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Rutgers NJ FEMA 1% Chance Annual Flood Plus 3 Feet (rev. 04/09/2024)

Terms of Use

This dataset is an estimate of the extent of an additional three feet of flooding on top of the current FEMA 1% Chance Annual Flood for New Jersey. This dataset was created to support planning activities in accordance with the New Jersey Department of Environmental Protection's (NJDEP) Inland Flood Rule, effective July 17, 2023. More information about the NJDEP Inland Flood Rule can be found at: https://dep.nj.gov/inland-flood-protection-rule/. For this analysis, the current FEMA 1% Chance Annual Flood extent was derived from the NJ FEMA Modified Statewide Flood Hazard Area (Rutgers, 2023) dataset, which includes both effective and preliminary Flood Insurance Rate Map (FIRM) data and represents the worst-case flooding from both EFIRMs and PFIRMs. This may result in areas being shown in the Flood Hazard Area that only exist in one of the FEMA maps, and therefore are not meant to represent official FIRMs.

The accuracy of the dataset is limited by the data and methods available to create it. This dataset is not based on survey quality data and must not be used in replacement of survey data. It is meant to be used as a high-level screening tool for planning reference only and should not be relied upon for site-specific flood impact analyses, permitting, or other legal purposes. Rutgers University makes great effort to provide secure, accurate, and complete data and metadata. However, portions of this data and metadata may be incorrect or not current. If an end user identifies any errors or omissions, they are encouraged to report it to Rutgers via email to: ora-its@njaes.rutgers.edu.

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Summary

This dataset was produced using ArcGIS Pro 3.1.2 to estimate the extent of an additional three feet of flooding on top of the current FEMA 1% Chance Annual Flood for New Jersey. For this analysis, the current FEMA 1% Chance Annual Flood extent was derived from the NJ FEMA Modified Statewide Flood Hazard Area (Rutgers, 2023) dataset, which includes both effective and preliminary Flood Insurance Rate Map (FIRM) data and represents the worst-case flooding from both EFIRMs and PFIRMs. If the flooding

extent varied between EFIRM and PFIRM, the greater flooding extent was used. The new Rutgers NJ Hydro-Flattened 10ft DEM (Rutgers, 2023) was used to extract flood zone boundary elevations and calculate the extent of the flood zone after an additional three feet were added. Topo to Raster (TTR), which creates a hydrologically correct surface, was the primary tool used to interpolate a new flood surface. The Inverse Distance Weighted (IDW) technique was used as a secondary tool to interpolate areas for which TTR would not run. Included in this dataset are low-lying areas within the new expanded flood extent that are below the elevation of the expanded flood zone, and therefore have the potential to flood, but are hydrologically disconnected from the rest of the flood zone.

Data Sources

- The **Rutgers NJ FEMA Modified Statewide Flood Hazard Area (rev. 07/23)** (Rutgers, 2023), which includes both effective and preliminary FIRM data.
- The **Rutgers NJ Hydro-flattened 10ft DEM** (Rutgers, 2023) is a hydro-flattened, 10ft resolution, digital elevation model created by updating NJDEP's 10ft DEM with the most recent LiDAR derived DEM's available as of December 2023.
- The **Height Above Nearest Drainage (HAND) Catchment Areas** dataset was downloaded from the Oak Ridge National Laboratory.
- The **12-digit and 14-digit Hydrologic Unit Code** datasets, part of the Watershed Boundary Dataset's 2-digit Hydrologic Unit geodatabase, were downloaded from the USGS's National Map (https://apps.nationalmap.gov/downloader/#/).
- The latest version (September, 2022) of the 10-digit Hydrologic Unit Code (HUS) Watershed Boundary geodatabase, part of the National Watershed Boundary Dataset, produced by the US Geological Survey and the US Department of Agriculture's National Resources Conservation Service, was downloaded from their Geospatial Data Gateway (https://datagateway.nrcs.usda.gov/catalog/productdescription/wbd.html).
- The **State Boundary of NJ** dataset, produced by the New Jersey Office of GIS, was downloaded from the NJ Geographic Information Network (https://njogis-newjersey.opendata.arcgis.com/datasets/state-boundary-of-nj/explore).
- The **Municipal Boundaries of NJ** dataset, produced by the New Jersey Office of GIS, was downloaded from the NJ Geographic Information Network (https://njogis-newjersey.opendata.arcgis.com/datasets/municipal-boundaries-of-nj-hosted-3424/explore).

Methodologies:

Rutgers NJ FEMA Modified 1% Chance Annual Flood (NJ_FEMA_Mod_1pct_04_09_24):

1. Select by Attributes to select Flood zones A, AE, AH, AO, and VE from the **NJ FEMA Modified Statewide Flood Hazard Area (rev. 07/23)** dataset.

2. Make Layer From Selected Features to create a new layer from the selection above (NJ_EFIRM_PFIRM_1pct_WC). Because both effective and preliminary data are included in the **NJ FEMA Modified Statewide Flood Hazard Area (rev. 07/23)** dataset, this represents the worst-case flooding from both EFIRMs and PFIRMs (If the flooding extent varies between PFIRM and EFIRM, the greater flooding extent is shown).
3. Dissolve to dissolve all 1pct annual flood features from NJ_EFIRM_PFIRM_1pct_WC into a single feature (NJ_EFIRM_PFIRM_1pct_WC_diss).
4. Pairwise Clip to clip the Municipal Boundaries of NJ dataset to the extent of NJ_EFIRM_PFIRM_1pct_WC_diss (NJ_EFIRM_PFIRM_100yr_WC_Muns).
5. Union to combine the clipped Municipal Boundaries of NJ dataset with the extent of NJ_EFIRM_PFIRM_1pct_WC_diss (NJ_EFIRM_PFIRM_100yr_WC_Muns_Union). This divides the flood extent along municipal boundaries and adds the municipality name and code, county, and flood extent area for each municipality as attributes to each dataset.
6. Delete feature without value for municipality. This is water.
7. Export Features to create a new feature class (NJ_FEMA_Mod_1pct_04_09_24).

Rutgers NJ FEMA 1% Chance Annual Flood Plus 3 Feet (NJ_FP3_04_09_2024):

Inverse Distance Weighting:

1. Steps 1-3 from NJ FEMA Modified 1pct Flood (NJ_FEMA_Mod_1pct_07_23) methodology.
2. Polygon to Line to convert the polygon feature class to a line feature class (NJ_EFIRM_PFIRM_1pct_WC_Diss_Line).
3. Extract by Mask to extract flood zone boundary elevations from the **New NJ Hydro-flattened 10ft DEM** using the line feature class (NJ_EFIRM_PFIRM_1pct_WC_Diss_Line_DEM).
   Input raster: New_NJ_DEM_10ft_HF
   Input raster or feature mask data: NJ_EFIRM_PFIRM_1pct_WC_Diss_Line
   Extraction area: Inside
4. Raster Calculator to add three feet to the extracted flood zone boundary elevations (NJ_EFIRM_PFIRM_1pct_WC_Diss_Line_DEM_P3):
   "NJ_EFIRM_PFIRM_1pct_WC_Diss_Line_DEM" + 3
5. Raster to Point to convert extracted flood zone boundary elevation raster to a point feature class (NJ_EFIRM_PFIRM_1pct_WC_Diss_Line_DEM_P3_Pt).
6. Raster to Polygon to convert HAND Catchment area rasters that intersect the NJ state boundary (020301catchhuc.tif, 020403catchhuc.tif, 020402catchhuc.tif, 020401catchhuc.tif, 020200catchhuc.tif) to polygon feature classes (Poly_020301catchhuc, Poly_020403catchhuc, Poly_020402catchhuc, Poly_020401catchhuc, Poly_020200catchhuc).
7. Erase and edit Poly_catchhucs in preparation for Merge.

8. Merge to combine edited Poly_catchuc polygon feature classes into one polygon feature class (Poly_HAND_CatchHuc).
9. Select by Location to select HAND Catchment Area, 10-digit WBDHU, and 12- digit WBDHU polygon features that intersect the elevation point feature class.
10. Summarize Within to select all intersecting polygons in each polygon feature class that have more than one elevation point. IDW will not run unless there are at least two input points.
11. Export Features to create three new polygon feature classes from above selections (HANDCatch_Edit, HUC14_Edit, HUC12_Edit).
12. Create three new text fields in the three edited polygon feature classes (OBJECTID_txt, Pt, Shp).
13. Calculate the new Fields:

    OBJECTID_txt = !OBJECTID!
    Pt = "Pt_" !OBJECTID_txt! "
    Shp = "Shp_" !OBJECTID_txt! "
14. Create shape and point geodatabases for the three edited feature classes (6 geodatabases).
15. Split edited polygon feature classes into polygon shapefiles using edited polygon feature classes, with shape geodatabases as target workspaces:

    Input Features: Polygon feature class
    Split Features: Polygon feature class
    Split Field: Shp
    Target Workspace: Shp.gdb
16. Split elevation point feature class into point shapefiles using edited polygon feature classes, with point geodatabases as target workspaces:

    Input Features: NJ_EFIRM_PFIRM_1pct_WC_Diss_Line_DEM_P3_Pt
    Split Features: Polygon feature class
    Split Field: Pt
    Target Workspace: Pt.gdb
17. Create a geodatabase for the IDW results of each of the split elevation point feature classes.
18. IDW to interpolate a new flood surface for each split polygon feature class using an inverse distance weighted technique (IDW_pt_[OBJECTID_txt]). Defaults were used except:

    Input point features: Pt_[OBJECTID_txt]
    Z = grid_code
    Output cell size = 10
    Processing Extent: Shp_[OBJECTID_txt]
    Mask: Shp_[OBJECTID_txt]
19. Mosaic to New Raster to combine the IDW results for each of the three split polygon feature classes (IDW_ HANDCatch_Full, IDW_HUC14_Full, IDW_HUC12_Full):

    Input Rasters: IDW_pt_[OBJECTID_txt]s
    Raster Dataset Name with Extension: IDW_[…]_Full
    Spatial Reference: NAD_1983_2011_StatePlane_New_Jersey_FIPS_2900_Ft_US
    Pixel Type: 32 bit float

Cell Size: 10
Number of Bands: 1

20. Nibble each mosaiced raster to fill in NoData cells between IDW results using that same mosaiced raster as a mask (Nibble_IDW_HANDCatch_Full, Nibble_IDW_HUC14_Full, Nibble_IDW_HUC12_Full):
    Input raster: IDW_[…]_Full
    Input raster mask: IDW_[…]_Full
    Use no data cells if they are the nearest neighbor: unchecked
    Nibble NoData cells: checked
21. Extract by Mask to extract the three Nibble outputs using the three polygon feature classes from above (HANDCatch_Edit, HUC14_Edit, HUC12_Edit). This is done because the Nibble tool does not honor the Mask environment, so the Nibble output extends to the extent of the input raster (Nibble_IDW_HANDCatch_Full_Extract, Nibble_IDW_HUC14_Full_Extract, Nibble_IDW_HUC12_Full_Extract).
22. Mosaic to New Raster to combine extracted Nibble outputs into one raster with Nibble_IDW_HANDCatch_Full_Extract as primary Nibble_IDW_HUC14_Full_Extract secondary, and Nibble_IDW_HUC12_Full_Extract tertiary:
    Input Rasters: Nibble_IDW_HANDCatch_Full_Extract
    Nibble_IDW_HUC14_Full_Extract
    Nibble_IDW_HUC12_Full_Extract
    Output Location: IDW_NJ_FP3
    Raster Dataset Name with Extension: IDW_NJ_FP3
    Spatial Reference: NAD_1983_2011_StatePlane_New_Jersey_FIPS_2900_Ft_US
    Pixel Type: 32 bit float
    Cell size: 10
    Number of Bands: 1
    Mosaic Operator: First

Topo to Raster:

1. Steps 1-11 from Inverse Distance Weighting (IDW_NJ_FP3) methodology (HANDCatch_Edit, HUC14_Edit, HUC12_Edit).
2. Create Shp, Buff, and Buff_Pt geodatabases for each of the three edited polygon feature classes (9 geodatabases).
3. Create four new text fields in each of the three edited polygon feature classes (OBJECTID_txt, Shp, Buff, Buff_Pt).
4. Create one geodatabase for the TTR results for each of the three edited polygon feature classes (NJ_Poly_HAND_CatchHuc_DEM10_TTRs.gdb, Hydr_HUC14_bnd_DEM10_TTRs.gdb, NJ_WBDHU12_DEM10_TTRs.gdb).
5. Calculate the new Fields:
    OBJECTID_txt = !OBJECTID!

Shp = "Shp_" !OBJECTID_txt! "
Buff = "Buff_" !OBJECTID_txt! "
Buff_Pt = "Buff_Pt_" !OBJECTID_txt! "

6. Split the edited polygon feature class into polygon shapefiles using the same edited polygon feature class, with the Shp geodatabase as target the workspace:
   Input Features: Polygon feature class
   Split Features: Polygon feature class
   Split Field: Shp
   Target Workspace: Shp.gdb
7. Pairwise Buffer to buffer the features of each of the three edited polygon feature classes by 500ft (HANDCatch_Edit_Buff500, HUC14_Edit_Buff500, HUC12_Edit_Buff500).
8. Split the buffered polygon feature class into polygon shapefiles using the same buffered polygon feature class, with the Buff geodatabase as target the workspace:
   Input Features: Buffered polygon feature class
   Split Features: Buffered polygon feature class
   Split Field: Buff
   Target Workspace: Buff.gdb
9. Split the elevation point feature class into point shapefiles using the buffered polygon feature class, with the Buff_Pt geodatabase as the target workspace:
   Input Features: NJ_EFIRM_PFIRM_1pct_WC_Diss_Line_DEM_P3_Pt
   Split Features: Buffered polygon feature class
   Split Field: Buff_Pt
   Target Workspace: Buff_Pt.gdb
10. Topo to Raster to interpolate a flood surface for each polygon shapefile in each edited polygon feature class (TTR_NJ_Poly_HAND_CatchHuc_DEM10_n, TTR_Hydr_HUC14_bnd_DEM10_n, TTR_NJ_WBDHU12_DEM10_n):
    Feature Layer: Pt_Buff_n
    Field: grid_code
    Type: Point elevation
    Output cell size: 10
    Output extent: Shp_n
    Margin in cells: 50
    Drainage enforcement: Enforce
    maximum number of iterations: 100
    Primary type of input data: Spot
    Processing Extent: Buff_n
    Mask: Shp_n

From Esri Help: "[Margin in cells is the d]istance in cells to interpolate beyond the specified output extent and boundary…If the Output extent and Boundary feature datasets are the same as the limit of the input data (the default), values interpolated along the edge of the DEM will not match well with adjacent DEM data. This is because they have been interpolated using one-half as much data as the points inside the raster, which are surrounded on all sides by input data. The Margin In Cells option allows input data beyond these limits to be used in the interpolation."

Using flood elevation points within the 500-foot buffered watershed (as opposed to within the original watershed boundary) as the processing extent, the watershed boundary as the output extent, and 50 cells (500 feet) as the "Margin in cells" assures that the output elevation values along the edge of the watershed are interpolated using the same amount of data as those in the rest of the watershed.

11. Mosaic to New Raster to combine the interpolated flood surfaces for each edited polygon feature class (TTR_NJ_Poly_HAND_CatchHuc_DEM10_Full, TTR_Hydr_HUC14_bnd_DEM10_Full, TTR_NJ_WBDHU12_DEM10_Full).
12. Nibble to fill in NoData cells in between the mosaiced flood surfaces for each mosaiced raster (from step 11) in each edited polygon feature class (Nibble_TTR_NJ_Poly_HAND_CatchHuc_DEM10_Full, Nibble_TTR_Hydr_HUC14_bnd_DEM10_Full, Nibble_TTR_NJ_WBDHU12_DEM10_Full):
    - Input raster: TTR_[…]_Full
    - Input raster mask: TTR_[…]_Full
    - Use no data cells if they are the nearest neighbor: unchecked
    - Nibble NoData cells: checked
13. Create a mask for each edited polygon feature class to extract the polygons for which TTR ran successfully.
14. Extract by Mask to extract the polygons for which TTR ran successfully from the Nibble output for each polygon feature class (Nibble_TTR_NJ_Poly_HAND_CatchHuc_DEM10_Full_Extract, Nibble_TTR_Hydr_HUC14_bnd_DEM10_Full_Extract, Nibble_TTR_NJ_WBDHU12_DEM10_Full_Extract).
15. Mosaic to New Raster to combine nibbled mosaiced flood surfaces (from step 12) of each edited polygon feature class with Nibble_TTR_NJ_Poly_HAND_CatchHuc_DEM10_Full_Extract as primary, Nibble_TTR_Hydr_HUC14_bnd_DEM10_Full_Extract as secondary, and Nibble_TTR_NJ_WBDHU12_DEM10_Full_Extract as tertiary (NJ_TTR_Full):
    - Input Rasters: Nibble_TTR_NJ_Poly_HAND_CatchHuc_DEM10_Full_Extract
Nibble_TTR_Hydr_HUC14_bnd_DEM10_Full_Extract
Nibble_TTR_NJ_WBDHU12_DEM10_Full_Extract
    - Raster Dataset Name with Extension: NJ_TTR_Full
    - Spatial Reference: NAD_1983_2011_StatePlane_New_Jersey_FIPS_2900_Ft_US
    - Pixel Type: 32 bit float
    - Cell size: 10
    - Number of Bands: 1
    - Mosaic Operator: First

16. Nibble a second time to fill in NoData cells in between the mosaiced flood surfaces for the three mosaiced rasters (Nibble_NJ_TTR_Full):
    Input raster: NJ_TTR_Full
    Input raster mask: NJ_TTR_Full
    Use no data cells if they are the nearest neighbor: unchecked
    Nibble NoData cells: checked
17. Create a second mask for the mosaiced raster to extract the polygons for which TTR ran successfully from the Nibble output.
18. Extract by Mask to extract the polygons for which TTR ran successfully from the second Nibble (Nibble_NJ_TTR_Full_Extract).
19. Mosaic to New Raster to combine Nibble_NJ_TTR_Full_Extract (primary) and IDW_NJ_FP3 (secondary) (NJ_TTR_IDW_Full). **This is the interpolated surface of the FEMA 100-year flood plain with an additional three feet added**:
    Input Rasters: Nibble_NJ_TTR_Full_Extract
    IDW_NJ_FP3
    Raster Dataset Name with Extension: NJ_TTR_IDW_Full
    Spatial Reference: NAD_1983_2011_StatePlane_New_Jersey_FIPS_2900_Ft_US
    Pixel Type: 32 bit float
    Cell size: 10
    Number of Bands: 1
    Mosaic Operator: First
20. Raster Calculator to derive the flood extent of the interpolated flood surface using the 10ft Hydro-flattened DEM (NJ_TTR_IDW_FP3_Extent):
    Con("New_NJ_DEM10ft_HF" <= "NJ_TTR_IDW_FP3", 1)
21. Filter to fill in any pixel size holes in NJ_TTR_IDW_FP3_Extent (NJ_TTR_IDW_FP3_Extent_filter):
    Filter type: Low pass
    Ignore NoData in calculations: checked

Extracting Low-Lying, Hydrologically Disconnected Areas:

The following methodology was used to extract the low-lying areas in the new expanded flood extent that are below the elevation of the expanded flood zone, and therefore have the potential to be flooded, but are hydrologically disconnected from the rest of the flood zone. Because the FEMA 1pct chance annual flood in New Jersey consists of thousands of disconnected areas throughout the state, as opposed to a single continuous flood zone, the Region Group method used by NOAA to extract low-lying, disconnected areas for sea level rise projections is not efficient in this case.

1. Int to convert NJ_TTR_IDW_FP3_Extent_filter from float to integer (FP3_int).
2. Raster to Polygon to convert the integer raster to a polygon feature class (FP3_int_poly).
    Simplify polygons = Unchecked
3. Select Layer By Location to select the features in the polygon feature class that intersect with NJ_FEMA_Mod_1pct_07_23:

Input Features: FP3_int_poly
Relationship: Intersect
Selecting Features: NJ_FEMA_Mod_1pct_07_23
Selection Type: New selection

4. Export Features to create a new feature class from the selected (FP3_int_poly_con). This is the extent of the hydrologically connected areas within the expanded flood zone.
5. Erase to remove the hydrologically connected areas from FP3_int_poly using FP3_int_poly_con (FP3_int_poly_discon). This is the extent of the hydrologically disconnected areas within the expanded flood zone.
6. Select Layer by Attribute to select hydrologically disconnected areas from FP3_int_poly_discon that are an acre or larger (FP3_int_poly_discon_acre):

   Shape_Area >= **43560**

Final Processing:

1. Merge to combine FP3_int_poly_con with NJ_FEMA_Mod_1pct_07_23 (FP3_int_poly_con_merge).
2. Dissolve to combine the features in FP3_int_poly_con_merge into a single feature (FP3_int_poly_con_merge_diss).
3. Dissolve to combine the features in FP3_int_poly_discon_acre into a single feature (FP3_int_poly_discon_acre_diss).
4. Pairwise Clip to clip the Municipal Boundaries of NJ dataset to the extent of both the hydrologically connected and disconnected areas within the expanded flood zone (FP3_int_poly_con_merge _diss_muns, FP3_int_poly_discon_acre_diss_muns).
5. Union to combine the clipped Municipal Boundaries of NJ datasets with the extent of both the hydrologically connected and disconnected areas within the expanded flood zone (FP3_int_poly_con_merge _diss_muns_union, FP3_int_poly_discon_acre_diss_muns_union). This divides each flood extent along municipal boundaries and adds the municipality name and code, county, and flood extent area for each municipality as attributes to each dataset.
6. Delete feature without value for municipality in each dataset. This is water.
7. Export final datasets (FP3_int_poly_con_merge_diss_muns_union, FP3_int_poly_discon_acre_diss_muns_union) for publishing (NJ_FP3_04_09_2024, NJ_FP3_LL_04_09_2024).

Corrections

The above methodology produced a new surface that did not conform to the topography in certain areas. In these cases, the flood extent ended at the catchment boundary even though the topography would dictate it continue due to the use of HAND catchment areas for the output extent in these areas.

Where this occurred, the 10-foot resolution interpolated surface for the next largest watershed boundary that did not result in an error was mosaiced on top of the flood surface with the error.

For some areas in and around Wharton State Forest and Brendan T. Byrne State Forest, a 100-meter resolution surface was interpolated. This was done because of a lack of flood zone elevation points in the area that fell within the smaller watershed boundary units being used for the new surface. For these areas, the larger 10-digit HUC boundary was used so that flood zone elevation points were included. Because the 10-digit HUCs are too large to run TTR at a 10-foot resolution, 100-meter resolution was used.

Notes on Interpolation Methods and Assessment of Outputs

Inverse Distance Weighted (IDW) interpolation estimates an elevation surface by averaging known elevation sample points within a certain distance from the point being estimated, giving the greatest weight to the sample points closest to the point being estimated and the least weight to the sample points furthest away. IDW works best when known elevation points are dense and evenly dispersed, which is not the case for the sample points used to interpolate the FEMA +3 surface. The high variability in elevation coupled with the great distance between flood areas, as well as data gaps in the original FEMA 100-year flood zone result in a less-than-ideal expanded FEMA +3 surface using IDW that does not always conform to topography and exhibits artifacting.

Topo to Raster (TTR) was created to estimate hydrologically correct elevation surfaces by constraining the estimated surface so that it maintains a connected drainage structure and correctly represents ridges and streams. It is computationally expensive, but it produced a FEMA +3 surface that conforms to topography better than IDW and does not exhibit artifacting. Compared to IDW, it performs particularly well where there are great distances between flood areas and in areas where it appears flood assessment may have not been made for the original FEMA 1% chance annual flood.

Of the two methods, TTR is the most hydrologically correct and likely the most accurate estimate of the extent of flooding from an additional 3 feet on top of the current FEMA 1% chance annual flood. Unfortunately, Topo to Raster did not run successfully for all polygon shapefiles. This resulted in gaps in the interpolated flood surface. The IDW surface was used to fill in these gaps.

The following are links to the documentation for Esri's IDW and Topo to Raster tools as well as further reading on elevation surface interpolation and a comparison of the two methods:

https://pro.arcgis.com/en/pro-app/latest/tool-reference/spatial-analyst/idw.htm

https://pro.arcgis.com/en/pro-app/latest/tool-reference/spatial-analyst/how-idw-works.htm

https://pro.arcgis.com/en/pro-app/latest/tool-reference/spatial-analyst/topo-to-raster.htm

https://pro.arcgis.com/en/pro-app/latest/tool-reference/spatial-analyst/how-topo-to-raster-works.htm

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https://pro.arcgis.com/en/pro-app/latest/tool-reference/3d-analyst/comparing-interpolation-methods.htm

https://pro.arcgis.com/en/pro-app/latest/help/analysis/geostatistical-analyst/deterministic-methods-for-spatial-interpolation.htm#:~:text=Deterministic%20interpolation%20techniques%20create%20surfaces,properties%20of%20the%20measured%20points

https://gisresources.com/types-interpolation-methods_3/

Chetty, P. and Tesfamichael, S. A Comparison of Interpolation Techniques in Producing a DEM from the 5 m National Geospatial Institute (NGI) Contours. DOI: 10.5220/0010525100370047 In Proceedings of the 7th International Conference on Geographical Information Systems Theory, Applications and Management (GISTAM 2021), pages 37-47.