundation Polygon file name for a 1D study should be structured as:

DamName_1D_Scenario_MaxInunPoly.shp

Mandatory attribute field: ***gridcode*** (Figure 2)

- Type: Long Integer
- Value: a single 3 or 4-digit number (usually 1000 for 1D) that is unique from gridcode values used in a 2D study.

ExampleDam_1D_MaxInunPoly

OBJECTID *	Shape *	GRIDCODE
1	Polygon	1000

Figure 2. 1D Maximum Inundation polygon attribute table.

Note: Ensure that the dataset consists of one continuous polygon. If there are multiple 1D polygons, merge them into one.

The Mapping Cross-Section Lines file name for a 1D study should be structured as:

DamName_Mapping_CrossSections.shp

Mandatory attribute field: ***River_Mile***

- Type: Double
- Values: River-mile distances of cross-sections downstream from dam, to one decimal place (e.g., 2.5 as shown in Figure 3).

ExampleDam_1D_CrossSections		
OBJECTID *	Shape *	River_Mile
1	Polyline	2.5
16	Polyline	6.6
2	Polyline	11.1
17	Polyline	16.0

Figure 3. 1D Mapping Cross-Section attribute table.

Note that these are "selected" cross sections. Cross-sections are selected by the hydraulic engineer during the modeling process at areas of interest to include on the maps.

4.3.3. 2D Study Standards

The Maximum Inundation Polygon file name for a 2D study should be structured as:

DamName_2D_Scenario_MaxInunPoly.shp

Mandatory attribute field: ***gridcode*** (Figure 4***)***

- Type: Long Integer
- Value(s): ***2, 4, 6, 10, 15, 20, and at 10 ft intervals up to the maximum depth value. Note that mapping of depths uses the ranges 2, 4, 6, 10 and greater than 10. The higher flood depth classification requirements are for data archiving purposes (water depth in feet as defined in the legend).***

ExampleDam_FastSeismic_2D_MaxInunPoly		
OBJECTID *	Shape *	gridcode
67	Polygon	11
68	Polygon	6
69	Polygon	2
70	Polygon	4
71	Polygon	11
72	Polygon	10

Figure 4. 2D Maximum Inundation polygon attribute table.

The Time to Leading Edge Lines file name for a 2D study should be structured as:

DamName_Scenario_LeadingEdgeLines.shp

Mandatory attribute field for the ***T2LE*** (the amount of time for leading edge of inundation to arrive at line location) (Figure 5)

- Type: String/Text
- Values: ***HH:MM*** (hours and minutes)

ExampleDam_FastSeismic_LeadingEdgeLines

OBJECTID *	Shape *	T2LE
1	Polyline	0:15
4	Polyline	0:30
3	Polyline	0:45
2	Polyline	1:00

Figure 5. Leading Edge Line attribute table.

The Discharge Lines file name for a 2D study should be structured as:

DamName_Scenario_DischargeLines.shp

Mandatory attribute field for the ***T2QM*** (time to maximum discharge):

- Type: String/Text
- Values: ***HH:MM*** (hours and minutes)

The Mandatory attribute field for the ***QMAX*** (maximum discharge) explains the maximum amount of discharge at the line location (Figure 6).

- Type: Double
- Values: ***###,###*** (maximum discharge in cubic feet per second [cfs])

ExampleDam_FastSeismic_DischargeLines

OBJECTID *	Shape *	T2QM	QMAX
1	Polyline	1:20	2,443,700
2	Polyline	1:30	2,340,100
3	Polyline	1:30	2,335,100
4	Polyline	1:35	2,332,200

Figure 6. Discharge Line attribute table.

4.3.4. Combined 1D and 2D Studies

The Maximum inundation polygon file name for combined study should be structured as:

DamName_Scenario_Merged_MaxInunPoly.shp

Gridcodes in a combined study correspond to the standards described above in the individual sections for 1D and 2D studies as shown in Figure 7.

Note: For 1D portion of combined study dataset, ensure that the 1D area consists of one continuous polygon for each 1D reach. If there are multiple 1D polygon within a single reach, merge them into one.

ExampleDam_FastSeismic_Merged_MaxInunPoly		
OBJECTID *	Shape *	gridcode
1	Polygon	1000
2	Polygon	2
3	Polygon	4
4	Polygon	6
5	Polygon	2
6	Polygon	6
7	Polygon	10

Figure 7. Combined 1D & 2D Maximum Inundation polygon attribute table. Gridcode 1000 represents 1D polygon while all other gridcodes correspond with 2D polygons.

4.3.5. Commonly Used Ancillary Datasets

The following datasets are typically included on inundation maps. Tailor these datasets as needed for the study area. Data outside of the study area (as defined by the index frames) is not needed and will slow the refresh time as you move around in the map. If needed, create new data layers derived from the master datasets and ensure that these new layers also contain only study-area related data.

Required ancillary datasets include:

- **Imagery basemap**
  One of the following:
  - National Agriculture Imagery Program (NAIP) imagery.
    Source: Reclamation GIS resources (Source: Dataspace > Imagery > NAIP Natural Color) or the U.S. Department of Agriculture (USDA) NAIP server: http://gis.apfo.usda.gov/arcgis/services.
  - ESRI Imagery Basemap
- **Census Place Points**
  - USA Census Populated Place Points (below 1:500k)
    Source: ESRI ArcGIS Online.
- **Rivers and Streams**
  - Rivers and Streams – Medium Resolution National Hydrography Dataset (NHD) Flowlines.
    Source: Reclamation GIS resources (Dataspace > Hydrography > Rivers and Streams - Medium Res NHD Flowlines)
- **Roads**
  - StreetMap USA: 25 -15k layer.
    Source: Reclamation files (Dataspace > Transportation > StreetMap USA)

Additional ancillary data may be added when necessary, such as state boundary lines, railroads, etc.

5. Mapping Process

5.1. Data Input and Verification

Ensure that all field names and attribute values are in the correct format in the data layer attribute tables so that the data and data labels display correctly. Typically, the hydraulic engineer delivers data in .shp (shapefile) format. Before importing the data into a geodatabase or equivalent storage structure, the mapping specialist will perform a quality assurance/quality control process (QA/QC) to ensure that all data has the correct attribute field names and values. Coordinate with the study modeler to address any missing or outlier information.

5.2. Mapping Steps

5.2.1. Create Working Map Document

1. **Name and save working map document.** The file name should consist of dam name and scenario, for example:

   Boca_Dam_FastSeismic

2. **Use relative pathing.** Relative pathing prevents broken data-links should the data used in the map move to a new directory location.

3. **Determine page set up.** Set the size, orientation (landscape vs. portrait), and scale. Set page print size. The most common page size used is D (34” x 22”).

4. **Set map margins**. A half-inch border margin is typical.

5. **Set scale.** The typical scale is 1:24,000. Make all design decisions and changes in the desired scale of your final output product.

6. **Ensure the map is set to the correct geographic projection.** The hydraulic engineer will determine the appropriate projection for the given study.

5.2.2. Develop Index Frames

Design the map series by fitting the index frames to the inundation data. First bring in the inundation data and then design the index frames. If the index frames do not fit the inundation data, then reconfigure the index frames.

1. **Create new polygon feature class data layer.** Structure the data layer name as:

   ***DamName*_Index_Frames**

2. **Add field "PageNumber" (Format: string).**

3. **Create new rectangle feature.** The dimensions of the feature are based on the scale and page size of your map(s). Figure 8 shows common index frame dimensions, by scale, designed for the standard D size paper sheet.

	Scale	Frame Width (meters)	Frame Length (meters)
Preferred Scales	1:24,000	12,801.60	20,116.80
	1:36,000	19,202.40	30,175.20
Other Scales as Appropriate	1:6,000	3,200.40	5,029.20
	1:12,000	6,400.80	10,058.40
	1:18,000	9,601.20	15,087.60

Figure 8. Common index frame dimensions for D-size maps.

4. Copy, paste, and **adjust index frame polygon**(s) until inundation data is fully encompassed by the index frames. Use the inundation polygon data as the reference to determine the most efficient placement of the index frames. In many cases, placing each index frame at an angle will provide a better fit for the data and will optimize the map layout.

5. **Calculate "PageNumber" field** (e.g. 1, 2, etc.). A page number to each index frame, starting at the dam (Page 1) and continuing downstream consecutively.

ESRI software tips:
The "Strip Map Index Features" tool in the Data Driven Pages toolbox is also helpful for creating the layout and calculating orientation angle and page numbers for the index polygons.

Turn on "Data Driven Maps" capability to allow automatic scaling and adjustment of map frame orientation when switching between index frames in layout view.

Use index polygon feature class to drive data driven maps.

- Name Field: "PageNumber": This allows the data driven maps function to switch between map sheets.
- Rotation: "Angle" (if known): This allows the map data to rotate according to the map sheet orientation.

5.2.3. Add Data

1. Add the **data inundation layers**, including the inundation polygons, discharge lines, leading edge lines, and/or cross-section lines.
2. Add **ancillary data** (e.g., roads, rivers, census place points)
3. Add **background imagery**

Organize the drawing-order of the data layers in the following order, from top-most layer to bottom layer (*Note: depending on the inundation study, some of these layers may not be required. For example, a 2D study will not have Mapping Cross-Section Lines).*

1. Census Place Points
2. Rivers and Streams
3. Mapping Cross-Section Lines
4. Discharge Lines
5. Leading Edge Lines
6. Inundation Polygons
7. Roads
8. Index Frames
9. Imagery Basemap

5.2.4. Symbolize Data and Draft Labels

1. Format **standard symbols and labels** for all dataset layers.
   - See section 5.3, Symbology and Label Conventions, for guidance.

   Add **call-out boxes** where needed. Every map series will have at least two call-out boxes (dam location and the end of the study area). Additional

call-out boxes may include other dams downstream and inundation model transition areas (inundation changes from 2D model to 1D model).
Tip: Add call-out boxes in Data View so that each call-out box is anchored to a specific geo-location and will move with the map during panning.

Define the call-out boxes as shown in Figure 9. Figure 10 shows examples of call-out boxes.

Font Type	Arial
Font Size	10.0
Font Style	Bold
Font Color	
RGB Value	215, 25, 28
ESRI Color	*N/A*
Text Background	Balloon Callout
Margins	5
Fill Color	
RGB Value	255, 255, 190
ESRI Color	Yucca Yellow
Outline Width	1
Outline Color	Black

Figure 9. Set up for call-out boxes.

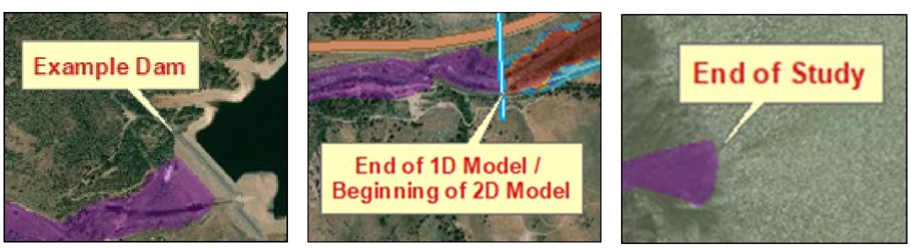


Figure 10. Examples of call-out boxes.

2. Add label for the **reservoir.** Define the call-out boxes as shown in Figure 11. Figure 12 shows examples of call-out boxes.

Text Style	Splined Text
Font Type	Arial
Font Size	9.0
Font Color	
RGB Value	0, 169, 230
ESRI Color	Moorea Blue
Mask Size	1.5
Mask Color	White

Figure 11. Set up for reservoir name.

Figure 12. Example of reservoir name.

5.2.5. Add Map Elements and Finalize Map Design

Create and add the map elements as necessary. Every map sheet will have a title block, north arrow, scale bar, disclaimer, and legend.

When possible, include the map notes and tables from the study report, as provided by the hydraulic engineer when they provide the mapping data.

Placing these map elements will depend on how the inundation data fills the map sheet. Place map elements so that they do not cover any inundation data.

If there is not enough room on the map sheets for all the map elements, create a separate reference sheet containing the additional map elements (e.g., tables, map notes) to accompany the maps.

Set guides (Figure 13).

- ½-inch border around map sheet.
- ¼-inch buffer from edge of data frame.

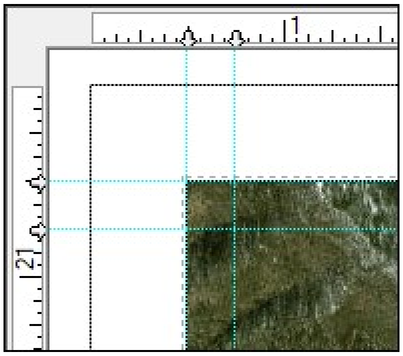


Figure 13. Example of rulers and guide lines.

Other than the title block, which should always appear the same, the design and format of the map elements is fluid. The mapping specialist makes the design and format decisions to best fit the map sheet and data context. A good rule of thumb is to maintain a 1/8" border for all map elements. This helps improve readability and minimizes the appearance of crowding between the map element box outline and the text/graphic context. This section shows the map elements to include on each map, along with examples of suggested design aspects.

5.2.5.1. Title Block

The title block should be standard for all maps, with the same information and color in the same order, as shown in Figure 14.

Figure 14. Sample title block.

The title block contains:

- **Title Text**
  - *Dam Name*
  - *Reclamation Project,* and *State*
  - *Reclamation Region*
  - Dam Failure Inundation Study, *Date (Month, Year)*
    - Reclamation Logo
      - Obtain from Reclamation Visual Identity
    - *Scenario Type*

- Map Sheet # of #
  - This code will allow automatic update to page numbers when using Data Driven mapping:
    - Map Sheet <dyn type="page" property="index"/> of <dyn type="page" property="count"/>
- Sensitive Information – CONTROLLED UNCLASSIFIED INFORMATION
  - Bold
  - RGB Color: 215, 25, 28

ESRI formatting tip:

Tip: Use these text formatting tags to create one text block containing multiple formatting variables:

<CLR red = "37" green = "73" blue = "157">Granby Dike 3</CLR>
<FNT size = "12">Colorado-Big Thompson Project, Colorado<LIN leading = "5">
Great Plains Region</LIN>
Dam Failure Inundation Study, April, 2019</FNT>

Figure 15 shows formatting appearance when the code is used. Overall text properties are set to size of 14.0 and font color of 60% gray. The code decreases all text but the dam name to 12.0, and changes the dam name color to Reclamation Blue:

Figure 15. Example of code-formatted title text

5.2.5.2. Disclaimer Box

The map notes will contain the disclaimer text, provided by the hydraulic engineer (Figure 16).

> The flooding depicted on this map represents extremely rare events, and is in no way intended to reflect upon the integrity of XXXXXXX Dam. Due to numerous variations in actual conditions, this map may not reflect the exact areas that would be impacted.
>
> Please refer to Reclamation Manual, Directives and Standards (SLE 02-01), Identifying and Safeguarding Controlled Unclassified Information (CUI), for guidance on the appropriate use and sharing of the information produced by this study.
>
> Prepared by: United States Bureau of Reclamation (April, 2019)
> Study: Bruce Feinberg, PE (86-68260)
> Mapping: Jakeb Prickett, GISP (86-68260)
> Peer Review: Jose Feliciano, PE (86-68260)

Figure 16. Disclaimer example.

5.2.5.3. Legend, North Arrow, and Scale

Legends should have the same text, colors, and style as shown in Figure 17 through Figure 19.

Note that standard colors and lines are used for the inundation layers, cross-section lines, discharge lines, time to leading edge lines, etc. and the symbology for each is defined in Section 5.3.

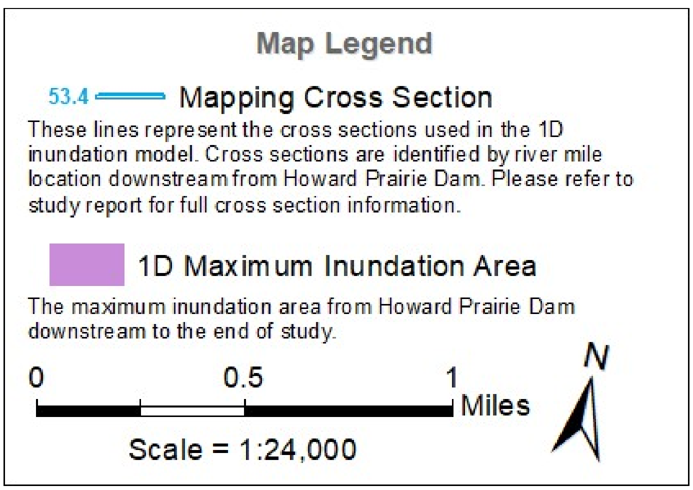


Figure 17. Example of a 1D study legend.

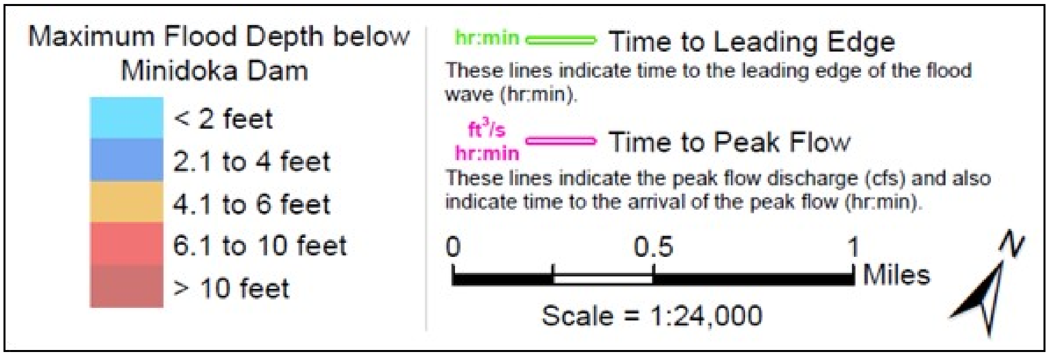


Figure 18. Example of a 2D study legend.

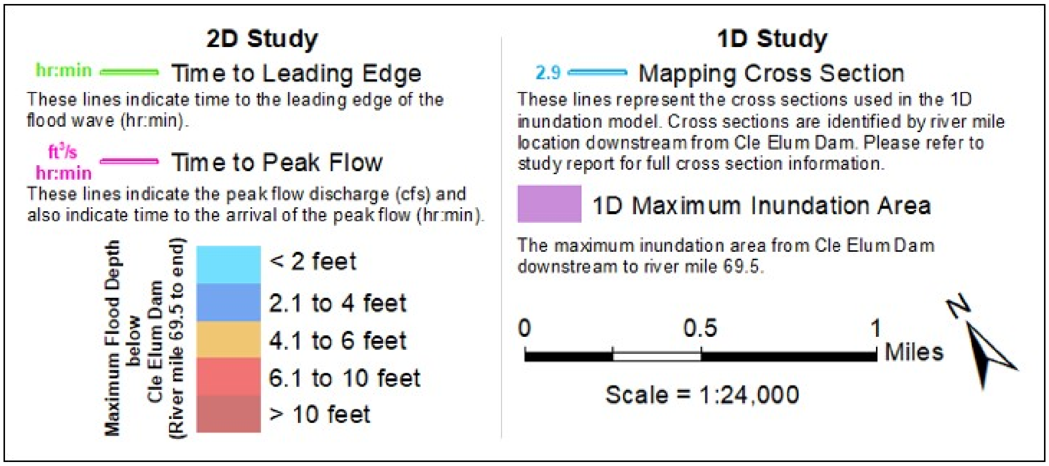


Figure 19. Example of a combined 1D and 2D study legend.

5.2.5.4. Map Notes

Map notes are provided by the hydraulic engineer with the inundation data (Figure 20). If there is not enough room on map sheet, add map notes to a supplemental reference sheet.

Example Dam
XXXXXX Project, State
XXXXXX Region

RECLAMATION
Managing Water in the West

Dam Failure Inundation Study, July, 2017

--- Fast Seismic Failure Scenario ---

Map Sheet 1 of 6

Sensitive Information – CONTROLLED UNCLASSIFIED INFORMATION

A new inundation study for XXXXXX Dam was requested by Reclamation's Dam Safety Office in support of a Corrective Action Study. The goal of this study is to update the previous inundation analysis for XXXXXX Dam with one which makes use of current "state of the practice" inundation models and methods, higher resolution terrain data and realistic potential failure modes. Two scenarios are evaluated, and are described as follows:

- Fast seismic failure of the dam with an initial reservoir level at 5609.0 feet.
- Slow seismic failure of the dam with an initial reservoir level at 5579.0 feet

The flood inundation analysis was completed using the Danish Hydraulic Institute's (DHI) MIKE11 one-dimensional (1D) hydraulic model, and the DHI MIKE21 two-dimensional (2D) hydraulic model. 1D modeling was used to simulate the dam breach and to route flows downstream to river mile XXX. 2D modeling was used to route flows from river mile XXX, through the cities of XXXXX and XXXXX, XX, to river mile XXX where 1D modeling was again used for the remainder of the study to the XXXXX inlet. Breach simulations were performed using the National Weather Service DAMBRK formulation, which is available within the MIKE11 1D hydraulic model.

Terrain data for the study area came from a combination of sources, including Interferometric Synthetic Aperture Radar (IFSAR) terrain data and Light Detection and Ranging (LiDAR) data. IFSAR data, obtained from Intermap/Carahsoft, was used in its native 5-meter resolution for the upstream 1D reach from XXXXX Dam to river mile XXX. The 2D reach made use of LiDAR data obtained from the XXXXX GIS office. This data, obtained in .LAS format, was sampled at a 10-meter resolution. The downstream 1D reach used LiDAR data obtained from the XXXXX office of the U.S. Corps of Engineers. The data, obtained in .LAS format, was sampled at a 5-meter resolution.

Note that all elevations related to the reservoir, the dam, and its breaching are referenced to the NAVD 88 vertical datum. This is the same vertical datum as is used for all of the digital terrain data employed by this study.

Breach parameter assumptions are presented in Tables 1 and 2. Input parameters and other information related to the MIKE21 simulations are presented in Table 3.

Figure 20. Example of map notes combined with title block.

5.2.5.5. Tables

Tables are included in map notes provided by the hydraulic engineer (Figure 21 through Figure 23). If there is not enough room on map sheet, then add tables to a supplemental reference sheet. Tables should comply with Reclamation VI standards (typically Arial 10 point font.)

Tip: Format the tables in a spreadsheet program and copy/paste into the map sheet for better control over design and appearance.

Table 2: MIKE21 Modeling, Details and Input Parameters

Cell Size (grid resolution)	10 meters
Dimensions of DEM Terrain Model	5421 x 1917 grid cells
Simulation Time Step	0.5 second
Manning Roughness Coefficient	0.045
Flooding/Drying Parameters	0.1/0.05 meters
Eddy viscosity	2 m^2 s^{-1}
Model Simulation Time	23 hours

Figure 21. Example of table formatting for items with different unit measurements.

Table 1. Fast Seismic, Breach Parameter Assumptions and Results

Initial reservoir level[1]	5609.0 feet
Crest elevation of dam[1,2]	5615.9 feet
Initial elevation of slumped crest[1]	5595.9 feet
Initial slumped crest width	250 feet
Breach bottom elevation[1]	5500 feet
Breach bottom width	330 feet
Breach side slopes	0.5:1
Time of breach formation	1:10 (hours : minutes)
Total volume released by breach	41,141 acre-feet
Peak breach discharge	504,400 ft^3/s

[1] All elevations referenced to vertical datum NAVD 88

[2] Assume that parapet wall on dam's crest collapses due to seismic loading

Figure 22. Example of table formatting with footnotes.

Table 4. 1D Outputs, Fast Seismic Scenario

River Miles	Max. Depth (ft)	Max. Water Surface (ft)	Max discharge (ft^3/s)	Time to leading Edge (hr:min)	Time to Max. Flooding (hr:min)
0.5	47	5,537	498,000	0:00	0:50
1.1	51	5,524	493,500	0:05	0:55
2.4	45	5,490	487,300	0:10	0:55
4.4	47	5,438	475,500	0:15	1:00
7.3	45	5,325	470,100	0:30	1:05
10.9	41	5,161	464,800	0:40	1:10
13.6	37	5,052	461,700	0:50	1:20
15.0	39	4,967	460,700	0:55	1:20
15.0 to 39.0	2D Modeling				
39.0	16	4,392	15,400	4:35	6:15
41.6	11	4,348	15,400	5:05	6:35
43.0	13	4,328	15,400	5:20	6:50
45.2	13	4,305	15,300	5:50	7:20
48.3	13	4,272	15,200	6:25	8:00
50.3	12	4,252	15,100	7:00	8:45
52.6	14	4,239	15,000	7:55	10:25
55.1	12	4,217	14,900	8:25	10:50

Figure 23. Example of table formatting with multiple sections and columns.

5.2.5.6. Inundation Area Overview Box

The inundation area overview box provides a “big picture” view of the entire map series and the extent of the inundation modeling (Figure 24). To provide context for where the map sheet falls within the overall map series, highlight the index frame in the inundation area overview box that corresponds with the current map sheet and display map sheet numbers.

To create an inundation area overview box:

1. Create new data frame.
2. Add inundation polygon layer and index frames layer.
3. Highlight the index frame that corresponds with the current map sheet.
4. Apply page numbers and highlight current page number.
5. Add north arrow and scale.

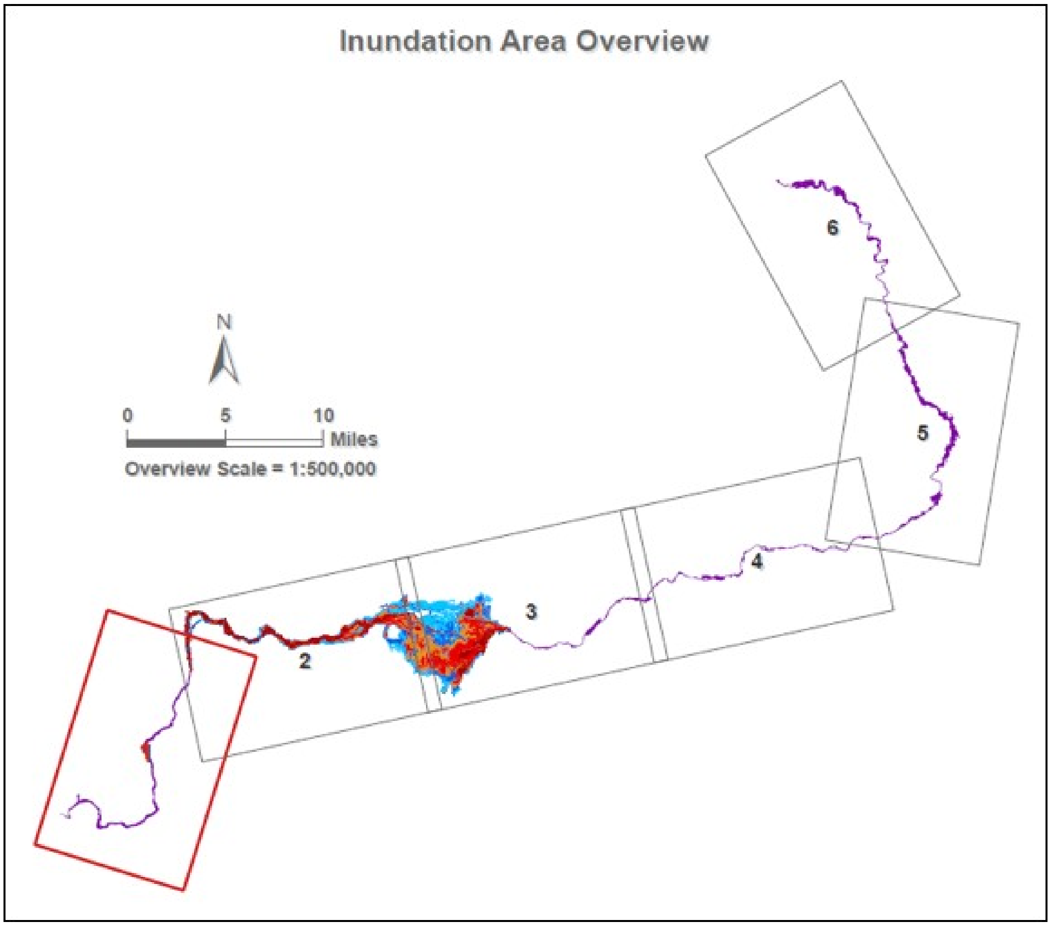


Figure 24. Example of inundation area overview box.

5.2.6. Review Maps

1. **QA/QC maps.** Verify correct scale, symbology, map elements, etc.

2. **Peer review.** Have maps peer reviewed for necessary corrections and/or changes/adjustments. Typically, the maps are reviewed by the hydraulic engineer who completed the inundation analysis, and by the overall peer reviewer for the inundation study.

5.2.7. Export Map Sheet(s) to PDF

Export each map sheet to a separate PDF.

ESRI tip for exporting map sheets to PDF

ArcMap: For quick exportation of a map sheet to PDF, first, save each map sheet in the study as a separate .mxd document. Then use the "*Export MXD to PDF*" script tool to export multiple .mxd documents to PDF at the same time. The script tool must be used via ArcCatalog.
Export MXD to PDF tool:
(https://www.arcgis.com/home/item.html?id=4ddd1323ae0d4ebe8f8250992faab0f4)

Arc GIS Pro: The use of the *Map Series* feature in ArcGIS Pro is a major time saver when producing multiple map sheets for multiple scenarios.

5.2.8. Deliver Maps

Send the PDF maps sheets to the hydraulic engineer for delivery to the client.

Move all data, relevant working files, map document files (.mxd) and PDFs to the correct location on the TSC network (see section 4.1. Project Folder Storage and Naming).

5.3. Symbology and Label Conventions

5.3.1. Inundation Polygon - Depth Symbology

Inundation polygons for a given study may show 1D model results, 2D model results, or a combination of 1D & 2D.

When overlaid on an imagery background, inundation polygons should have a layer transparency level of 50%-60%. The transparency level selected will be determined by the composition of the imagery and what appears best for the area being mapped.

Inundation polygon (depth) properties are listed in Figure 25.

	Attribute Field	gridcode Range	Legend Label	Symbol Color	RGB Value	ESRI Color Style
2D	gridcode	2	< 2 feet		0, 197, 255	Big Sky Blue
		3 - 4	2.1 to 4 feet		0, 92, 230	Lapis Lazuli
		5 - 6	4.1 10 6 feet		230, 152 , 0	Seville Orange
		7 - 10	6.1 to 10 feet		230, 0, 0	Poinsettia Red
		11 - 110	> 10 feet		168, 0, 0	Tuscan Red
1D		11 - 1000	*1D Study: Maximum Inundation Area		132, 0, 168	Dark Amethyst

*Note: 1D inundation study polygons depict inundation extent only, not depth.

Figure 25. Inundation polygon properties.

5.3.2. Transects - Line Symbology and Labels

Figure 26 and Figure 27 show standard symbology and label properties for transect lines by line type.

	Mapping Cross Section	Leading Edge Line	Discharge Line
Line Type	Simple Line		
Line Style	Solid		
Line Width 1	1.0		
Line Width 2	3.0		
Color 1			
RGB Value	0, 169, 230	76, 230, 0	255, 0, 197
ESRI Color	Moorea Blue	Quetzel Green	Ginger Pink
Color 2	White		
Symbol Preview			

Figure 26. Line properties.

	Mapping Cross Section	Leading Edge Line	Discharge Line
Label Field(s)	River_Mile	T2LE	*QMAX + T2QM
Font Type	Arial		
Font Size	10.0		
Font Style	Bold		
Font Color			
RGB Value	0, 169, 230	76, 230, 0	255, 0, 197
ESRI Color	Moorea Blue	Quetzel Green	Ginger Pink
Mask Size	1.0		
Mask Color	White		
Orientation	Parallel		
Position	On the line		
Location	At Start		
Priorities	Before:1, At: 0, After: 0		
Distance	25 map units		

* VBScript Expression: [QMAX] & vbnewline & [T2QM]

Figure 27. Line label formatting.

Figure 28 shows an example of combined 1D and 2D inundation polygons with mapping cross-section, discharge, and leading edge lines.

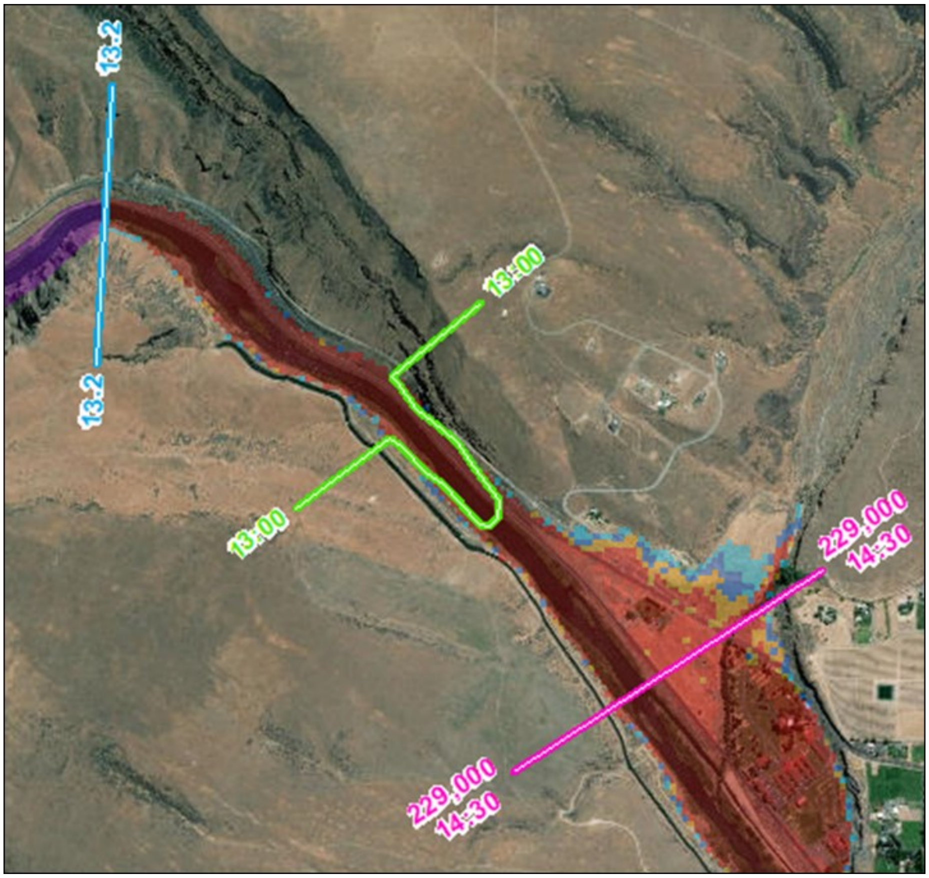


Figure 28. Example of line labels and line symbology.

5.3.3. Ancillary Dataset Symbology and Labels

5.3.3.1. Census Place Points

Do not use symbols for census place points—use text labels only (Figure 29).

Label Field	NAME
Font Type	Arial
Font Size	14.0
Font Style	Bold
Font Color	White
Mask Size	2.0
Mask Color	Black
Placement	Top Right
Example	Sparks

Figure 29. Census place point label properties.

5.3.3.2. Rivers and Streams

Do not use symbols for rivers and streams—use text labels only (Figure 30).

Label Field	GNIS_NAME
Font Type	Arial
Font Size	8.0
Font Style	Italic
Font Color	
RGB Value	0, 112, 255
ESRI Color	Cretan Blue
Character Spacing	7.0
Mask Size	1.5
Mask Color	White
Orientation	Curved
Position	On the line
Duplicate Labels	One label per feature
Example	

Figure 30. Rivers and streams label properties.

5.3.3.3. Roads

Use the symbology and labeling as shown in Figure 31 and Figure 32.

	Interstate	**US Highway**	**State Hwy / Major Road**	**Minor Road**
Value: FCC	A10 - A19	A20 - A29	A30 - A39	A40 - A62
Line Type	Cartographic Line Symbol			
Line Style	Line Caps: Butt, Line Joins: Round			
Line Width 1	3.6	2.9	1.8	1.1
Line Width 2	5.2	4.2	3.2	*N/A*
Color 1				
RGB Value	205, 137, 102		250, 237, 212	212, 196, 176
ESRI Color	Nubuck Tan		*N/A*	
Color 2				*N/A*
RGB Value	142, 94, 29	179, 109, 84	204, 179, 128	*N/A*
ESRI Color	*N/A*			
Symbol Preview				

Figure 31. Road symbology properties and colors.

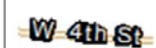
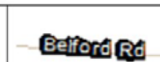
	Interstate	US Highway	State Highway	Major Road	Minor Road
Label Field	HWY_NUM			PREFIX + PRETYPE + NAME + TYPE + SUFFIX	
Symbol	Intersate Shield	US Hwy Shield	State Hwy Shield	*N/A*	
Font Type	Arial				
Font Size	7.0	7.5	7.0	9.0	8.0
Font Color	White	Black		White	
Character Spacing	1.4	10.0	1.0	20.0	10.0
Mask Size	*N/A*			1.5	
Mask Color	*N/A*			Black	
Orientation	Horizontal			Curved	
Position	*N/A*			On the line	
Duplicate Labels	One label per feature			Remove Duplicate Labels	
Example					

Figure 32. Road label properties and examples.

ESRI symbology tips:

- Import symbology settings from a layer file (.lyr) to save time in applying the standard symbology to datasets. The Template layer files can be found on the TSC network drive here:
  Z:\DO\GIS\data\Inundation_Mapping\Inundation_Mapping_Resources

- To import label settings from a layer file, use the Import Labels From Layer add-in tool.
  http://www.arcgis.com/home/item.html?id=dbb7be9d2c1c491e8c1a067ffd58aea8

6. Special Cases

6.1. Multiple Scenarios

For multiple scenarios associated with a dam failure study (e.g., fast seismic, static failure), create a separate map series for each scenario. Be sure to use the inundation data and transect data specific to the given scenario. Make any textual/label changes to the map elements as necessary (e.g. scenario type in title block, scenario specific tables).

For multiple 1D scenarios, a "nested" display method may be employed, where both scenarios are shown in conjunction with each other (Figure 33).

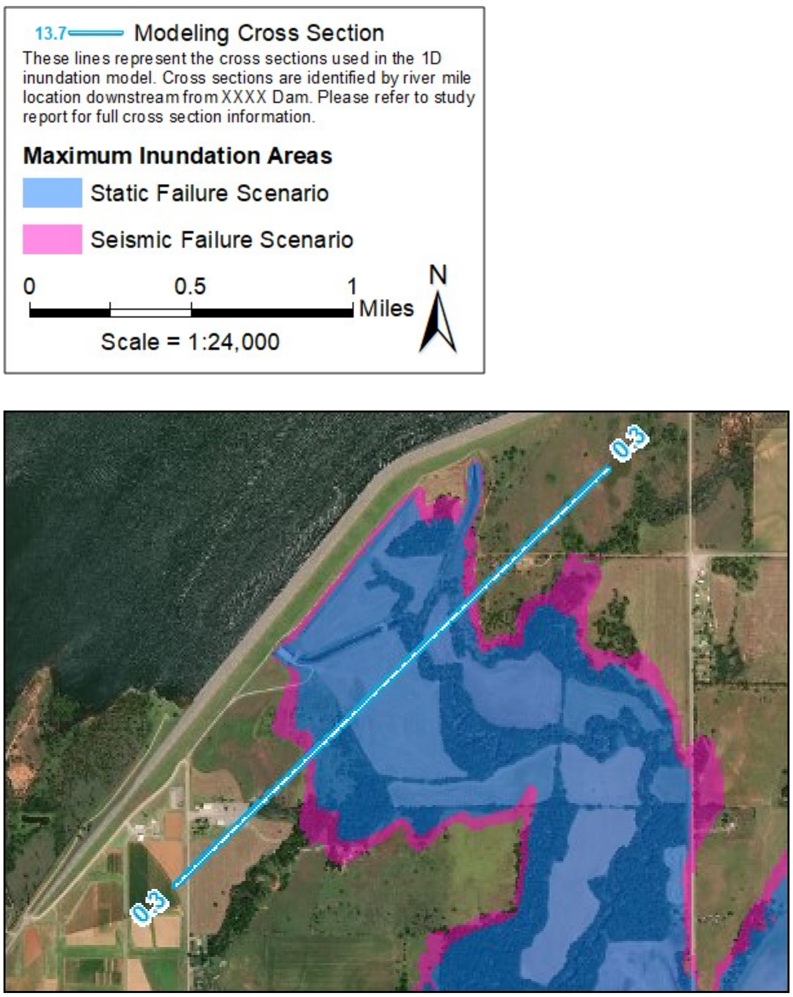


Figure 33. Example of a "nested" display method for multiple scenarios.

6.2. DV Maps

The product of Depth and Velocity (DV) maps show the maximum inundation extent, classified by ranges of maximum DV values. DV values are calculated by the hydraulic engineer using output data from the inundation model. While not every mapped inundation study will include DV maps, many studies do. DV maps are typically “working maps” which are used by dam safety risk analysis teams, to aid in the selection of dam failure life loss fatality rates.

6.2.1. DV Data Study Standards

DV Polygon file name: ***DamName_Scenario_DV_MaxDVPoly.shp***

- Mandatory attribute field: ***gridcode (water depth times velocity)***
  - Type: Long Integer

Values: ***the DV values*** **(e.g., 25, 50, 75, 160, 200, 500, 700, 1,000, 2,000, 3,000)**. Grid codes above a certain threshold get wrapped into an “above” value (e.g., above 3,000)

DV_MaxDVPoly

OBJECTID *	gridcode
86	160
97	500
37	700
20	500
91	1000
96	160
95	75
12944	500

Figure 34. Example of a DV table.

6.2.2. Creating DV Maps

For DV maps, use the overall design of the inundation map sheets (Figure 35). Remove the flood inundation polygons and leading edge/discharge lines from the maps. DV maps should include:

- **Basic map elements**
  - Title block (with addition of: “Maximum DV Inundation Map”
  - Legend (with DV values)
  - Disclaimer
  - Maps notes, tables, overview box.

- **DV inundation polygons**
    - o There is no set standard symbology for DV inundation values. The mapping specialist will make color symbology choices based on the number of unique DV values and what works best when overlaid on the imagery. Multiple tests of color combinations may be necessary to find the best solution.

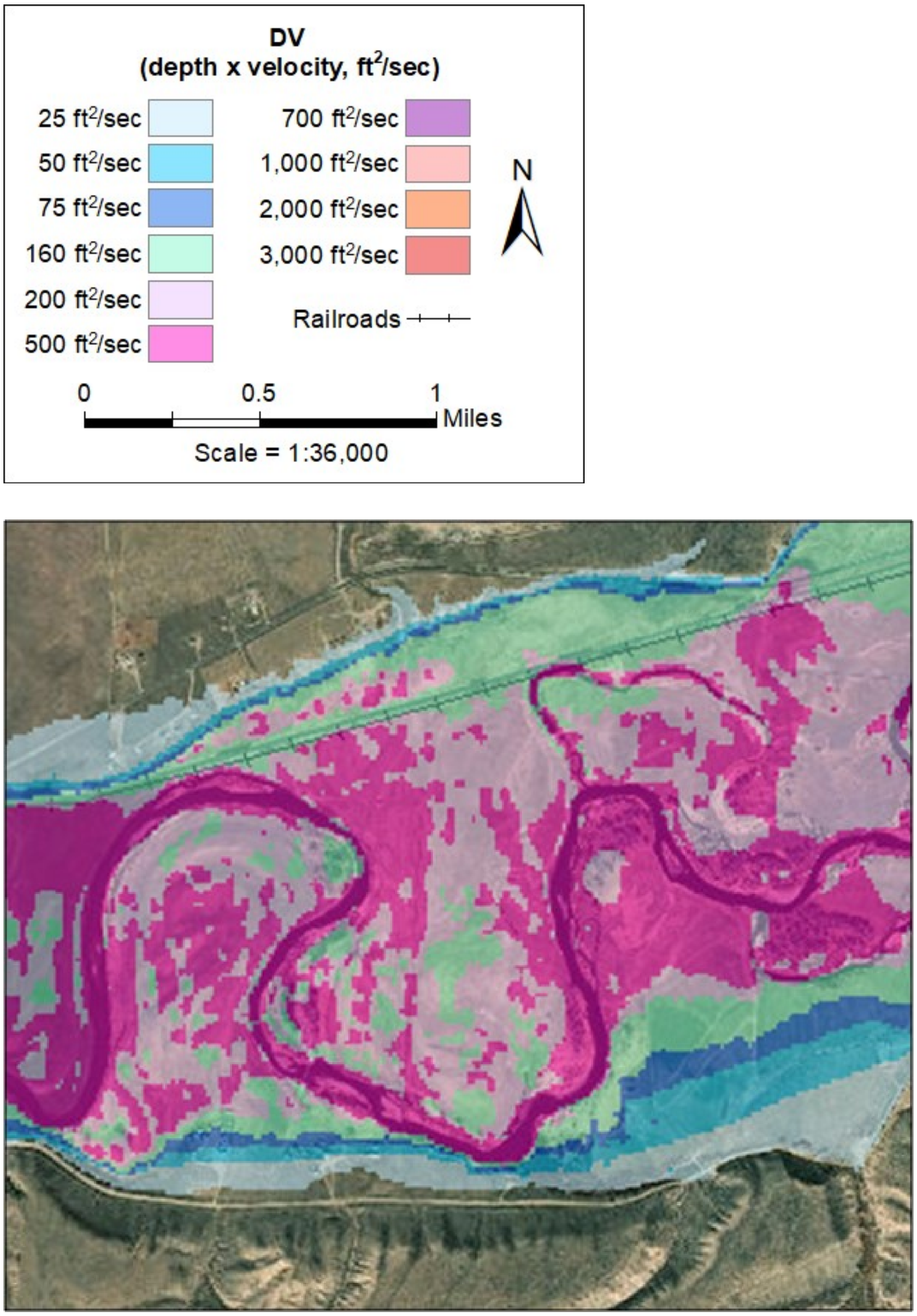


Figure 35. Example of DV legend and DV polygons.

6.3. Color Contrasts

Special attention to color contrast of overall map design may be required in certain situations, such as designing a map for color blind individuals. In such a case, the inherent nature of inundation maps (multi-color symbolized inundation data, colored transect lines, varying colors and shades in base imagery) provides a challenge for the mapping specialist to create a map that can be read and understood for clarity and context. The following tools may assist in making design choices for choosing contrasting colors:

- Color Oracle
  - This stand alone application applies a filter to the monitor screen which simulates the effect of the varying types of colorblindness, allowing the mapping specialist to view the map as it would be viewed by a colorblind individual.
    - www.colororacle.org.

- Color Brewer 2.0
  - Color Brewer is an interactive website which provides color combination advice for mapping. One of the options it allows is to provide color combinations that are “colorblind safe”.
    - www.colorbrewer.org.

6.4. Split Panel Maps

Split panel mapping allows for placement of multiple map panels on a single map sheet, thus reducing the overall number of map sheets produced for the study. This mapping approach typically works best for study scenarios that result in flood inundation areas that are generally narrow and linear (see Figure 36 for example). When feasible, split panel mapping should be utilized.

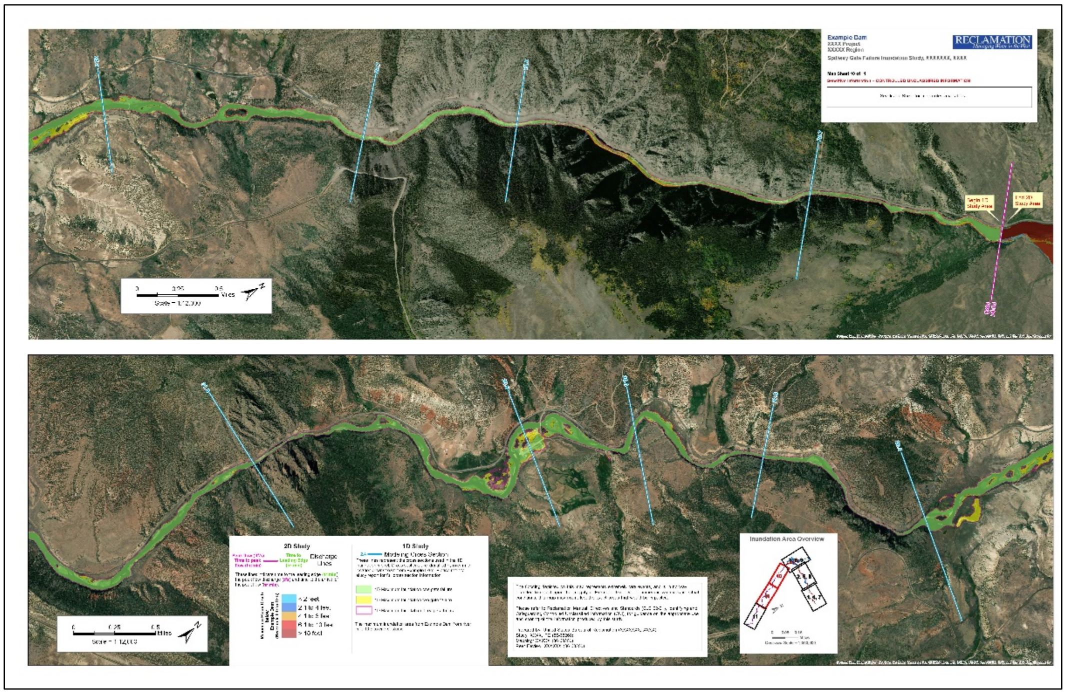


Figure 36. Example of Split Panel Mapping