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Updating Rainfall Zones and Intensities in Nebraska for Improved Design of Non-bridge-sized Drainage Structures

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Updating Rainfall Zones and Intensities in Nebraska for Improved Design of Non-bridge-sized Drainage Structures – Phase I

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16. Abstract

This study assesses the effectiveness of precipitation zones and Intensity-Duration-Frequency (IDF) curves used by the Nebraska Department of Transportation (NDOT) for designing drainage structures. Twenty stations were selected for the analysis of revised IDF curves out of forty-two stations. Datasets have been considered from the National Center for Environmental Information (NCEI). By Comparing the new curves with existing ones, the study efforts examine the frequency, duration and severe rainfall. The results show that the IDF curves for various zones and stations varied noticeably from one another. Also, noticed that Zone A and B shows lower rainfall intensities in short to medium duration. While, Zone C shows higher rainfall intensities short to medium duration. The variation can be seen by a verification using ATLAS-14 IDF curves and historical data, suggesting the necessity for an updated methodology.

Additionally, this study used the Kriging and Inverse Distance Weighting (IDW) approach to analyze rainfall spatially. The study employed the k-means clustering technique to identify if the new cluster was considered to be a rainfall zone. The studies show the development of three spatial zones and a new IDF is created based on this clustering analysis. The research being conducted provides crucial information to ensure the sustainability of the Nebraska transportation system and increase the accuracy of hydrological assessments.

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List of Abbreviations

University of Nebraska-Lincoln (UNL)

Nebraska Department of Transportation (NDOT)

Intensity Duration Frequency (IDF)

National Centers for Environmental Information (NCEI)

National Oceanic and Atmospheric Administration (NOAA)

Within-cluster sum of squares (WCSS)

Inverse Distance Weighting (IDW)

Peak Over Threshold (POT)

Generalized Extreme Value (GEV)

Disclaimer

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Abstract

This study assesses the effectiveness of precipitation zones and Intensity-Duration-Frequency (IDF) curves used by the Nebraska Department of Transportation (NDOT) for designing drainage structures. Twenty stations were selected for the analysis of revised IDF curves out of forty-two stations. Datasets have been considered from the National Center for Environmental Information (NCEI). By Comparing the new curves with existing ones, the study efforts examine the frequency, duration and severe rainfall. The results show that the IDF curves for various zones and stations varied noticeably from one another. Also, noticed that Zone A and B shows lower rainfall intensities in short to medium duration. While, Zone C shows higher rainfall intensities short to medium duration. The variation can be seen by a verification using ATLAS-14 IDF curves and historical data, suggesting the necessity for an updated methodology.

Additionally, this study used the Kriging and Inverse Distance Weighting (IDW) approach to analyze rainfall spatially. The study employed the k-means clustering technique to identify if the new cluster was considered to be a rainfall zone. The studies show the development of three spatial zones and a new IDF is created based on this clustering analysis. The research being conducted provides crucial information to ensure the sustainability of the Nebraska transportation system and increase the accuracy of hydrological assessments.

Executive Summary

This study assesses how effectively the Nebraska Department of Transportation (NDOT) presently uses the rainfall zones and associated IDF curves when designing drainage infrastructure smaller than bridges. The analysis compares new IDF curves developed using data from 1981-2020 with existing curves based on older data (1961 and 1988).

Chapter 1 Implementation: Introduction

1.1 Background

This Project research study goal is to increase knowledge of communities, public safety and the value of promoting economic activity with the Nebraska Department of Transportation (NDOT). To protect infrastructure from the devasting impacts of heavy rains, NDOT supervises developing and maintaining culverts as well as sewer storm and drainage structures. For effective drainage design requires precise rainfall data and Intensity Duration Frequency (IDF) curves.

This research aims to evaluate the efficacy of current precipitation zones and IDF curves utilized by the NDOT for drainage structure design. These zones were originally established by analyzing the overall pattern of rainfall isohyets or precipitation contour lines, as outlined in the National Oceanic and Atmospheric Administration (NOAA) and Technical Paper 40 (TP-40) from 1961.

However, given the dynamic nature of climate conditions, the reliability of these rainfall zones and IDF curves are based on data spanning more than 60 years may be called into inconsistency. The 30 years average that climate researchers usually use to calculate the climate normal emphasize how inadequate it is to use rainfall information that is more than 60 years old to show Nebraska current climate. Therefore, updating rainfall information is essential to evaluate and potentially improve these methods.

The accuracy of the current rainfall zones and IDF curves used by NDOT for drainage structure design is thoroughly evaluated in this study. Employing information from the National Centers for Environmental Information (NCEI), a division of the NOAA, spanning a 40-year period from 1981 to 2020 with a 15-minute duration, the research aims to evaluate and compare the most recent rainfall intensities to the current NDOT intensities used in the rational method and show if they have changed current rainfall zones and IDF curves.

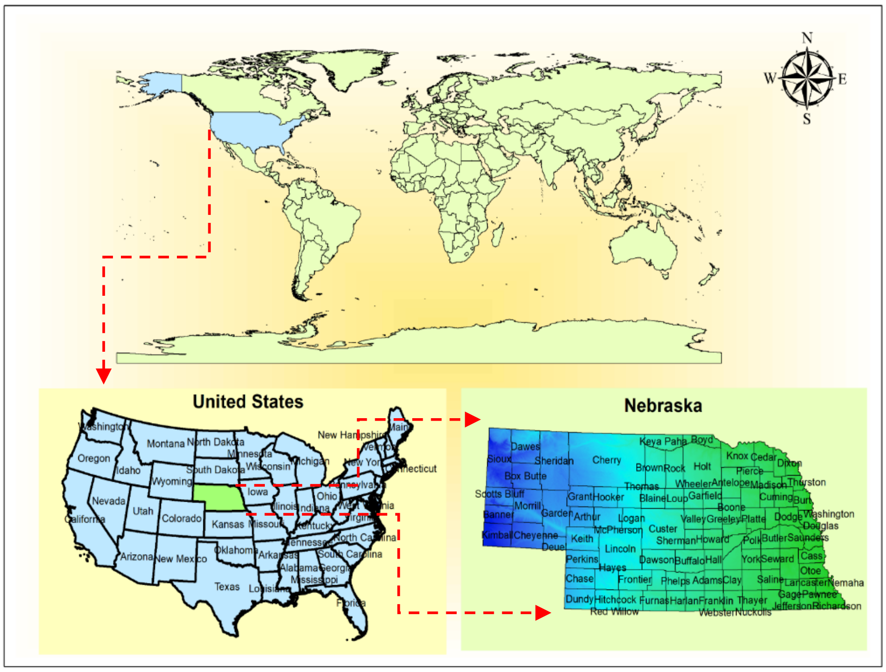


Figure 1.1 Study location.

The research study aims to assess the precipitation zones and their associated IDF curves currently used by the NDOT in their effectiveness when designing non bridge sized drainage structures. In 1988, Dr. Tom Riley and Dr. R. R. Marlette conducted a study on hydrologic and hydraulic designs for culverts at 24 different stations across Nebraska, employing various hydrologic methods based on drainage area shown in Figure 1.2.

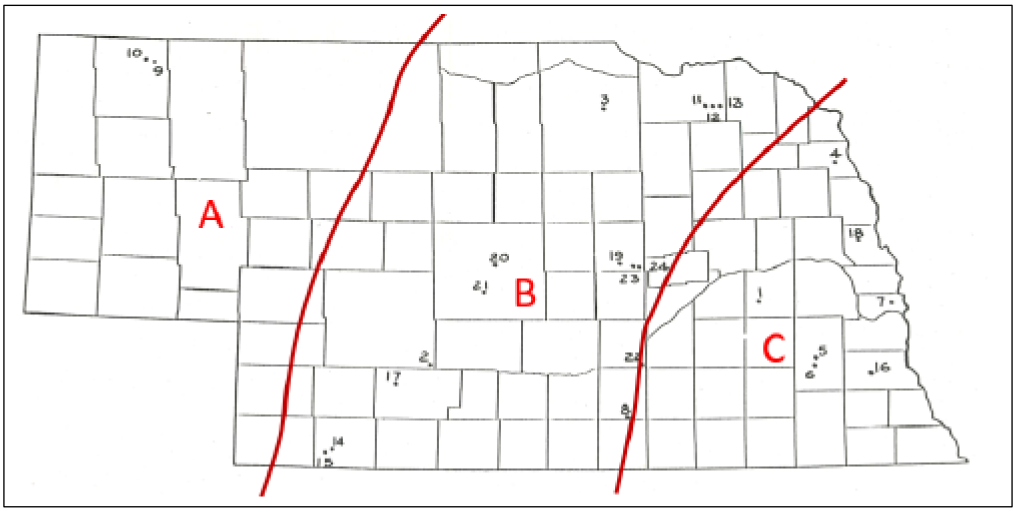


Figure 1.2 The 24 stations used in Riley and Marlette (1988) and their proposed rainfall zones.

In Figure 1.2 the current IDF zones are also delineated based on the previous zone classification A, B, C. However, in recent years, new stations have been added, and some old station data have been removed, spanning the years 1981-2020, as sown in Figure 1.3. A total of 42 new stations have been listed, surrounding zones A, B, and C. We have observed that 20 stations have less than 20% missing data availability for a 15-minute, while 22 stations have more than 20%. In our research, we have focused on datasets with less than 20% missing data. Zone A comprises four stations, Zone B contains 13 stations, and Zone C includes 3 stations, thus providing sufficient data for analysis.

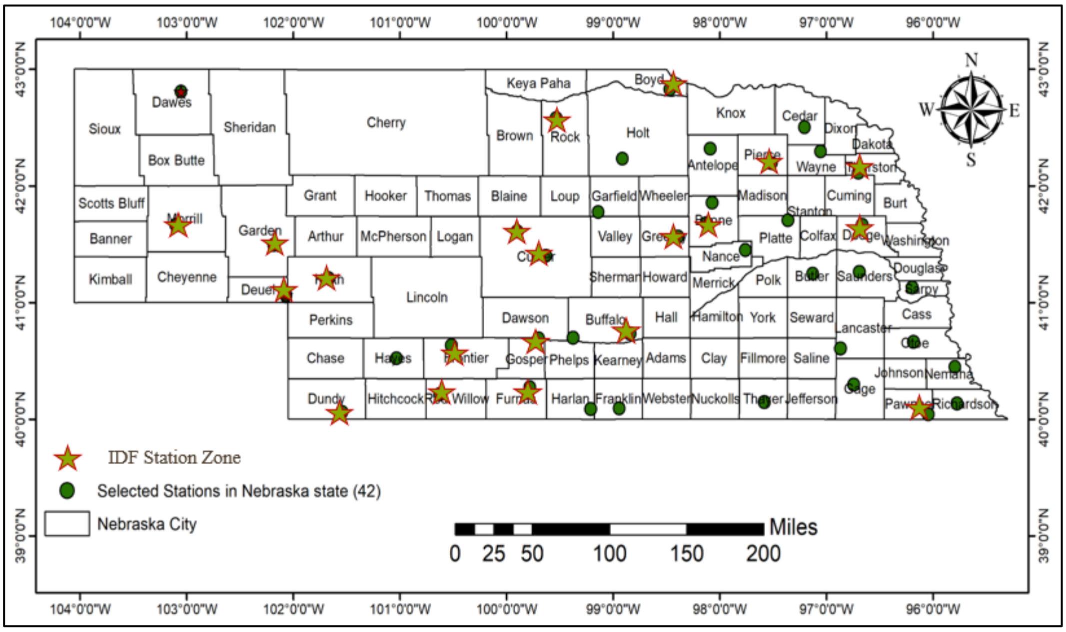


Figure 1.3 The total number of stations located for all zones considering the period from 1981-2020 period.

1.2 Limitation of Existing Methods

Current methods used by NDOT to evaluate rainfall zones and IDF curves have three main limitations.

1. **Outdated Precipitation Datasets:** The data discrepancy could lead to inaccurate design calculations and heightened susceptibility to extreme weather events. The NDOT IDF curves currently in use are 60 years old, probably not reflecting the current climate.
2. **Limited Scope:** The rainfall patterns total precipitation variance throughout Nebraska County is not adequately captured by the current rainfall zones A, B, and C, which may result in inconsistent design approaches.
3. **Advanced Technology:** IDF curves have been created using new dataset collection and evaluation techniques. This advanced method may make the outcome more precise and understandable.

To identify potential issues when designing drainage structures with the outdated rainfall zone maps and IDF curves currently employed by NDOT, this study aims to determine whether the existing maps and curves accurately represent present conditions and, if not, to enhance them with the latest data. In climate conditions, it will be more accurate to incorporate the most recent precipitation data into NDOT hydrologic research. Design of storm water drainage system including with recent precipitation data is essential since this captures the changing precipitation patterns due to anthropogenic activites.

The primary objective of this proposed research is to perform an extensive evaluation of the efficiency of the rainfall zones and associated IDF curves that NDOT currently uses when designing drainage structures that are not bridge-sized. Adjustments to the current methodology will be recommended based on the findings. The following are the specific objectives of the suggested research.

1. Compare the intensities in the rainfall data in 1961 with those in the current data.
2. Review and revise the existing rainfall zones.
3. Review and update the IDF curves.
4. Propose an updated calculation method for peak flow based on revised rainfall intensities applicable to Nebraska.
5. Make suggestions for practitioners based on the current research findings.

Chapter 2 Task 1: Methodology

The present method involves updating rainfall zones (A, B, and C) and intensities in Nebraska to upgrade the design of non-bridge-sized drainage structures. The process follows the workflow steps given below Figure 2.1.

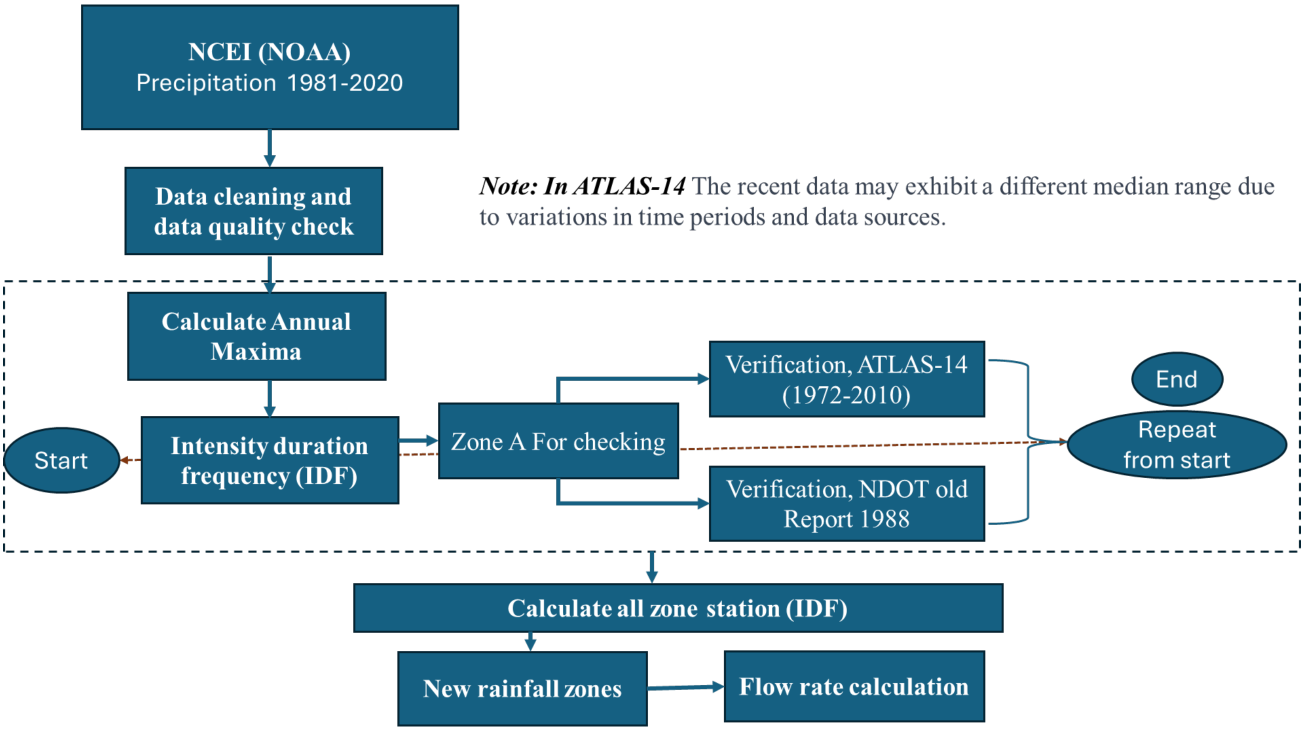


Figure 2.1 Workflow steps.

The workflow shows how we have completed all tasks outlined in the proposal (section 1.2 to 1.5).

2.2 Data Source

The research datasets were obtained from the NCEI, a division of the NOAA from 1981 to 2020 (15-minutes duration). This agency is responsible for collecting and providing access to various Climatology, hydrology, oceanic, geophysical, and environmental data.

2.3 Identifying the Missing Data Types

Significant gaps in the data, the lack of recent records, and missing data information on close stations led to the identification of 42 stations as dataset limits (Figures 2.2 and 2.3). Limitations were implemented outside the Nebraska boundary at 25, 50, and 100 miles in order to exclude neighboring stations. The availability of data has been identified using spatial analysis techniques (heat maps). This technique is important for the study of spatial analysis. To be more certain, we also manually verified the missing data.

2.4 Station Selection Process

Represent in Figure 2.2 is the selection of precipitation station data outside the Nebraska boundary at different distance intervals of 25, 50, and 100 miles.

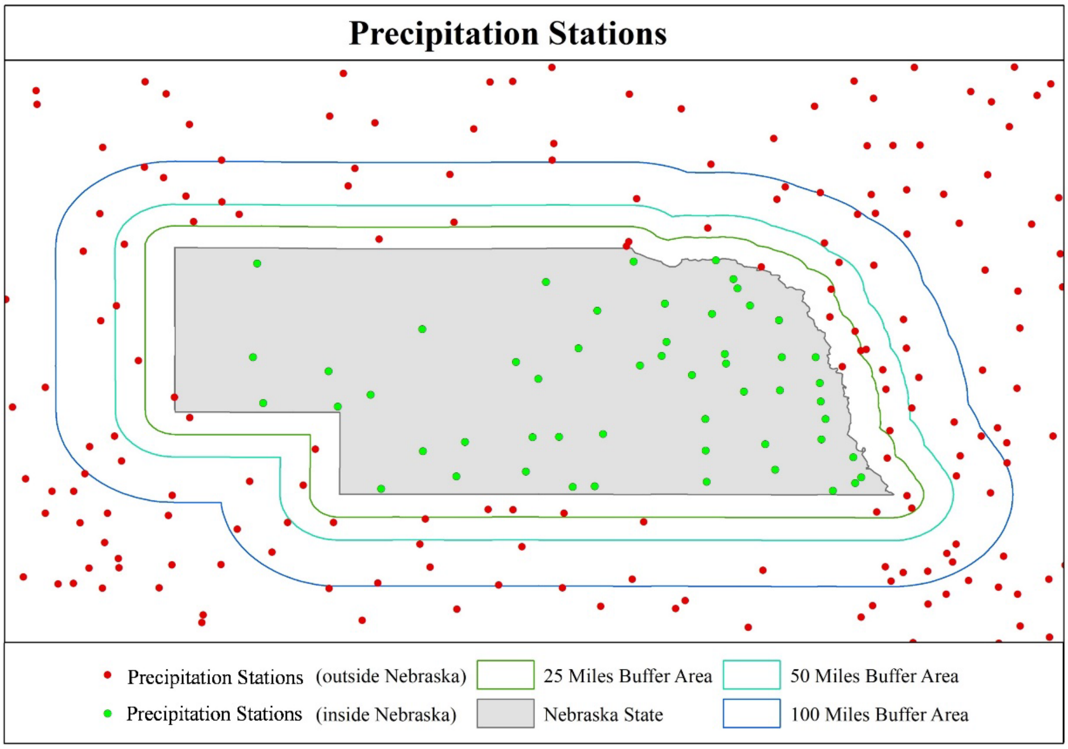


Figure 2.2 Selection of precipitation stations beyond the Nebraska boundary at distances of 25, 50, and 100 miles.

2.5 Heat Map Analysis

The development of heat maps using the spatial analysis method to identify missing data records, significant gaps in datasets, and the absence of missing records in datasets is shown in Figure 2.3. Additionally, it shows that 20 out of 42 stations have 20% missing data, while 22 have more than 20% missing data.

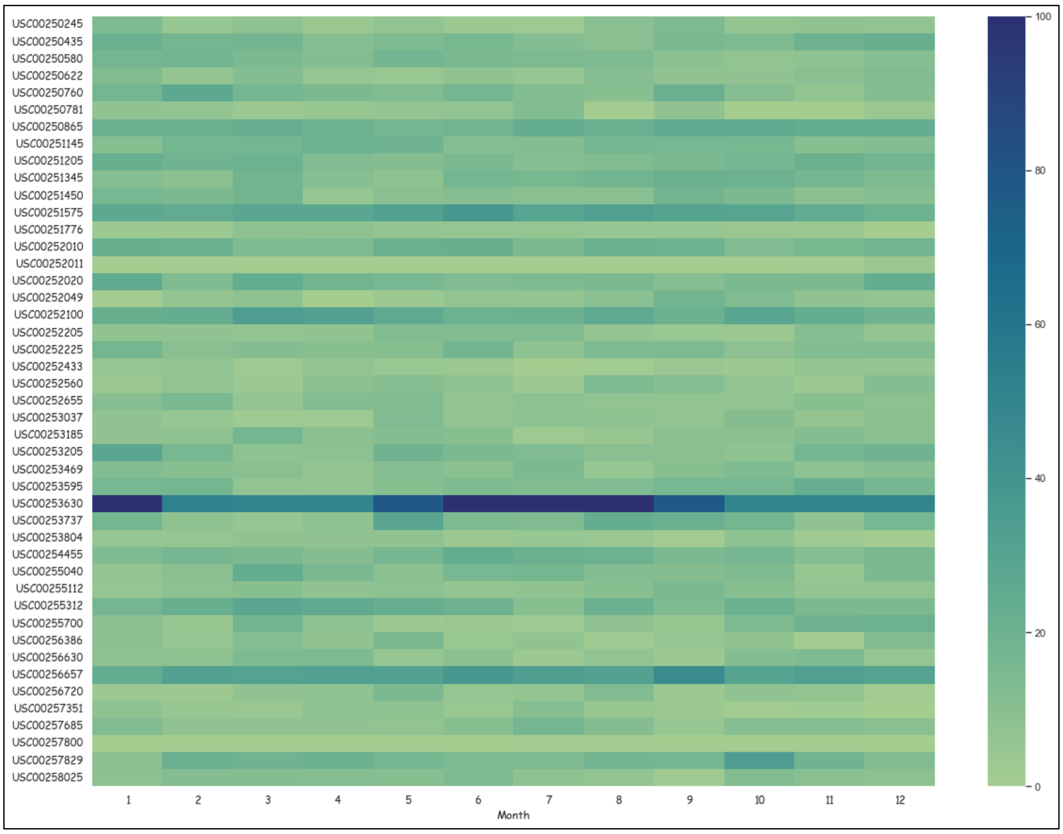


Figure 2.3 Heat map: Availability of missing data for each station from period 1981-2020.

We carefully selected 20 stations (less than 20% missing) to create IDF curves for each station using precipitation data and the data quality information for the current study. This data has been used to update IDF curves for Nebraska's three current rainfall zones (A, B, and C).

We did sensitivity tests to evaluate data quality and enhance our confidence in the datasets. Our analysis led us to identify a particular station (USC00256386) in zone A exhibiting anomalously high values. Specifically, we observed daily maximum precipitation values exceeding 34.3 hundredths of inches, with corresponding 15-minute data reaching a surprising 440 hundredths of inches. To reduce data quality issues, we decided to replace 34. 3 hundredths of inches with NA (not available). This NA was replaced with the 34. 3 values in the available precipitation station data, which address the disparity of the datasets. Also, we ensured that the precipitation values matched our daily data records by checking that they were equal to or greater than 34.3 hundredths of inches at the maximum level. The extreme outlier, 440 hundredths of inches, was replaced with the second-highest value in the dataset, around 140 hundredths of inches (mentioned to Figure A.1 in the appendix section). The unit conversion was done in hundredths of inches for 15-minute intervals. To work with actual inches, we converted the values appropriately. Additionally, we verify the results with the ATLAS-14 data (Figure A.2) and for clarity, also included a verification with the PRISM gridded dataset as mentioned in the appendix (Figure A.3). Verification with ATLAS-14 and updated data (1981-2020) is an example of two stations of IDF curves for (Morrill and Redwillow) mentioned in the appendix (Figure A.4). This thorough step ensured that our data set remained within a reasonable and reliable range, supporting the reliability of our analysis.

This allows for a updated curves and the currently used ones (based on outdated data) for all zones. The process of IDF curve preparation incorporates durations and frequencies similar to those in the existing curves but includes more recent records spanning from 1981 to 2020 period (40 years) of datasets.

Two distinct methods were employed for the preparation of IDF curves: (1) annual maxima and (2) peak over threshold. In the first method, the maximum precipitation values for various durations within each year were selected as extremes and later, a Generalized

Extreme Value (GEV) distribution was fitted using L-moment methods. Our current research uses the GEV method based on annual maxima and the L-moment estimation technique to generate the IDF curve. Our findings are validated using ATLAS-14 in the study using the IDF curve creation logarithm scale. 10-1 in/hr is equal to 10 in/hr, or 10 inches of precipitation in an hour, and 10-2 in/hr is equal to 0.01 in/hr, or 0.01 inches of precipitation in an hour, according to the logarithmic scale. We also explored the peak-over-threshold (POT) method using annual maxima; the GEV method gave us more confidence in our outcomes, which closely matched with the ATLAS-14 (1 to 24-hour period) with our present period of data (1981-2020) as shown in appendix figures A2 and A4. According to this, further research is required to improve the POT method used to create IDF curves. All the IDF curves show that using GEV methods gives better results when analyzing annual maxima data.

Chapter 3 Task 2: Preparation of the updated IDF curves for the existing zones

The IDF curve results are shown in Figure 3.1 for each zone (A, B, and C) and each station. The IDF curves provide crucial information by describing the relationship between rainfall intensity, duration, and frequency for calculating rainfall amounts for durations and return periods. IDF curve figures in the x-axis represent the rainfall event duration in hours, and the y-axis shows rainfall intensity in inches per hour. The different return durations are shown by different line colors, where a 50% likelihood of recurrence in any particular year is indicated by a two-year return period (blue line). The red line shows a 1% chance of recurrence in any given year, representing a 100-year return period. The IDF curves for the four stations show distinct patterns that highlight differing rainfall characteristics.

3.1 Zone A, four stations updated IDF curve (1981-2020)

Figure 3.1 displays IDF curves for Zone A stations, including Deuel, Morrill, Keith, and Garden.

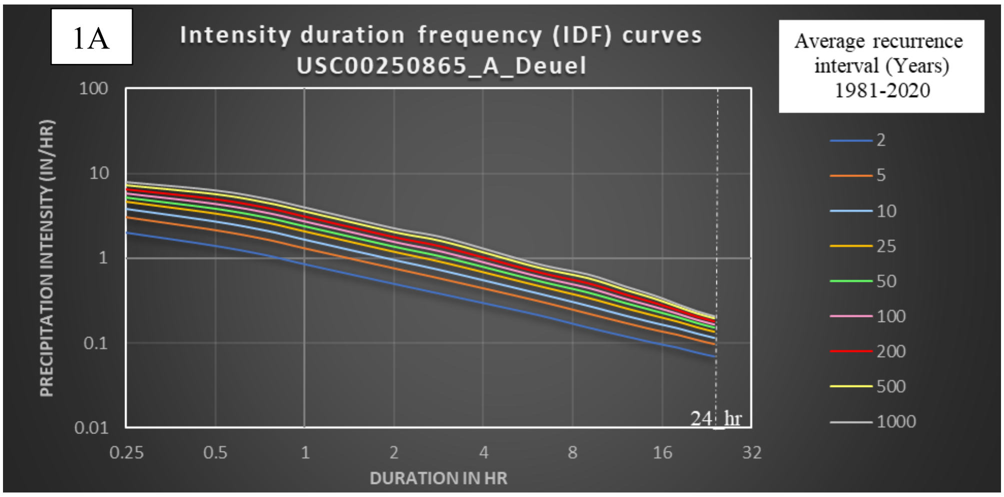
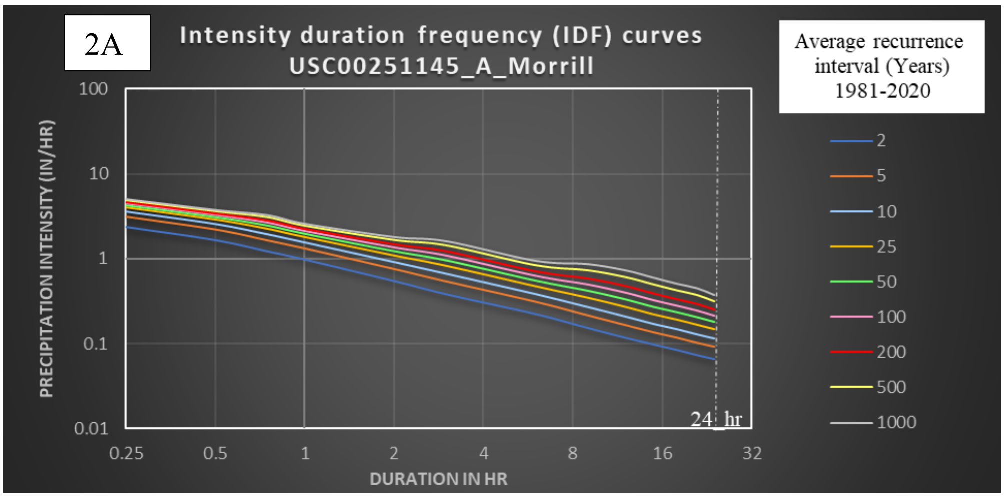
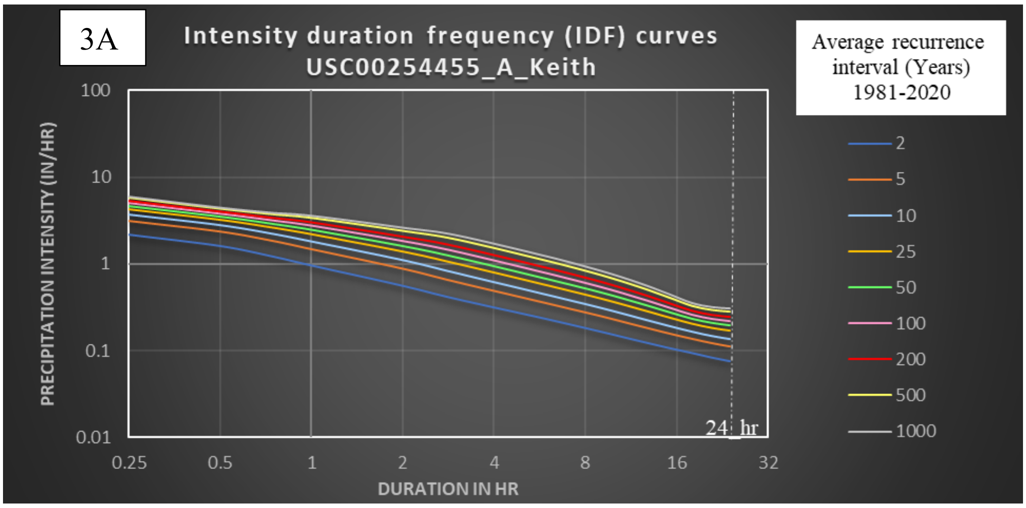


Figure 3.1 IDF curves for Zone A stations: (1) Deuel, (2) Morrill, (3) Keith, and (4) Garden. Note: 0.25 hours, and 0.5 hours are indicated 15 minutes and 30 minutes.





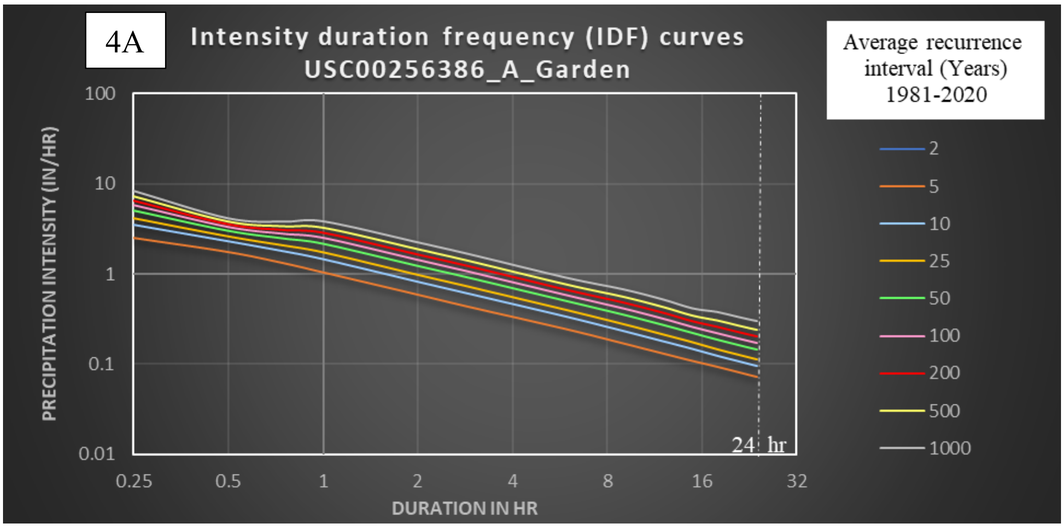


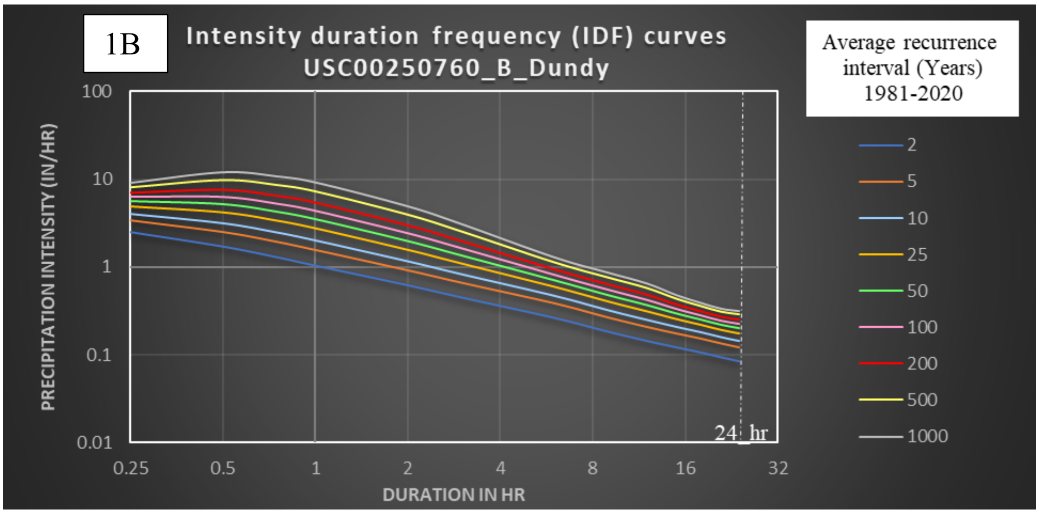
Figure 3.1 cont. IDF curves for Zone A stations: (1) Deuel, (2) Morrill, (3) Keith, and (4) Garden. Note: 0.25 hours, and 0.5 hours are indicated 15 minutes and 30 minutes.

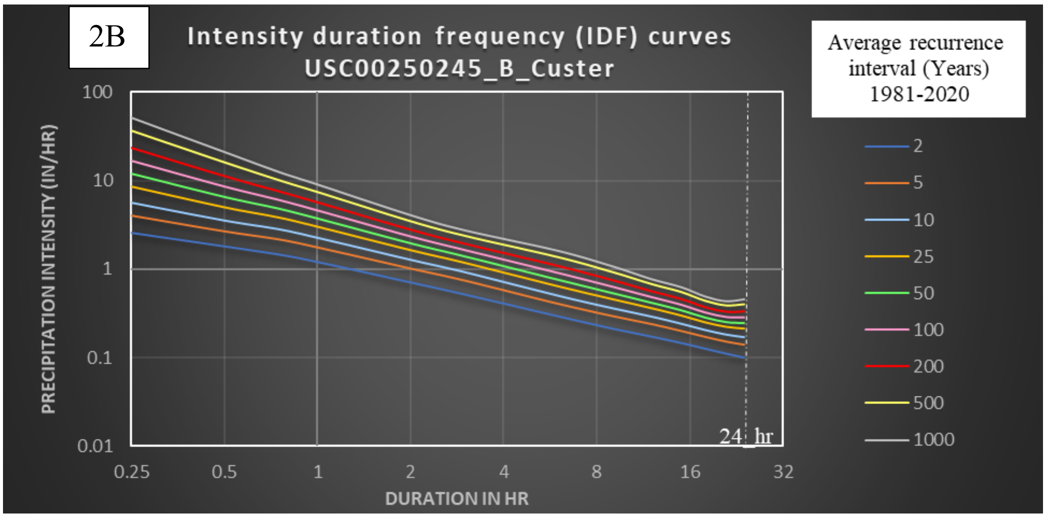
- **Deuel (1):** This station shows the lowest rainfall intensity for shorter durations. However, for longer durations (12 to 24 hours) Deuel rainfall intensity was slightly higher compared to some of the other stations.
- **Morrill (2):** Consistently showed heavy rainfall intensity across all durations. This shows a greater possibility of short-duration events and intense rainfall; a 2-year return period for 1 hour shows an instance of rainfall event in Morrill, which is higher than other stations.
- **Keith (3):** This station IDF curves closely followed Morrill (up to 4 hours) but for longer durations, it shows a slightly lower intensity.
- **Garden (4):** The Graden station IDF curves resembled Deuel for shorter durations, but for longer durations, its intensity increased and improved on Deuel for return periods beyond 5 years.

Morrill station showed the highest rainfall intensity across all durations, while Deuel had the lowest intensity for shorter durations. These variations likely decreased from differences in topography and climate among the four stations presented in Figure 3.1.

3.2 Zone B, 13 stations updated IDF curve (1981-2020)

Similarly, the IDF curves for the 13 stations in Zone B are represented in the Figure 3.2.





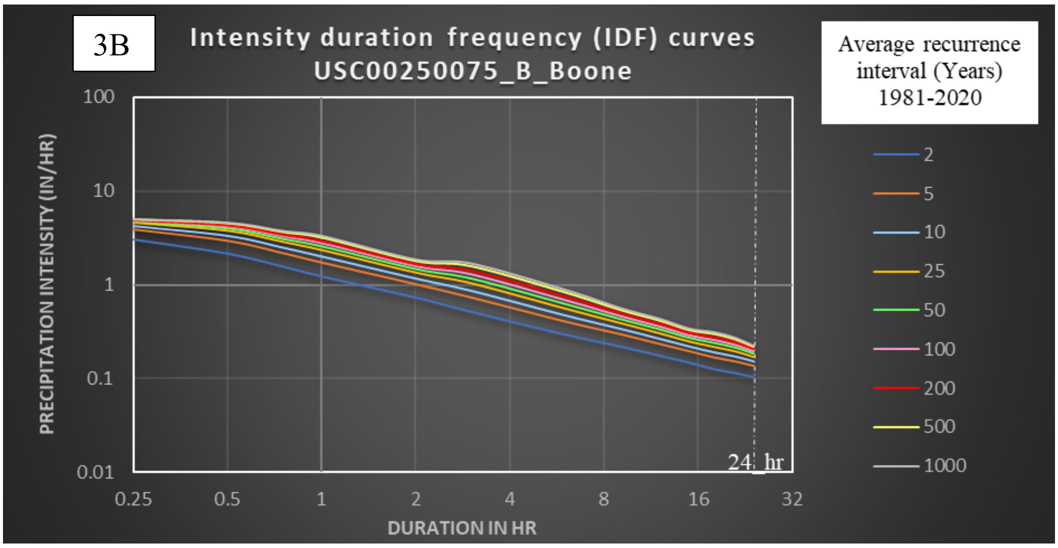
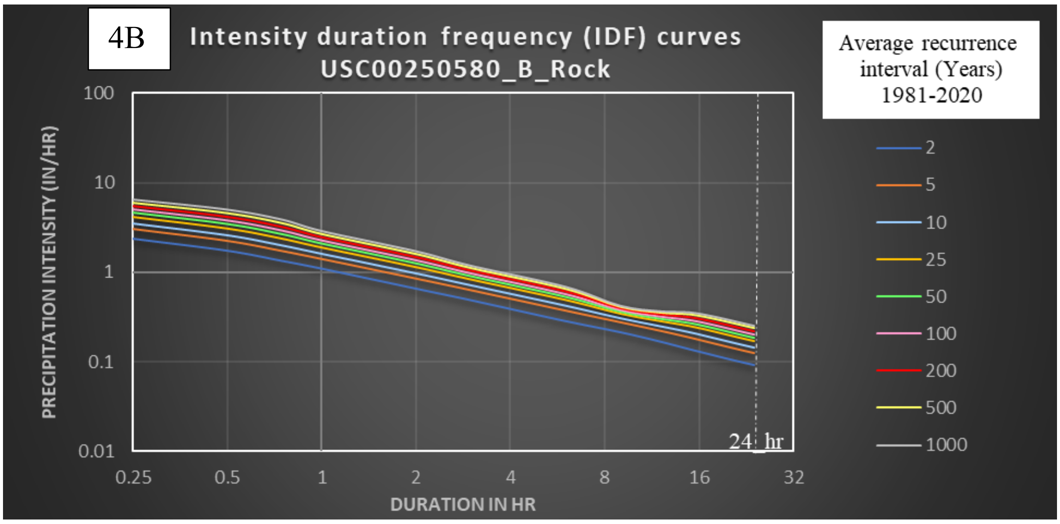
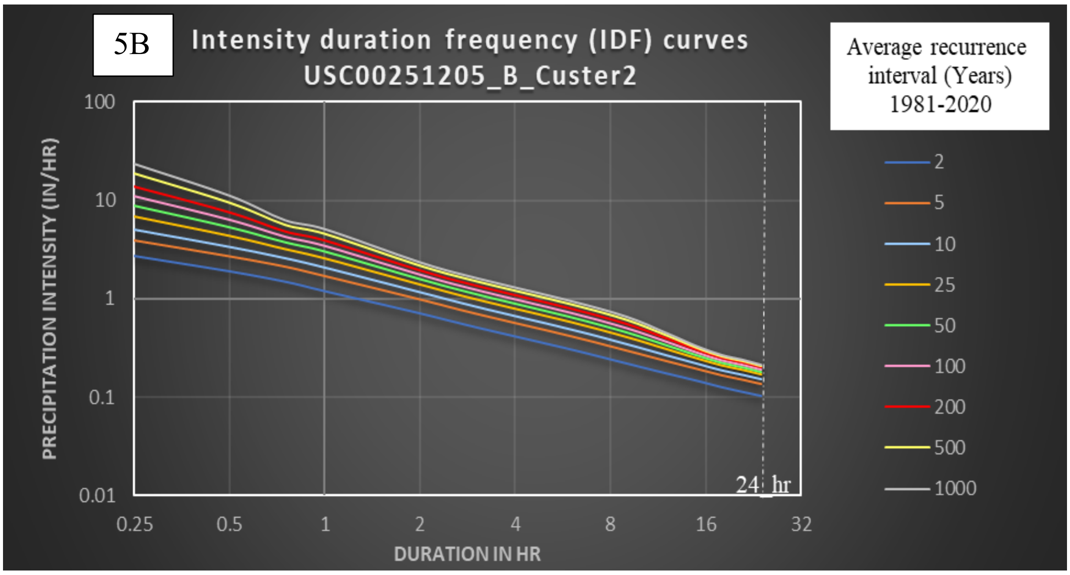


Figure 3.2 IDF curves for zone B stations (1-13) in Nebraska from 1981-2020 period. Note: 0.25 hours, and 0.5 hours are indicated 15 minutes and 30 minutes.





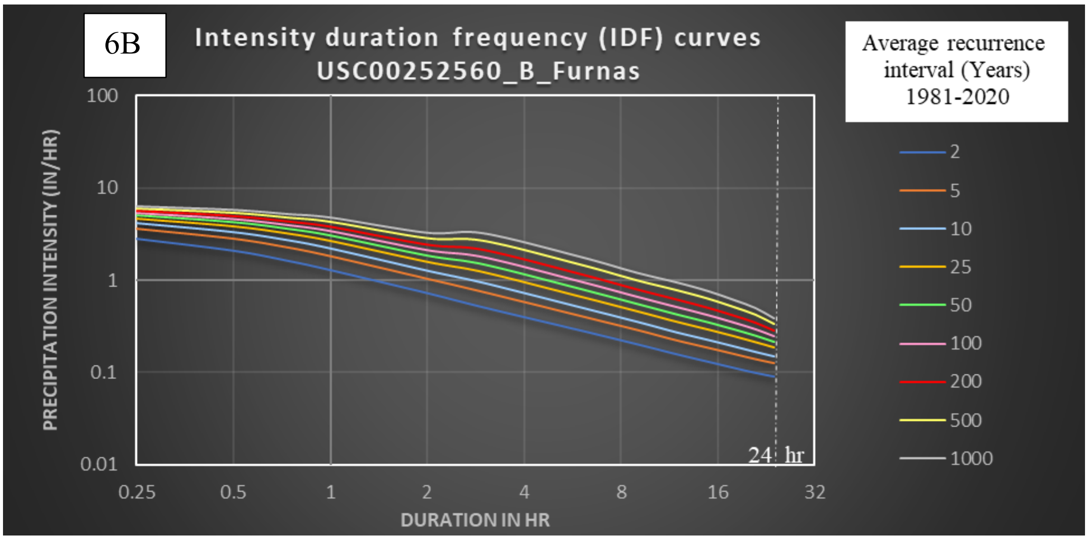
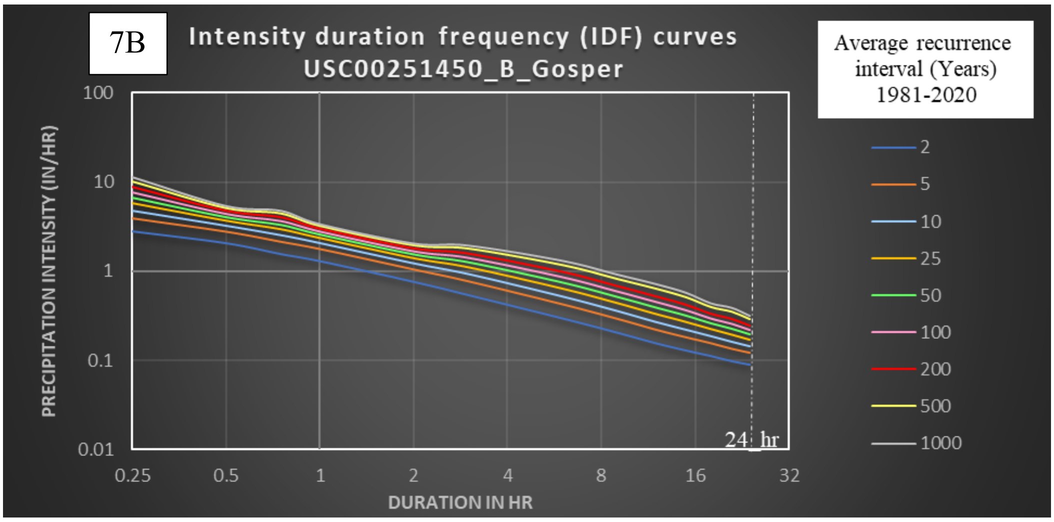
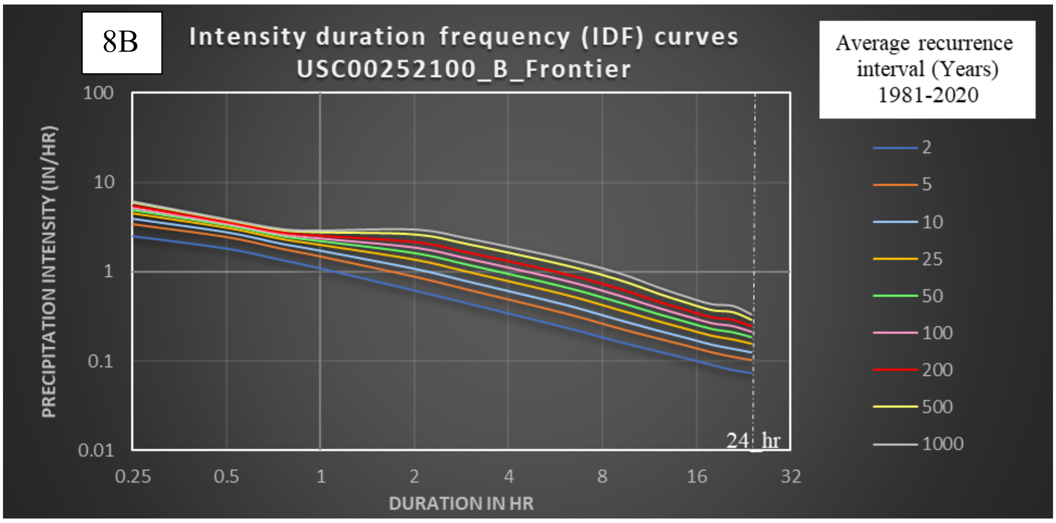
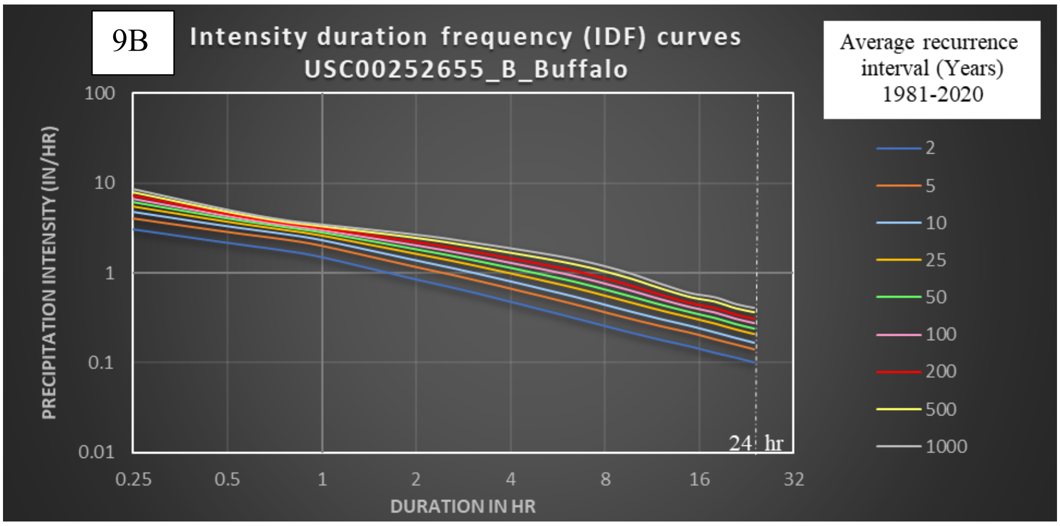


Figure 3.2 cont. IDF curves for zone B stations (1-13) in Nebraska from 1981-2020 period. Note: 0.25 hours, and 0.5 hours are indicated 15 minutes and 30 minutes.







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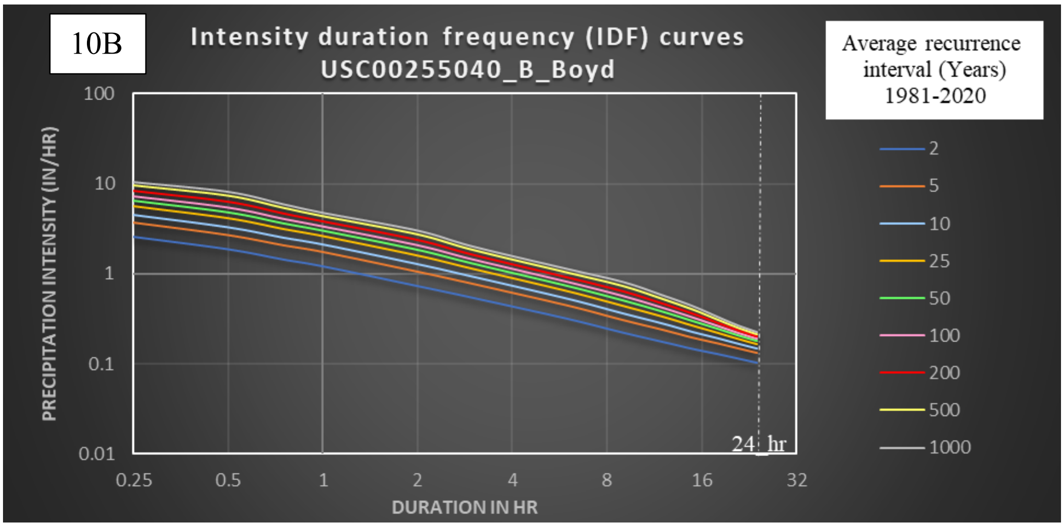

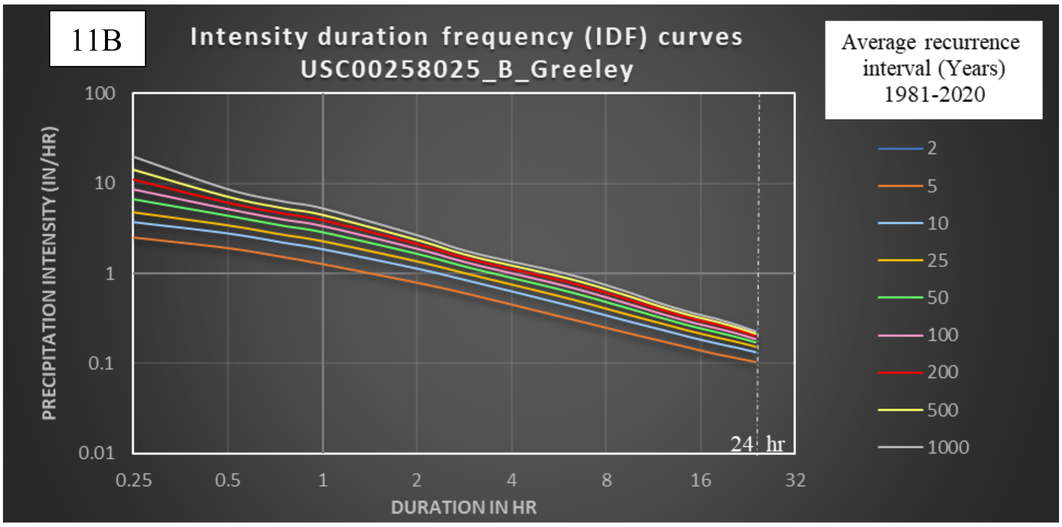

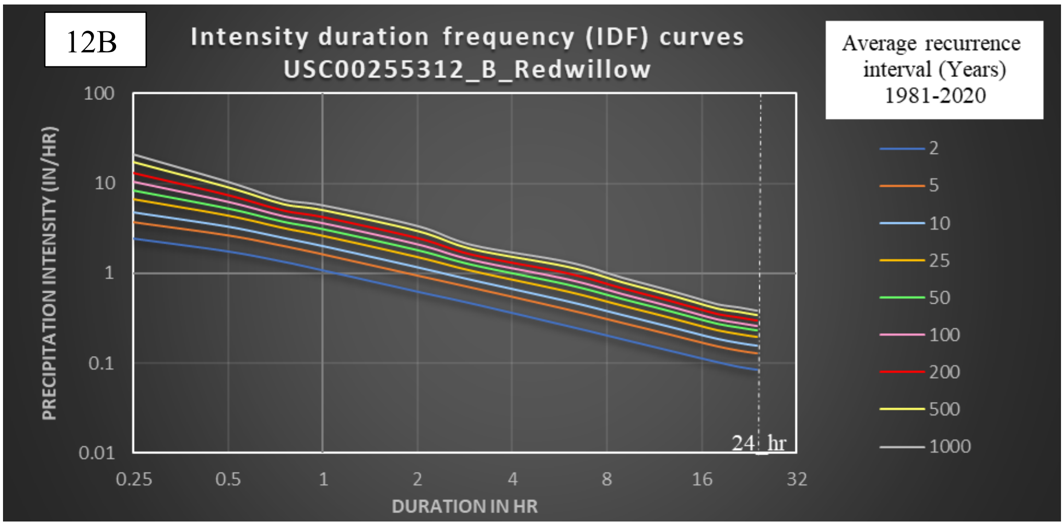

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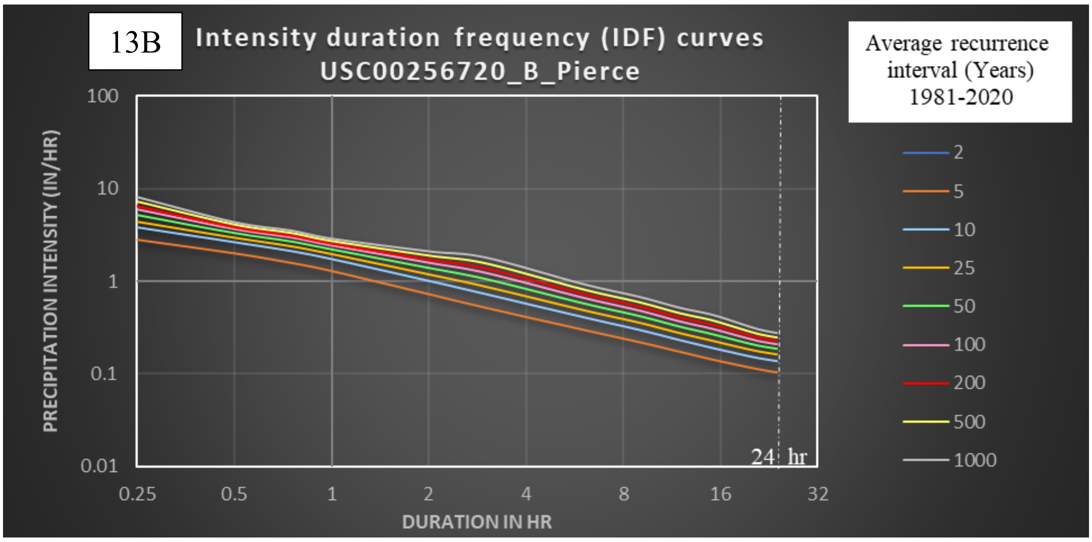


Figure 3.2 cont. IDF curves for zone B stations (1-13) in Nebraska from 1981-2020 period. Note: 0.25 hours, and 0.5 hours are indicated 15 minutes and 30 minutes.

As mentioned in Figure 3.2, each station presents a unique IDF curve, reflecting distinct rainfall patterns. A total of 13 stations are located in Zone B, identified by Nebraska county names and station IDs.

- **1B. USC00250760, Dundy**: This station shows relatively moderate rainfall intensities across all durations. The short-duration events (less than 1 hour) have a lower intensity compared to longer durations. The results show that the rainfall patterns are similar across all durations.
- **2B. USC00250245_B, Custer:** The IDF curves for Custer show low rainfall intensities across all durations, specifically for shorter ones. Also, the station shows similar behavior to Dundy station but with slightly lower intensities overall.
- **3B. USC00250075_B, Boone:** Boone exhibits moderate rainfall intensities with relatively stable curves. Like Custer and Dundy, this station does not show extreme intensity for short durations. The rainfall intensities are well-distributed across durations, with slight increases for events longer than 1 hour.

- **4B. USC00250580_B, Rock:** This station shows a balanced distribution of rainfall intensity, with slightly lower intensities for shorter durations compared to other stations. The intensity increases as the duration becomes longer. The curve for 24-hour events aligns closely with other stations, showing typical rainfall patterns for extended rain events.
- **5B. USC00251205_B, Custer 2:** Custer has two station locations, and both have good amount of precipitation datasets, so we have considered here both Custer station (Figure 3.2 Custer (2B) and Custer_2 (5B)). It shows similar patterns to Custer (2B), with slightly higher rainfall intensities for all durations. The difference between this station and Custer (2B) is more noticeable at shorter durations.
- **6B: USC00252560_B, Furnas:** This station has moderate rainfall intensities for all durations, without extremes. This shows that intense rainfall events are less likely at this station, like Boone and Custer. The station shows lower intensities for short durations compared to longer durations, making long-term rainfall events slightly more intense.
- **7B: USC00251450_B, Gosper:** This station has one of the lower rainfall intensities across all durations. This means it is less prone to short-duration, high-intensity rainfall and overall experiences lighter rainfall events compared to most other stations.
- **8B. USC00252100_B, Frontier:** This IDF curve for Frontier is similar to Custer and Boone, with moderate rainfall intensities. However, it shows slightly higher values for longer durations compared to shorter events. Frontier shows a balanced pattern, with no major deviations from the general trends of neighboring stations.

- **9B. USC00252655_B, Buffalo:** It shows moderate to low rainfall intensities for short durations, which gradually increase for longer durations. This implies the persistence of rainfall for longer duration resulting in higher intensity values for longer duration.
- **10B. USC00255040_B, Boyd:** This implies the station is experiencing moderate rainfall intensisties at short durations while higher intensites are observed for long duration. Similar to Gosper and Boyd which has lower rainfall intensity values, especially for shorter durations.
- **11B. USC00258025_B, Greeley:** This station shows a consistent increase in rainfall intensity for longer durations. The IDF curve look like the stations of Boone and Rock shows slightly higher values for short-duration events. Also, indicate more pronounced increase in intensity for 24-hour and longer durations compared to shorter durations.
- **12B. USC00255312_B, Redwillow:** It shows a pattern of moderate rainfall intensities, similar to stations like Buffalo and Boyd. It experiences slightly higher intensities for short-duration events than some of its neighboring stations. The IDF curve is slightly higher for short durations but overall moderate, suggesting balanced rainfall.
- **13B. USC00256720_B, Pierce:** Pierce station shows the highest rainfall intensities across all durations, making it prone to intense rainfall events over both short and long durations. Pierce station shows the highest intensity compared to the other Nebraska stations. For both short and long durations, the IDF curve has significant intensity, especially for return periods of 100 years or more.

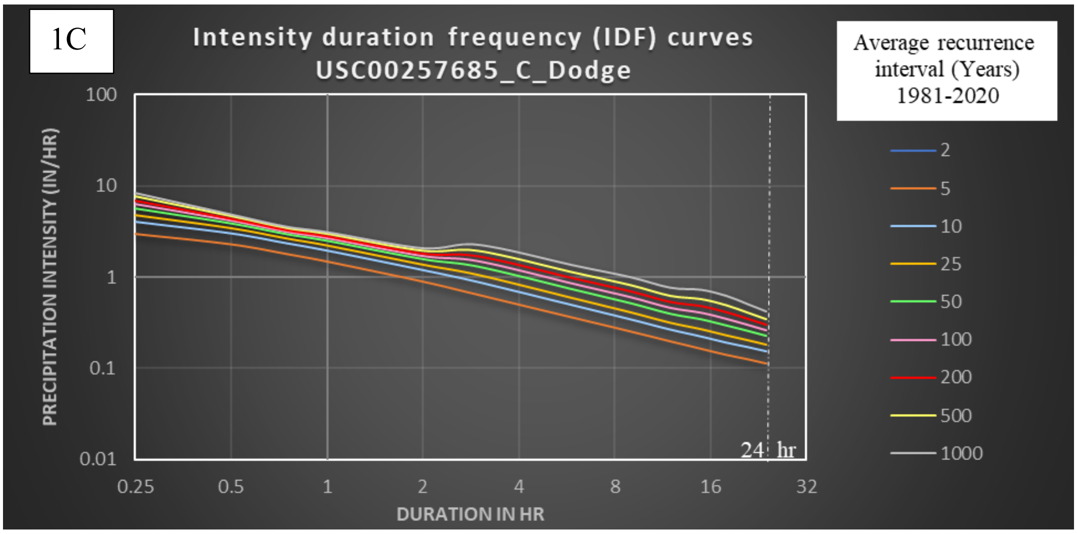
Key Observation:

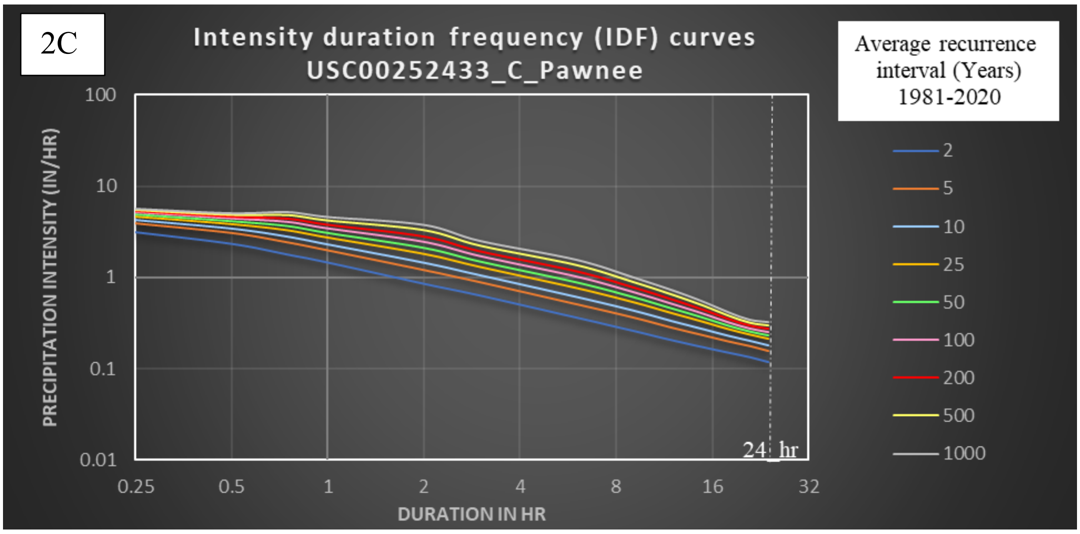
- ✓ **Pierce (13B):** Shows the highest rainfall intensities for all durations, which shows the higher possibility for intense rainfall events.
- ✓ **Gosper (7B):** It has relatively lower rainfall intensities, showing the least likelihood of intense rain for shorter durations.

The remaining stations, including **Dundy (1B)**, **Custer (2B, 5B),** and others, show moderate rainfall intensities with small variations, generally falling between Pierce and Gosper. Each station IDF pattern likely reflects local climatic and topographical factors, influencing the rainfall events they experience, as presented in Figure 3.2.

3.3 Zone C, 3 stations updated IDF curve (1981-2020)

Figure 3.3 shows IDF curves for three stations in Zone C: Dodge (USC00257685), Pawnee (USC00252433), and Thurston (USC00256630).





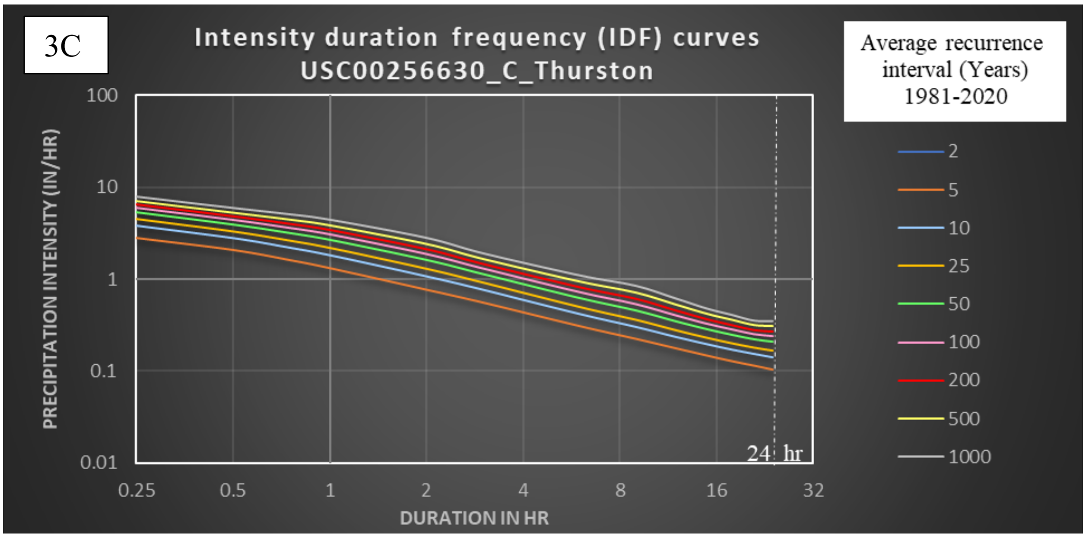


Figure 3.3 IDF curves for zone C stations: (1) Dodge, (2) Pawnee, and (3) Thurston, in Nebraska from 1981-2020 period. Note: 0.25 hours, and 0.5 hours are indicated 15 minutes and 30 minutes.

All three stations, Dodge (1C), Pawnee (2C), and Thurston (3C), show moderate rainfall intensities without any significant extremes. Pawnee shows a slight increase for medium-to-long durations compared to Dodge and Thurston. These stations fall within the general range observed across the previously described stations, neither showing extremely high nor low rainfall intensity values.

Chapter 4 Task 3: Comparison of the updated IDF curves and the existing curves

Based on the current research, our analysis suggests comparing the updated IDF curves with the existing ones. The current proposed study compares the analysis based on earlier reports from May 29, 1998, and ATLAS-14 IDF curves derived from Annual Maxima and Intensity-Based IDF for Zones A, B, and C.

4.1 Comparison of the updated IDF curves and the existing curves

4.1.1 Zone A Comparison

In Figure 1A, Zone A is shown using data from the 1988 report, while Zone A_updated (in Figure 2A) uses data from the 1981 to 2020 time series. The updated IDF curves for Zone A show more recent climate trends, making them more relevant than the older ones, presented in Figure 4.1.

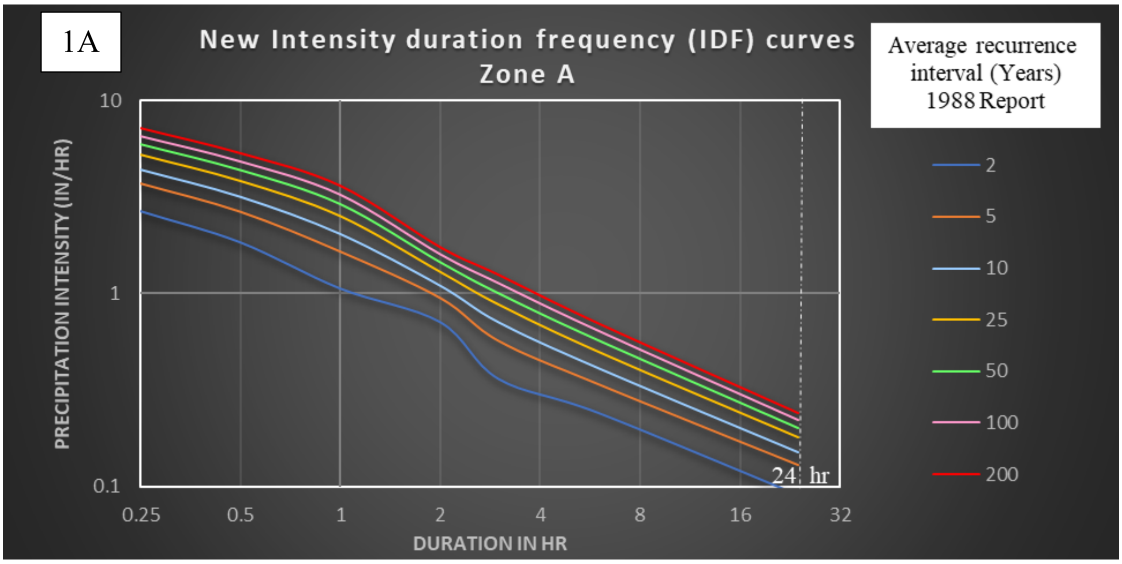


Figure 4.1 Zone A comparison of IDF curves: (1A) Existing IDF with old data from 1988 report and (2A) Updated IDF with updated data from 1981-2020 period. Note: 0.25 hours, and 0.5 hours are indicated 15 minutes and 30 minutes.

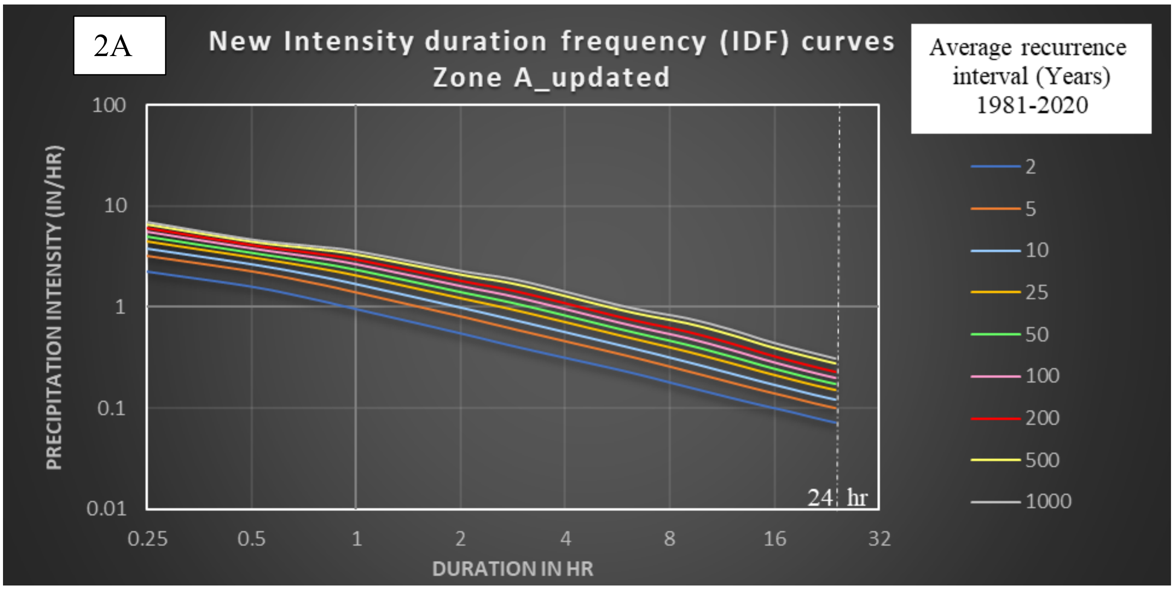


Figure 4.1 cont. Zone A comparison of IDF curves: (1A) Existing IDF with old data from 1988 report and (2A) Updated IDF with updated data from 1981-2020 period. Note: 0.25 hours, and 0.5 hours are indicated 15 minutes and 30 minutes.

The updated IDF curves for Zone A show generally lower rainfall intensities compared to the older data from 1988. This suggests a decrease in expected intense rainfall events, particularly for shorter durations (less than one hour). The difference between the old (Report 1988) and updated (1981-2020) curves becomes smaller as the duration increases.

4.1.2 Zone B Comparison

Similarly, Figure 1B compares Zone B IDF curves from the 1988 report with the updated ones shown in Figure 2B. The updated IDF curves based on 1981–2020 data indicate a different trend compared to the older dataset.

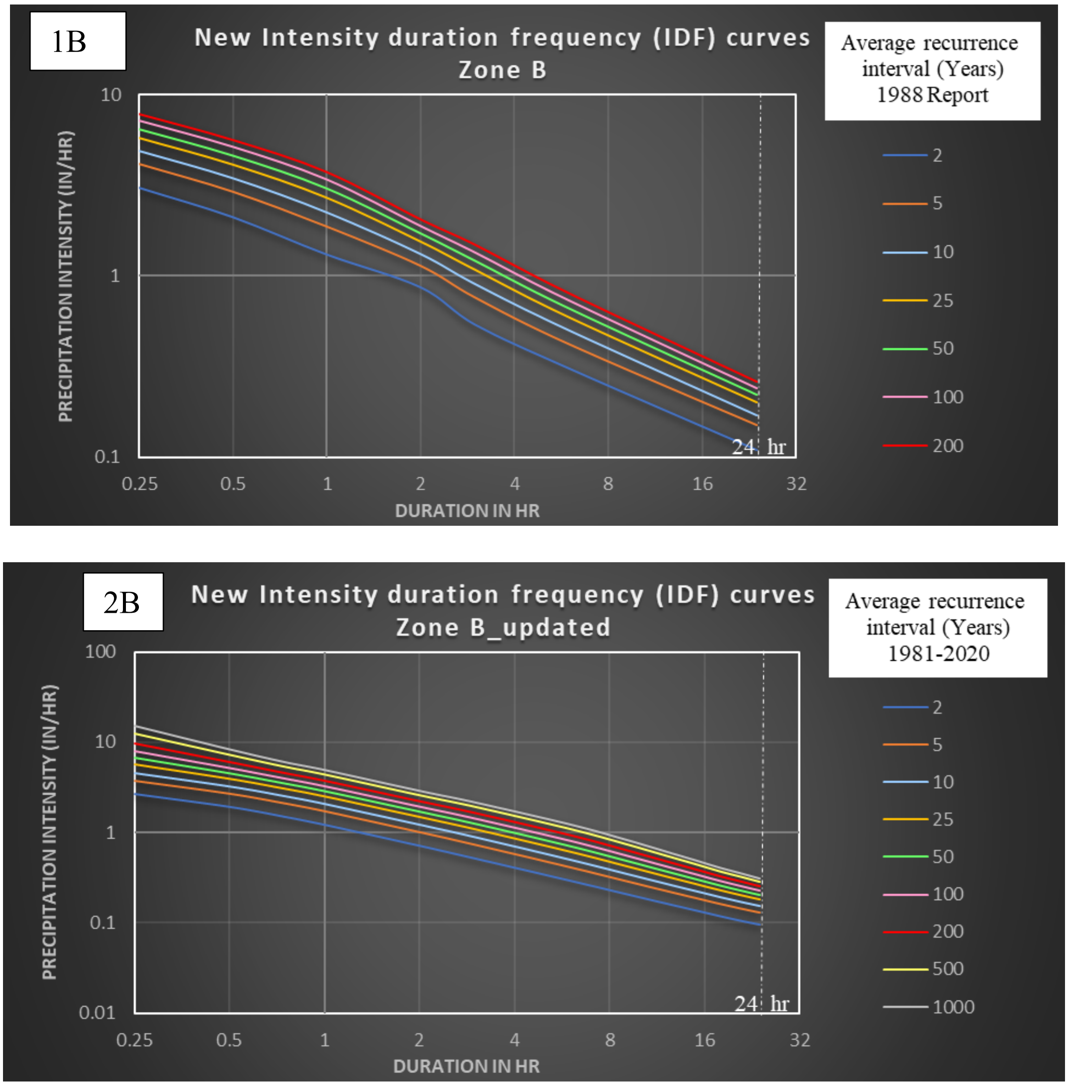


Figure 4.2 Zone B comparison of IDF curves: (1B) Existing IDF with old data from 1988 and (2B) Updated IDF with updated data from 1981-2020 period. Note: 0.25 hours, and 0.5 hours are indicated 15 minutes and 30 minutes.

- **Short durations (< 6 hours):** The updated IDF curves for Zone B (1981-2020) show slightly lower rainfall intensities for shorter durations compared to the 1988 data. For instance, the two-year return period for a one-hour rainfall event in the older data reaches two inches per hour, while in the updated data, it is slightly less.
- **Medium durations (6-12 hours):** The difference between the old and new curves with the updated curves aligning more closely with the older data.

- **Long durations (> 12 hours):** For longer durations, the updated curves show slightly lower intensities and in some cases, the 1988 report shows higher rainfall intensities than the new data for longer return periods.

4.1.3 Zone C Comparison

Figures 1C and 2C compare Zone C IDF curves from the 1988 report and the 1981-2020 update. Zone C shows the most pronounced changes in rainfall intensity among all zones, presented in Figure 4.3.

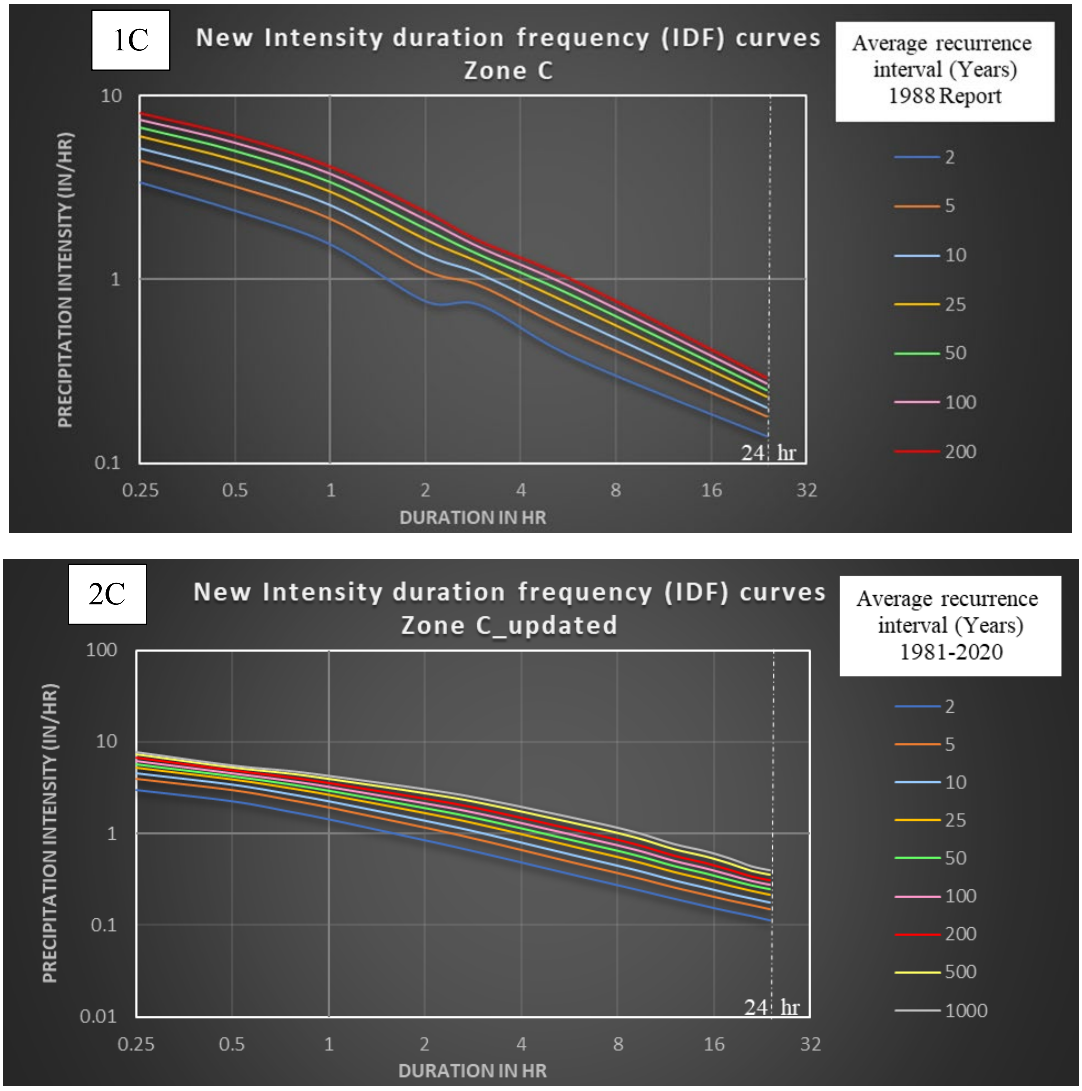


Figure 4.3 Zone C comparison of IDF curves: (1C) Existing IDF with old data from 1988 report and (2C) Updated IDF with updated data from 1981-2020 period. Note: 0.25 hours, and 0.5 hours are indicated 15 minutes and 30 minutes.

- **Short durations (< 6 hours):** The updated IDF curves from period 1981-2020 show a increase in rainfall intensity for short durations compared to the 1988 report.
- **Medium durations (6-12 hours):** The updated information continually shows higher intensities across all return times, confirming that the difference between the two datasets is still significant.
- **Long durations (> 12 hours):** Although the difference for longer durations, the updated IDF curves for Zone C still show higher rainfall intensities for most return periods compared to the older curves.

4.1.4 Observations Specific to Each Zone with Existing and Updated IDF Curves

- **Zone A:** The updated IDF curves show a decrease in intensity for shorter durations compared to the older dataset, but the difference becomes negligible for longer durations.
- **Zone B:** The updated IDF curves show a less pronounced reduction in rainfall intensity for short and medium durations compared to Zone A.
- **Zone C:** The updated IDF curves show a substantial increase in intensity for short to medium durations compared to the older dataset, indicating a trend towards more intense rainfall events in this zone.

Across all zones, the IDF curves based on 1981-2020 show changing rainfall patterns. While Zone C shows the most dramatic increase in intensity. Similarly, Zones A and B generally show decreases in expected rainfall intensity for shorter durations. The differences between the datasets are likely to result from updated methodologies, different techniques of data analysis and the additional station data in the newer IDF curves.

As part of the study, new rainfall zones in Nebraska were defined and identified using spatial analysis. To evaluate changes in rainfall patterns and station distributions throughout the Nebraska state, this research took consideration of updated station data from 1981 to 2020.

Chapter 5 Task 4: Spatial analysis of the data collected to create new rainfall zones

5.1 Spatial Analysis by Kriging Method

Figure 5.1 shows the application of the Kriging method (Kaymaz, 2005) for spatial interpolation of rainfall data. Each graph represents interpolated rainfall intensity over a geographic region for different time intervals, from 15 minutes to 24 hours based on updated IDF duration and intensity (unit: inches). The shaded areas indicate varying levels of rainfall intensity within three categories, with darker shades representing higher intensities as denoted by the legend in each panel. Red dots mark the locations of rain gauges, which provide the observed data points that the Kriging method uses to predict rainfall intensity at ungauged locations. A continuous spatial rainfall field is estimated through this method considering spatial correlations among rainfall stations, which is essential for distributing the rainfall throughout the area. The Kriging method is widely used due to its reliability and potentiality to generate uncertainty estimates for the interpolating values. These spatial maps clearly represent the rainfall zones for different temporal resolutions.

5.2 Spatial analysis by Inverse Distance Weighting (IDW) Method

Figure 5.2 illustrates the spatial interpolation of rainfall in Nebraska using the Inverse Distance Weighting (IDW) method (Chen et al. 2012) across different time scales between 15 minutes to 24 hours. This method considers the higher influence of the nearby rainfall stations than the farther distance. High rainfall intensity is illustrated in each panel with darker shades of blue and it changes through a range of less blue shades with less intensity. Red dots represent the locations of rain gauge stations, which are the data points used for the rainfall interpolation analysis. These rainfall interpolation maps represent rainfall distribution over a specific time period.

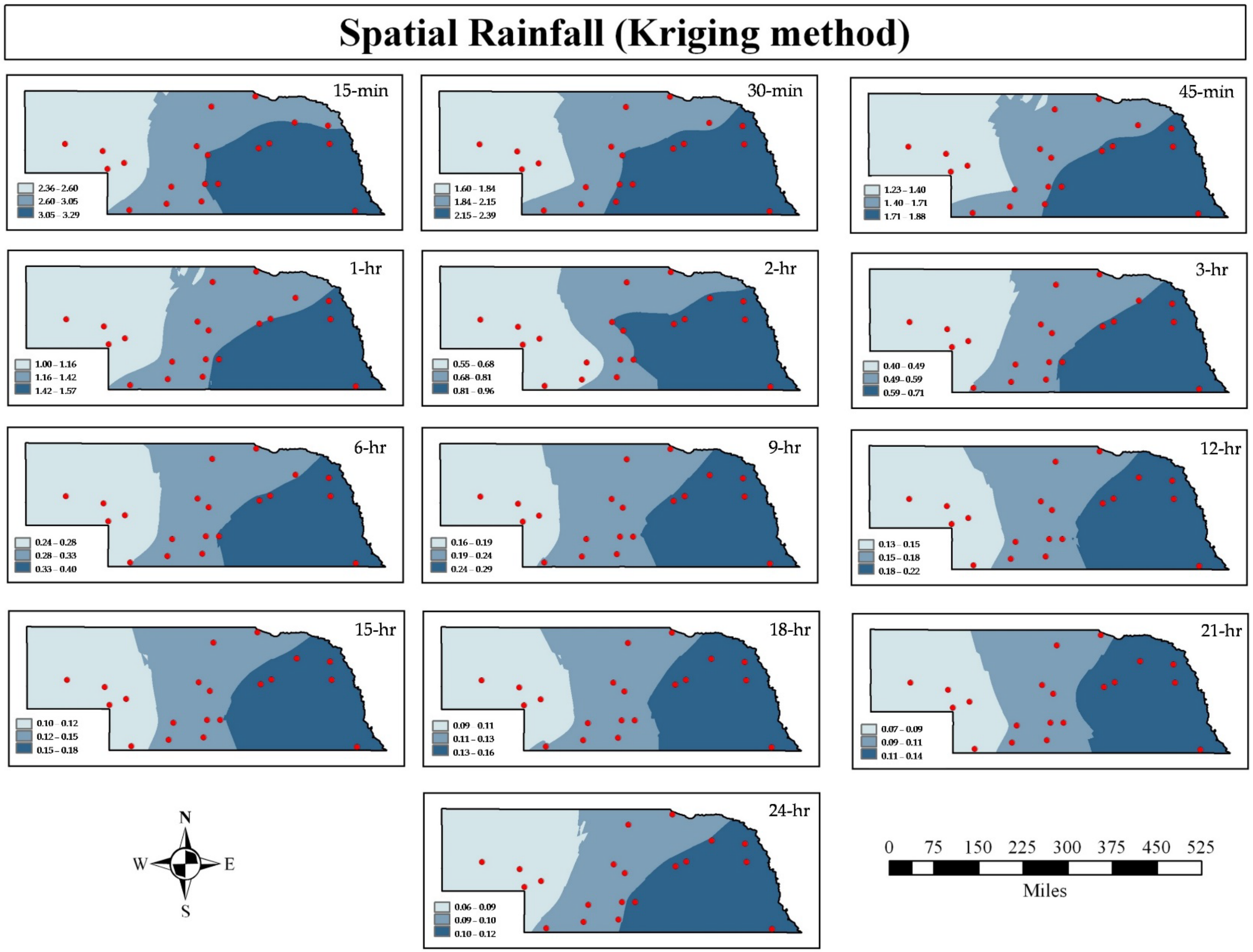


Figure 5.1 Spatial interpolation map by Kriging method for different return periods in Nebraska.

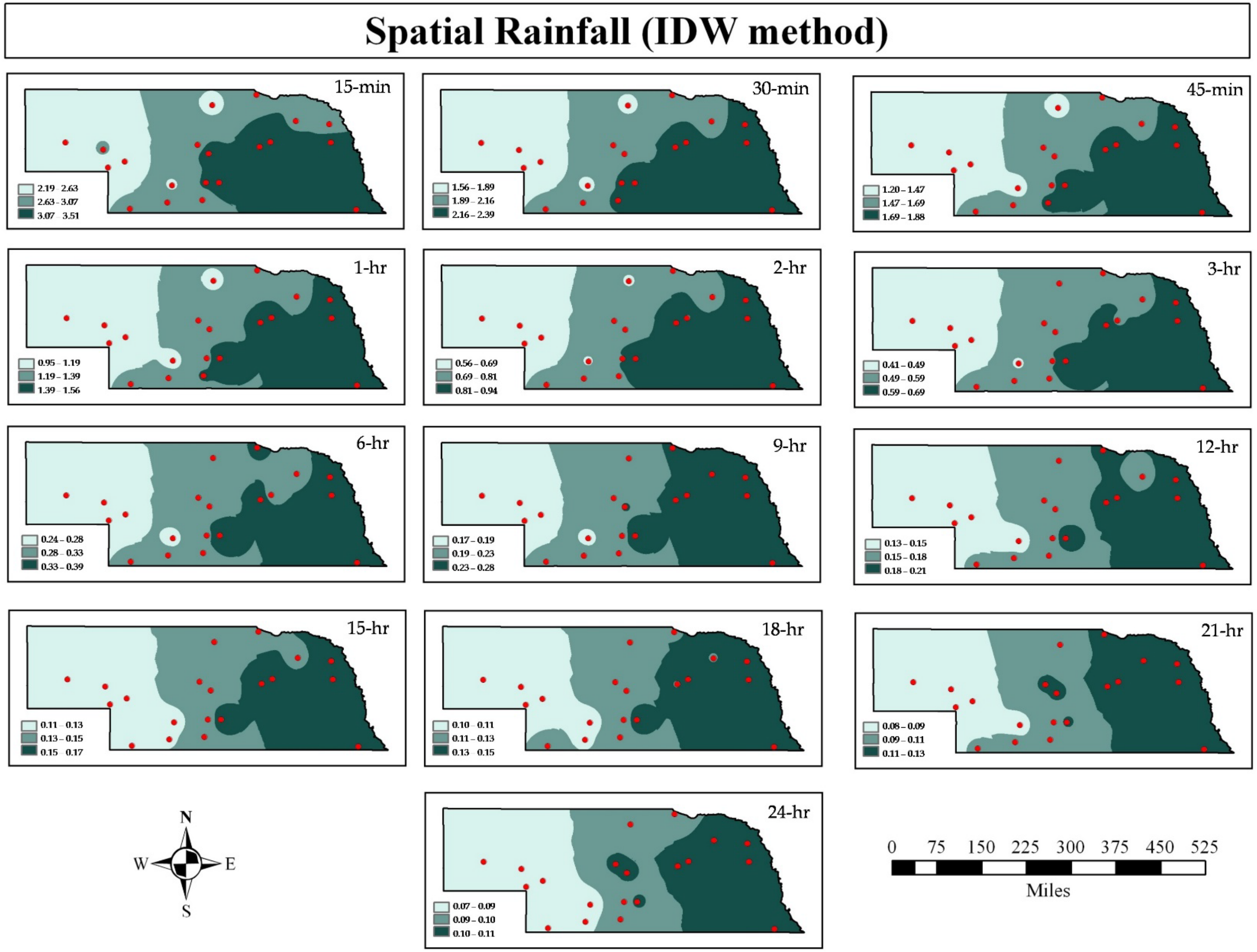


Figure 5.2 Spatial interpolation map by IDW method for different return periods in Nebraska.

5.3 Clustering method application to define the rainfall pattern

We applied the K-means clustering method (Likas et al., 2003) to detect the new rainfall cluster (or Zone), and the elbow method was used to plot the dataset considering one to six clusters. Figure 5.3 shows that the within-cluster sum of squares (WCSS) increases with the cluster number. To find the expected number of clusters, our objective was to find the “elbow” point or the location at which the WCSS slowed down. As a result, we found that the location where the WCSS breaks (at K=3) showed the most suitable cluster numbers or zones for the station dataset. Thus, the results indicated that our rainfall stations were defined in three zones (Cluster 1 as Zone A, Cluster 2 as Zone B, and Cluster 3 as Zone C).

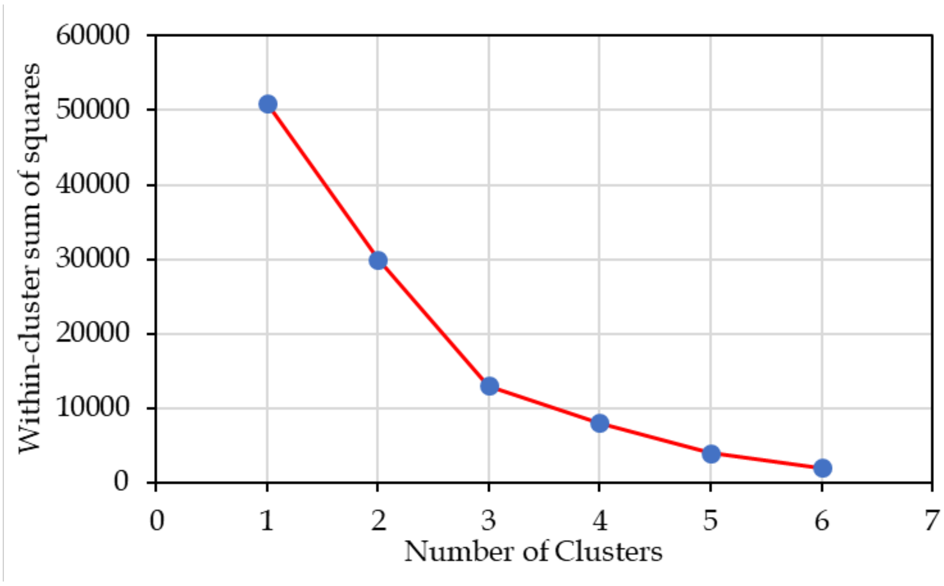


Figure 5.3 Elbow method for finding the optimal K (1 to 6).

Zone A, B and C consist of 4, 10 and 6 rainfall stations accordingly, which ensures each zones rainfall exhibits similar characteristics.

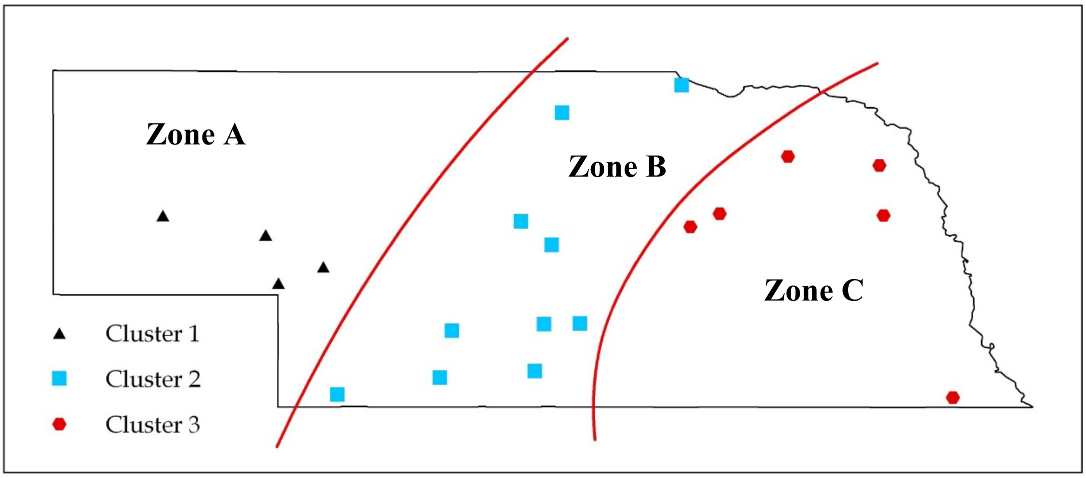


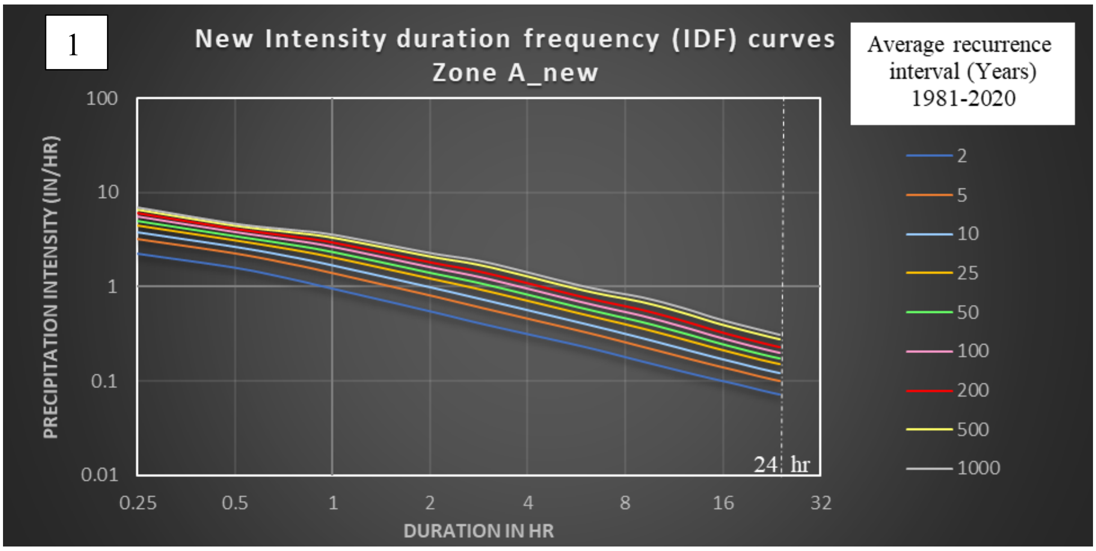
Figure 5.4 Geospatial distribution of station clusters.

Based on the analysis presented in Figure 5.4, a new rainfall zone was delineated. The stations identified within this new zonation are considered in Chapter 6 for the creation of a new IDF curve.

In our study, we applied k-means and hierarchical clustering methods for zonation analysis (Appendix A5). The k-means clustering method is the simplest one and provides an outcome consistent with our expectations for the hydroclimatic conditions in Nebraska. We can explore hierarchical clustering method further in the future.

Chapter 6 Task 5: Preparation of the new IDF curves for the new zones

Figure 6.1 shows the new IDF curve based on spatial analysis of the collected data to create new rainfall zones. Zone A (4 stations), Zone B (10 stations), Zone C (6 stations).



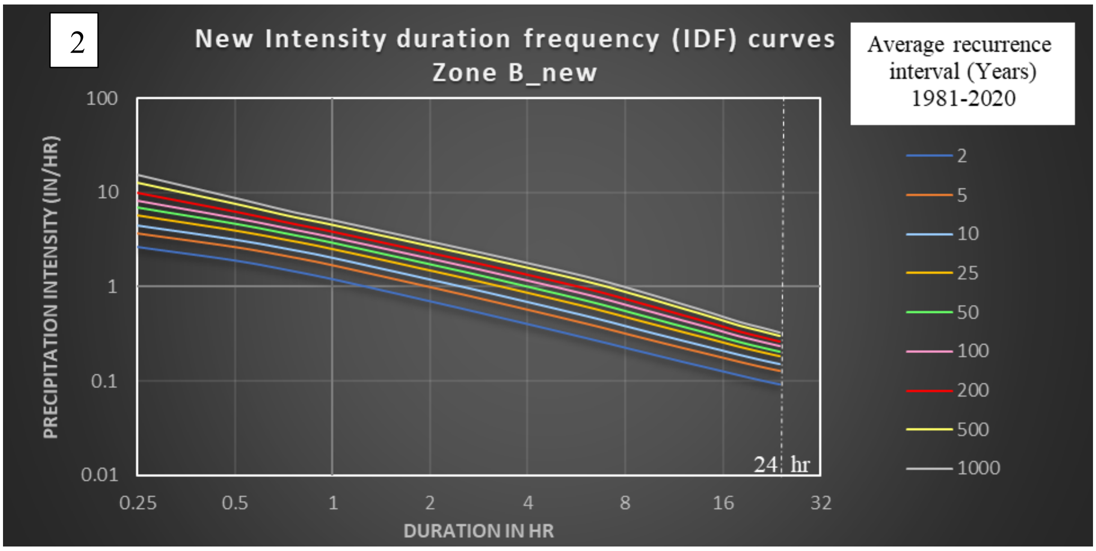


Figure 6.1 New IDF curves are developed based on the newly defined rainfall zones: (1) Zone A, (2) Zone B, and (3) Zone C, using data spanning 40 years (1981-2020). Note: 0.25 hours, and 0.5 hours are indicated 15 minutes and 30 minutes.

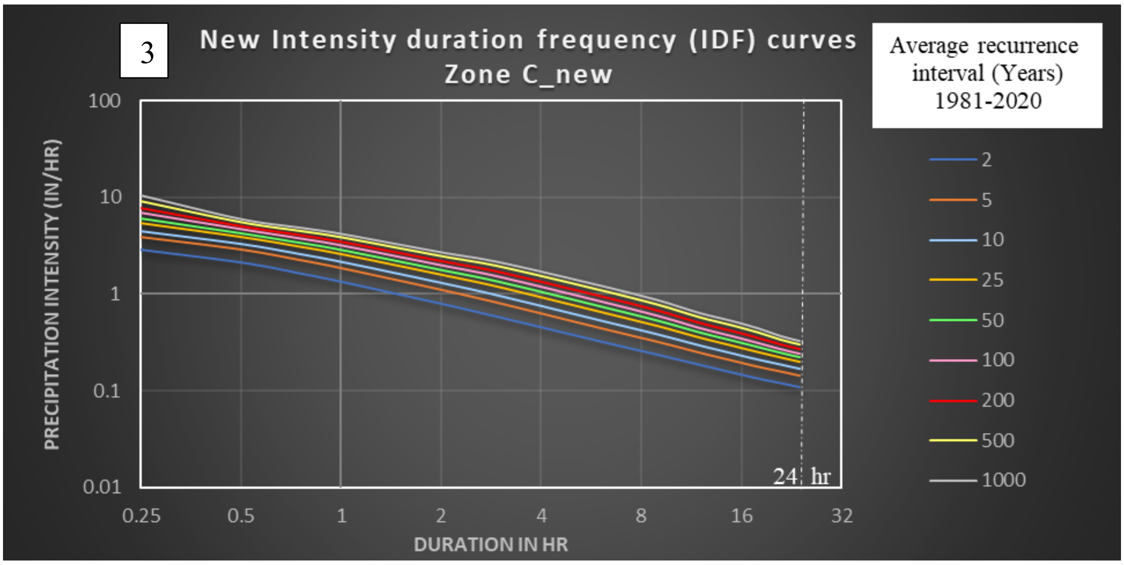


Figure 6.1 cont. New IDF curves are developed based on the newly defined rainfall zones: (1) Zone A, (2) Zone B, and (3) Zone C, using data spanning 40 years (1981-2020). Note: 0.25 hours, and 0.5 hours are indicated 15 minutes and 30 minutes.

Figure 6.1 (1,2, and 3) represents the three distinct precipitation zones within Nebraska (Zones A_new, B_new and C_new). These new IDF curves are based on spatial analysis from 1981 to 2020 showing current precipitation trends for these zones in Nebraska.

Zone A_new:

- Zone A_new shows relatively high rainfall intensities across various durations, especially in less than 1 hour (shorter duration). The curves for higher return periods, such as 100, 200 and 500 years, show steeper decreases at shorter durations, indicating more intense, less frequent rainfall events.
- For longer durations (16 to 24 hours), the curves become flatter, reflecting a decrease in intensity as storm duration increases.

Zone B_new:

- Zone B_new shows rainfall intensities are lower than Zone A_new but higher than Zone C_new for most durations.

- The curves follow a similar trend to Zone A_new, with higher return periods showing steeper curves for short durations. In terms of rainfall intensity, Zone B_new is an approximate condition between Zones A and C because the intensity values are significantly more moderate.

Zone C_new:

- Compared to Zone A_new and Zone B_new, Zone C_new shows the lower intensity rainfall, while IDF shows a smoother curve representing the less intense rainfall.
- Overall, curves are showing as flattening trend for longer duration while others are constant across all the zones.

Overall, in all zones trends show decrease in precipitation intensity with increasing storm duration, while Zone A_new trends show extreme rainfall patterns, followed by Zone B_new and then Zone C_new. Understanding the trends of climate change and becoming ready for possible changes in the frequency and severity of rainfall throughout Nebraska updated IDF curves.

Chapter 7 Rational Method for Flow Rate Calculation

Based on our IDF curves, we can improve our understanding of the flow rate, which is crucial to provide insights into what changes are required in the water management system. The study considered a rational method for a specific catchment or drainage system to calculate the flow rate.

We showed an example (calculation technique) based on our IDF information and how it can be helpful for the transportation system. Therefore, we estimated the flow rate (Q) in a residential Zone C for a 10-year return period of rainfall. Assume that the length (l) of the flow channel is 1000 meters, the slope (s) of that drainage channel is 0.012, and the area of the catchment area is 12 acres. Note that the frequency correction factor (Cf) for a 100-year return period is 1.25.

We can get the rainfall intensity of Zone C old and new intensity-duration frequency (IDF) curves. As a first step, we prepared a function to estimate the peak flow rate (Q) for a drainage channel. The equation of flow rate is: Q=C*i*A, where C is the rational runoff coefficient, which represents the runoff characteristics of the surface; i is the precipitation intensity in inches per hour; and A is the area of the drainage basin. The maximum flow rate is expressed in cubic feet per second. We prepared a Python code as follows:

Function for Peak Flow Rate (Q) Calculation

```python
def calculate_peak_flow(c, i, a):
    """
    Calculate the Peak Flow Rate (Q) using the Rational Method formula:
    Q = C * i * A

    Parameters:
    c: Rational Runoff Coefficient
    i: Intensity of precipitation (inch/hr)
    a: Area of the drainage basin/catchment (Acre)

    Return Results:
    Peak Rate of Flow (Q) in cubic feet per second
    """
    return c * i * a
```

Figure 7.1 Function for Peak Flow Rate (Q) Equation.

As a next step, we developed another function to calculate the time of concertation (Tc) using the Kirpich empirical formula. This function uses three parameters: length, the streamflow path length in meters; slope, the average watershed slope (m/m); and roughness coefficient, which describes surface roughness, typically based on land cover (referenced in the Nebraska Department of Transportation's guidance). The function provides a time of concentration value (Tc) for the specific watershed conditions.

Function for time of concentration (Tc) calculation

```
# Create a function for calculating time of concentration

def calculate_time_of_concentration(length, slope, roughness_coefficient):
    """
    Calculate time of concentration using an the Kirpich equation (empirical formula)

    Parameters:
    length (in meters): Length of the streamflow path
    slope (in m/m): Average watershed slope
    roughness_coefficient: Roughness coefficient, often based on land cover
    Information on Roughness coefficient: https://dot.nebraska.gov/media/d1ulhfsq/g2-appendix-b.pdf

    Tc (in minutes): Time of concentration
    """
    Tc = 0.01947 * (length ** 0.77) / (slope ** 0.385)
    return Tc


# Assuming the parameters for calculating Tc
length = 1000                   # length (in meters): Length of the streamflow path
slope = 0.012                    # slope (in m/m): Average watershed slope
roughness_coefficient = 0.03   # Roughness coefficient for Some grass & weeds in the stream

Tc = calculate_time_of_concentration(length, slope, roughness_coefficient)
print(Tc)
```

```
21.821327723090832
```

Figure 7.2 Function for Time of Concentration (Tc) Calculation.

The result of the time of concentration (Tc =21.82 mins) indicates that travel from the most distant point to the outlet in a watershed. From the Zone C_new IDF curve, we observed the rainfall intensity for 22 minutes and the result was 0.361 inches/hr (10-year return period).

The key parameters included a frequency correction factor of 1.25 (USDOT, 1979), a drainage basin area of 12 acres, and a runoff coefficient of 0.65 (Stephenson, 1981) to reflect typical residential land cover conditions. The runoff coefficient was adjusted using the correction factor, with a maximum allowable value of 1, to ensure realistic flow estimates.

Therefore, our peak flow estimates the essential data for assessing potential drainage requirements and designing stormwater infrastructure in residential areas. The precipitation intensity from the new IDF is 0.61 inches per hour. The peak flow rates of the new IDF are 5.947 cubic feet per second. This estimated peak flow rate is a critical input for designing bridge design and water management systems capable of handling 10-year storm events in similar residential areas. The Python codes are added below:

An application of Flow Rate Estimation from IDF Curve

```python
# Here is an example for a residential area for 10 year return period rainfall

def main():
    cf = 1.25                      #Frequency Correction Factor (dimensionless), Source: USDOT (1979)
    area = 12                      #Area of the drainage basin (Acre)
    runoff_coefficient = 0.65      #Runoff Coefficient, Source: Stephenson (1981)

    # We get precipitation intesity from IDF curve (From Zone C, For Tc = 22 min and
    # 10- year return period)
    new_intensity_in_per_hr = 0.61      #Unit: inches/hour

    # Estimation of Rational Runoff Coefficient
    c = cf * runoff_coefficient
    if c > 1:
        c = 1  # If the calculated runoff coefficient is greater than 1, it will be set to 1

    new_q = calculate_peak_flow(c, new_intensity_in_per_hr, area)

    print(f"Peak Rate of Flow for New IDF (Q): {new_q:.3f} cubic feet per second")

if __name__ == "__main__":
    main()
```

```
Peak Rate of Flow for New IDF (Q): 5.947 cubic feet per second
```

Figure 7.3 An application of Flow Rate Estimation from IDF Curve.

7.1 Key factors of IDF curve methods (old and updated IDF)

7.1.1 1988 (old report) IDF Curves

The 1988 IDF curves are based on historical rainfall data available at the time and they reflect precipitation patterns and intensities from earlier decades (Table 1). These curves show the following information:

- Lower Rainfall Intensities: Overall rainfall intensities can frequently be lower for the older curves, particularly for shorter durations and longer return intervals.
- Less Steep Curves: The curves for shorter durations (< 6 hours) are less steep compared to the updated and new curves, suggesting lower intensity for short, intense storms.

- Limited Data: The dataset used in 1988 report was smaller, with fewer stations and a shorter time span, which may not have captured the most extreme or updated precipitation trend.

7.1.2 Updated IDF Curves (1981-2020)

The current research study uses updated IDF curve, which shows significant climatic change, was generated using recent data from 1981 to 2020.

- Compared to 1988 (report) existing curve the updated IDF curve shows high intensity across all zones. Particularly, in shorter duration period in 1 hour.
- The updated curves show a steeper curve for short storms, showing significant rainfall events. This shift appears in zone C, where there has been a significant rise in short-duration storms.
- The updated IDF curve (1981-2020) includes datasets for extended periods of time. It shows recent precipitation trends with more accuracy and comprehensiveness.

Table 7.1 Summary for comparison between earlier (1988 report) IDF curve and updated IDF curve (1981-2020).

Zone A comparison (new(1981-2020)-old(1988 report))

		2 year	5 year	10 year	25 year	50 year	100 year	200 year
	15 min	-0.41	-0.49	-0.60	-0.76	-0.91	-1.06	-1.23
	30 min	-0.24	-0.39	-0.52	-0.72	-0.89	-1.08	-1.27
	1 hr	-0.10	-0.25	-0.35	-0.46	-0.55	-0.63	-0.70
	2 hr	-0.16	-0.14	-0.11	-0.07	-0.04	0.01	0.07
	3 hr	0.03	0.01	0.00	0.02	0.05	0.08	0.13
	6 hr	-0.01	-0.01	-0.01	0.00	0.02	0.03	0.07
	24 hr	-0.02	-0.03	-0.03	-0.03	-0.03	-0.02	-0.01

Zone B comparison (new(1981-2020)-old(1988 report))

		2 year	5 year	10 year	25 year	50 year	100 year	200 year
	15 min	-0.40	-0.45	-0.38	-0.11	0.27	0.87	1.78
	30 min	-0.19	-0.25	-0.26	-0.20	-0.09	0.08	0.35
	1 hr	-0.10	-0.17	-0.19	-0.20	-0.17	-0.11	-0.03
	2 hr	-0.16	-0.14	-0.11	-0.06	-0.01	0.06	0.15
	3 hr	-0.03	-0.03	-0.02	0.01	0.04	0.09	0.15
	6 hr	-0.02	-0.01	0.00	0.02	0.05	0.08	0.12
	24 hr	-0.02	-0.02	-0.02	-0.02	-0.02	-0.01	-0.01

Zone C comparison (new(1981-2020)-old(1988 report))

		2 year	5 year	10 year	25 year	50 year	100 year	200 year
	15 min	-0.39	-0.50	-0.62	-0.81	-0.98	-1.16	-1.36
	30 min	-0.12	-0.24	-0.37	-0.57	-0.76	-0.96	-1.19
	1 hr	-0.13	-0.21	-0.28	-0.37	-0.44	-0.50	-0.57
	2 hr	0.08	0.04	0.02	0.01	0.01	0.03	0.06
	3 hr	-0.11	-0.07	-0.04	0.02	0.09	0.15	0.24
	6 hr	-0.03	-0.04	-0.03	0.00	0.02	0.06	0.11
	24 hr	-0.03	-0.03	-0.02	-0.01	-0.01	0.01	0.02

7.1.3 New IDF Curves (1981-2020) for New Zones

The new IDF curves incorporate further analysis, which include some modifications to zone boundaries with the implementation of spatial analysis techniques.

- New curves revised the rainfall zones which reclassify some areas under different intensity profiles.
- Compared to the previous 1988 report (IDF curves), the new IDF curves continue show a significant constancy over the whole duration, especially from 12 to 24 hours. This could indicate a more consistent approach to data processing and spatial reanalysis.

- Rainfall intensity in zones A and C is continuing to rise, based on new IDF curves. This shows Nebraska experiences with intense precipitation.
- The incorporation of spatial analysis in the development of the new IDF curves emphasizes the importance of utilizing updated station data from the period 1981-2020.

  This was not identified in the previous 1988 report. The application of spatial analysis techniques has been instrumental in defining the new rainfall zones.

Table 7.2 Summary of Differences

Aspect	1988 IDF Curves	Updated IDF Curves (1981-2020)	New IDF Curves (1981-2020)
Data Coverage	Limited (pre-1988 data)	Broader (1981-2020 data)	Comprehensive (1981-2020 data + spatial zones)
Rainfall Intensities	Lower intensities, especially for short durations	Higher intensities, especially for short durations	High intensities, consistent across zones
Short-Duration Storms	Less steep curves, lower intensity	Steeper curves, higher intensity	Consistently steep, with some zone adjustments
Long-Duration Storms	Flatter curves, lower intensity	Slight increase in intensity for longer durations	Increased intensity, smooth across durations
Spatial Considerations	Based on older zone definitions	Incorporates more recent data	Potentially involves zone boundary adjustments
Return Periods	Lowest for extreme storms	Higher in short storms	High, with constant increase for extremes events

7.2 Implications

- Engineering & Design perspective: New IDF curves need more robust infrastructure design to manage high intensity of rainfall. Culverts, Drainage systems and flood protections may need to update the prevent water damage during extreme storms.
- Risk of Flooding: The updated and new IDF curves signal a higher likelihood of extreme storm events, especially in Zone A (shorter durations) and Zone C (all durations). Flood risk assessments should be adjusted accordingly.

- Climate Change: The differences between the 1988 report (IDF curves) and the updated/new curves may reflect long-term shifts due to climate change, particularly the increase in short, intense rainfall events.

These trends are critical for planning future infrastructure resilience, flood risk management and adaptation to changing climate conditions in Nebraska.

Chapter 8 Funding of Second Phase Project:

8.1 5-Minute Interval Datasets Research

We plan to apply for a second phase of funding to expand the scope of the current research. More specifically, we would like to focus on the following items:

- Including 5-minute interval precipitation data into the IDF analysis. This will also involve spatial statistics to regionalize the information. In our current research, we faced challenges due to the non-availability of 5-minute interval datasets, as NCEI does not provide long-term climatology datasets at this time scale for all stations. At the moment, only a small number of stations and datasets covering short timespans can be accessed. Missing data is also a big issue in this case. Due to these constraints, a comprehensive analysis of 5-minute interval data was not a part of our current research phase.
- We will investigate additional sources and methods for interpolating missing data to ensure more reliability and consistency.
- We will add the analysis of nonstationarity, which is a widely discussed topic at the moment.

Thus, our proposed Phase 2 effort will greatly expand both the scope and depth of our research and provide the scientific community with insightful information.

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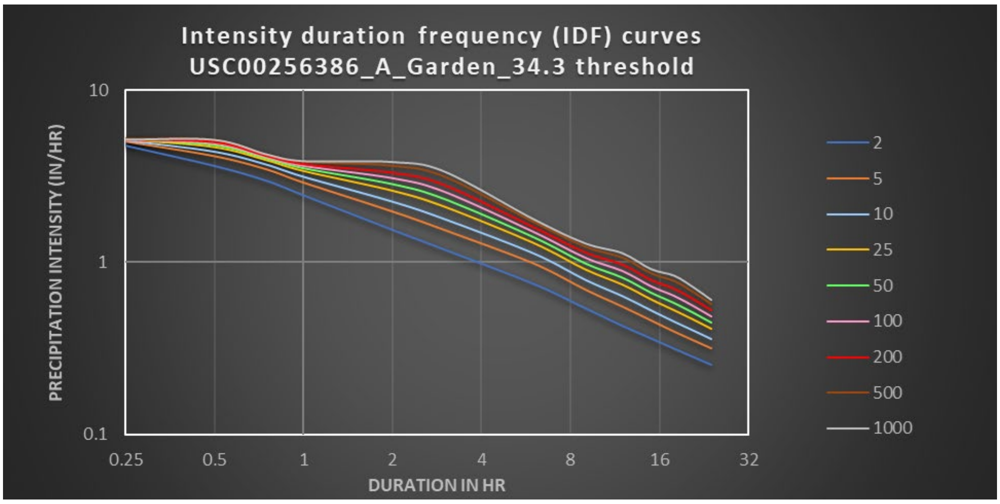
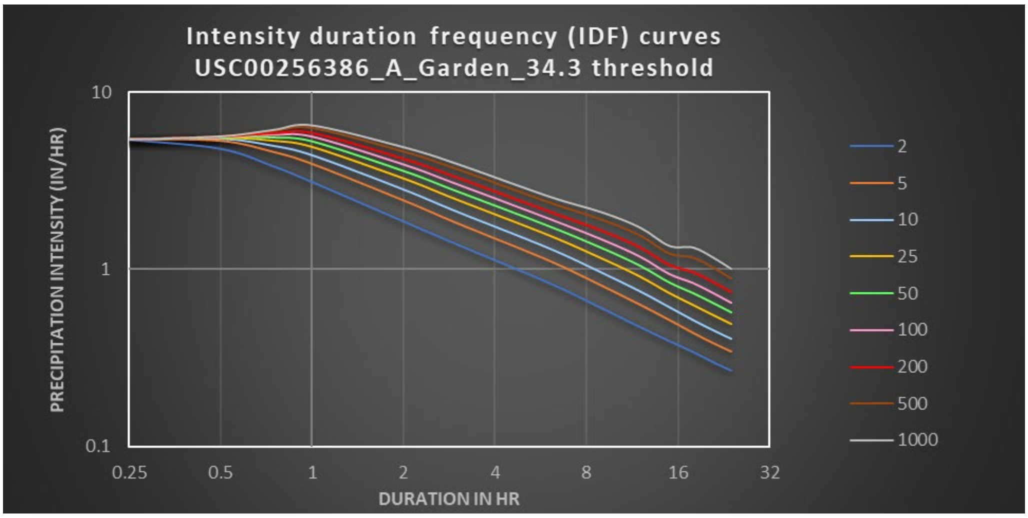
Appendix A

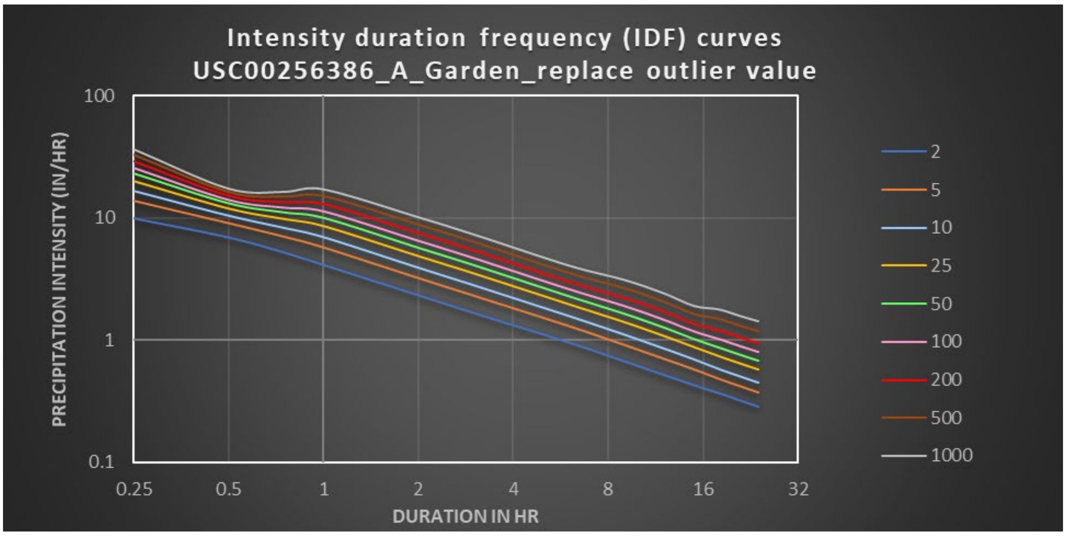


PRCP Value define = 34.3] <- 'not available' (NA, no data in the timeseries) Note: 0.25 hours, and 0.5 hours are indicated 15 minutes and 30 minutes.



PRCP Value define >= 34.3] <- 34.3 (unit: hundredths of inches) Note: 0.25 hours, and 0.5 hours are indicated 15 minutes and 30 minutes.

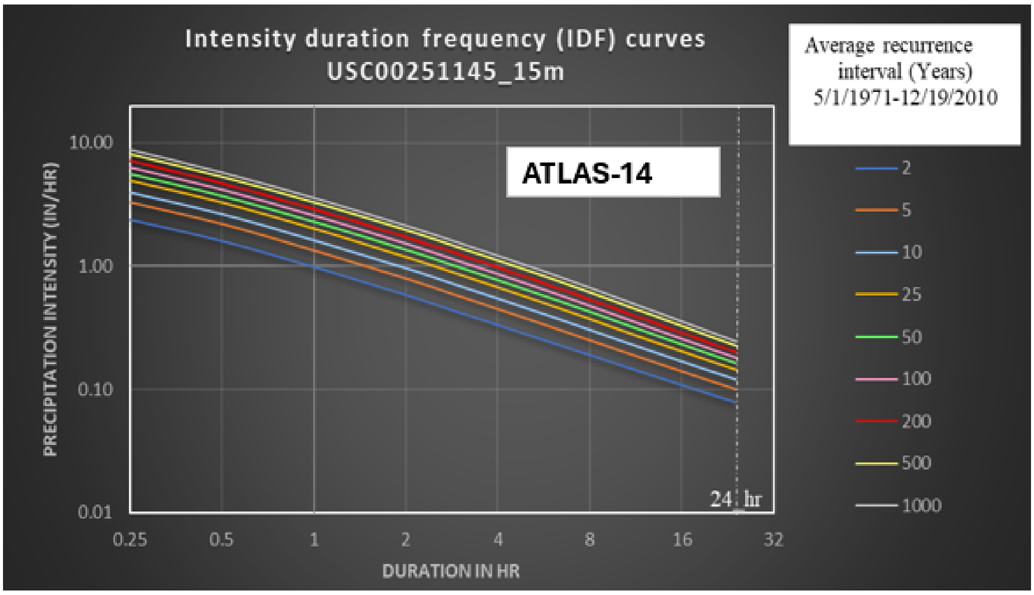
Figure A.1 Sensitivity test and comparison of the IDF curve with a test featuring higher rainfall values, followed by replacement with alternative values derived from daily rainfall station data at station A (USC00256386) from 1981-2010 period.



Replace the highest value (440) with the second highest value (140) Note: 0.25 hours, and 0.5 hours are indicated 15 minutes and 30 minutes.

Figure A.1 cont. Sensitivity test and comparison of the IDF curve with a test featuring higher rainfall values, followed by replacement with alternative values derived from daily rainfall station data at station A (USC00256386) from 1981-2010 period.

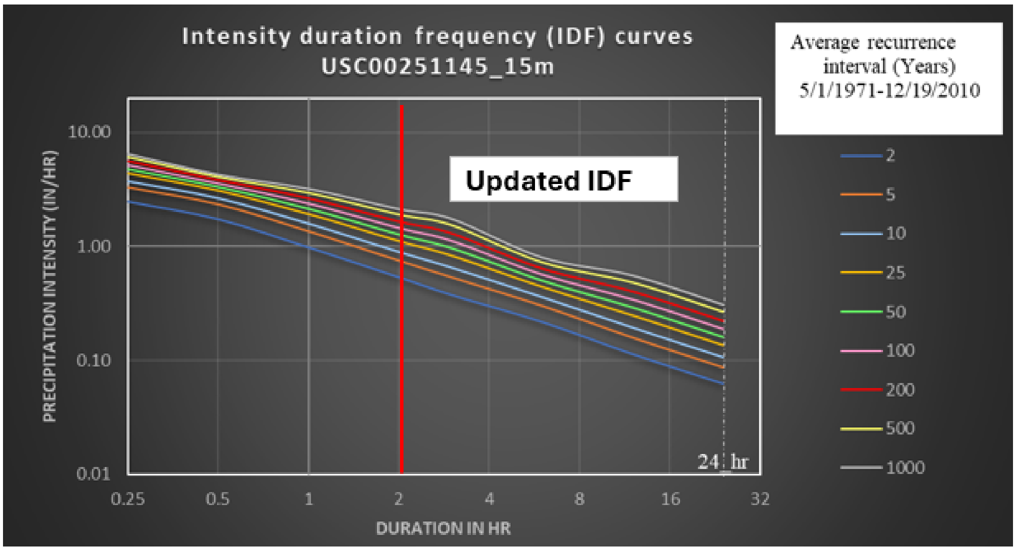
Verification with ATLAS-14:



ATLAS-14 IDF Curve May-1971 to Dec-2010

Figure A.2 Verification and comparison of the IDF curve with ATLAS 14 zone A station (USC00256386) from 1971-2010 period. Note: 0.25 hours, and 0.5 hours are indicated 15 minutes and 30 minutes.

Note: Example of one station to show (USC00251145, Morrill) how we have done the verification and comparison with ATLAS-14



Updated IDF Curve May-1971 to Dec-2010

(1971-2010) ***[Note: We are doing comparision here based on ATLAS-14 data period availability]***																
	15-min (NOW)	15-min (ATLAS-14)	30-min (NOW)	30-min (ATLAS-14)	60-min (NOW)	60-min (ATLAS-14)	2-hr (NOW)	2-hr (ATLAS-14)	3-hr (NOW)	3-hr (ATLAS-14)	6-hr (NOW)	6-hr (ATLAS-14)	12-hr (NOW)	12-hr (ATLAS-14)	24-hr (NOW)	24-hr (ATLAS-14)
2	2.487	2.360	1.738	1.590	0.983	0.979	0.538	0.580	0.375	0.417	0.217	0.239	0.114	0.136	0.063	0.078
5	3.260	3.280	2.320	2.190	1.347	1.340	0.748	0.794	0.534	0.569	0.302	0.321	0.159	0.179	0.088	0.101
10	3.752	3.980	2.667	2.650	1.593	1.620	0.900	0.960	0.654	0.688	0.361	0.386	0.195	0.213	0.107	0.119
25	4.350	4.920	3.065	3.260	1.909	2.000	1.109	1.180	0.824	0.849	0.440	0.475	0.247	0.259	0.136	0.144
50	4.779	5.640	3.334	3.730	2.147	2.290	1.276	1.360	0.965	0.975	0.502	0.544	0.292	0.296	0.160	0.162
100	5.192	6.360	3.582	4.200	2.387	2.580	1.453	1.530	1.119	1.100	0.566	0.616	0.342	0.333	0.188	0.182
200	5.591	7.100	3.810	4.680	2.629	2.880	1.642	1.710	1.288	1.240	0.633	0.690	0.398	0.372	0.220	0.201
500	6.099	8.080	4.084	5.310	2.953	3.290	1.911	1.960	1.536	1.410	0.727	0.791	0.483	0.424	0.267	0.227
1000	6.471	8.840	4.274	5.800	3.201	3.600	2.130	2.140	1.746	1.550	0.801	0.870	0.558	0.465	0.309	0.248

Note: "NOW" represent the GHCN NOAA station data (1971-2010)
"ATLAS-14" represent the data availability from ATLAS-14 (1971-2010)

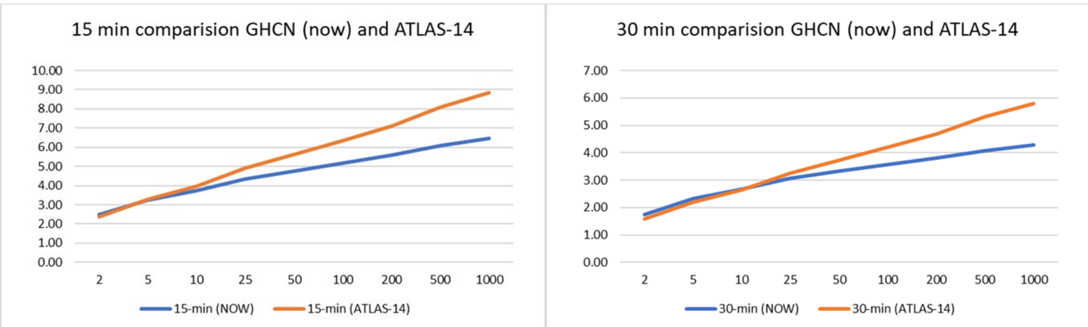


Figure A.2 cont. Verification and comparison of the IDF curve with ATLAS 14 zone A station (USC00256386) from 1971-2010 period. Note: 0.25 hours, and 0.5 hours are indicated 15 minutes and 30 minutes.

Note: Example of one station to show (USC00251145, Morrill) how we have done the verification and comparison with ATLAS-14

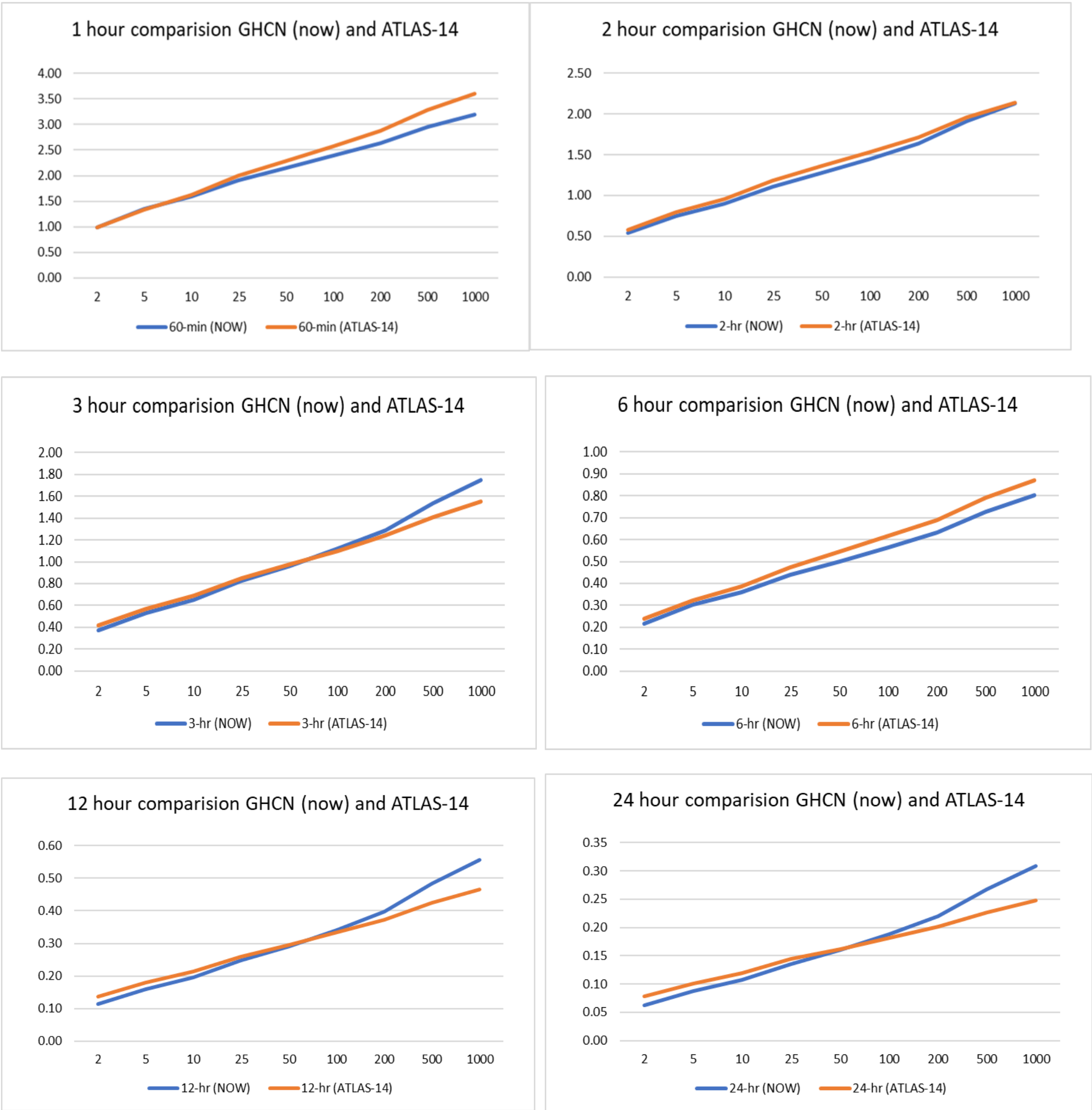


Figure A.2 Verification and comparison of the IDF curve with ATLAS 14 zone A station (USC00256386) from 1971-2010 period. Note: 0.25 hours, and 0.5 hours are indicated 15 minutes and 30 minutes.

Note: Example of one station to show (USC00251145, Morrill) how we have done the verification and comparison with ATLAS-14

Differences between ATLAS-14 and GHCN NOAA station from period 1971-2010

<u>Short Durations (15-min to 1-hr):</u>

For shorter durations, GHCN NOAA consistently shows slightly higher rainfall intensities compared to ATLAS-14:

15-min duration (2-year return period):

GHCN NOAA = 2.487, ATLAS-14 = 2.360 → Difference: +0.127 in/hr (~5.38% higher).

1-hr duration (2-year return period):

GHCN NOAA = 0.983, ATLAS-14 = 0.979 → Difference: +0.004 in/hr (~0.41% higher).

The differences increase slightly with higher return periods:

15-min duration (50-year return period):

GHCN NOAA = 4.779, ATLAS-14 = 5.640 → Difference: -0.861 in/hr (~15.27% lower).

Medium Durations (2-hr to 6-hr):

Differences are more variable, with GHCN NOAA intensities generally higher for return periods up to 50 years:

2-hr duration (25-year return period):

GHCN NOAA = 1.276, ATLAS-14 = 1.360 → Difference: -0.084 in/hr (~6.18% lower).

6-hr duration (50-year return period):

GHCN NOAA = 0.502, ATLAS-14 = 0.544 → Difference: -0.042 in/hr (~7.72% lower).

Long Durations (12-hr to 24-hr):

GHCN NOAA and ATLAS-14 show less pronounced differences for longer durations:

12-hr duration (10-year return period):

GHCN NOAA = 0.195, ATLAS-14 = 0.213 → Difference: -0.018 in/hr (~8.45% lower).

24-hr duration (100-year return period):

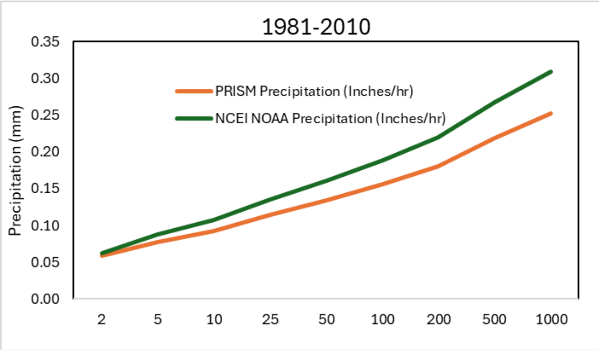
GHCN NOAA = 0.558, ATLAS-14 = 0.465 → Difference: +0.093 in/hr (~20% higher).

Variation in Return period Magnitude: Differences range from ~0.1% to ~20% depending on duration and return period, with larger variations typically observed for Shorter durations (15 min, 1 hour) and Higher return periods (e.g., 50-year, 100-year).

The variation magnitude described is relative to ATLAS-14, meaning the differences indicate how much GHCN NOAA values deviate from ATLAS-14.

- The variation (e.g., ~0.1% to ~20%) highlights how GHCN NOAA intensities differ from ATLAS-14 intensities across various durations and return periods.
- Larger variations (closer to ~20%) are observed for shorter durations (15 minutes to 1 hour) and higher return periods, where GHCN NOAA typically shows higher rainfall intensities compared to ATLAS-14.

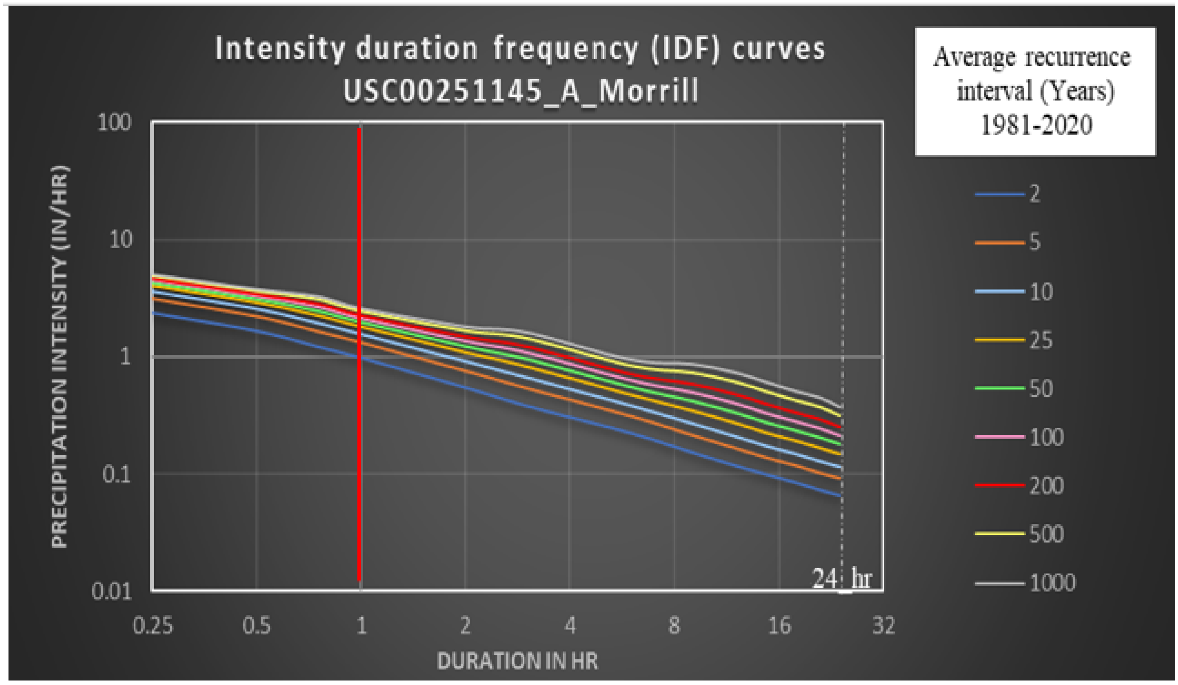
Note: Example of one station to show (USC00251145, Morrill) how we have done the verification and comparison with ATLAS-14



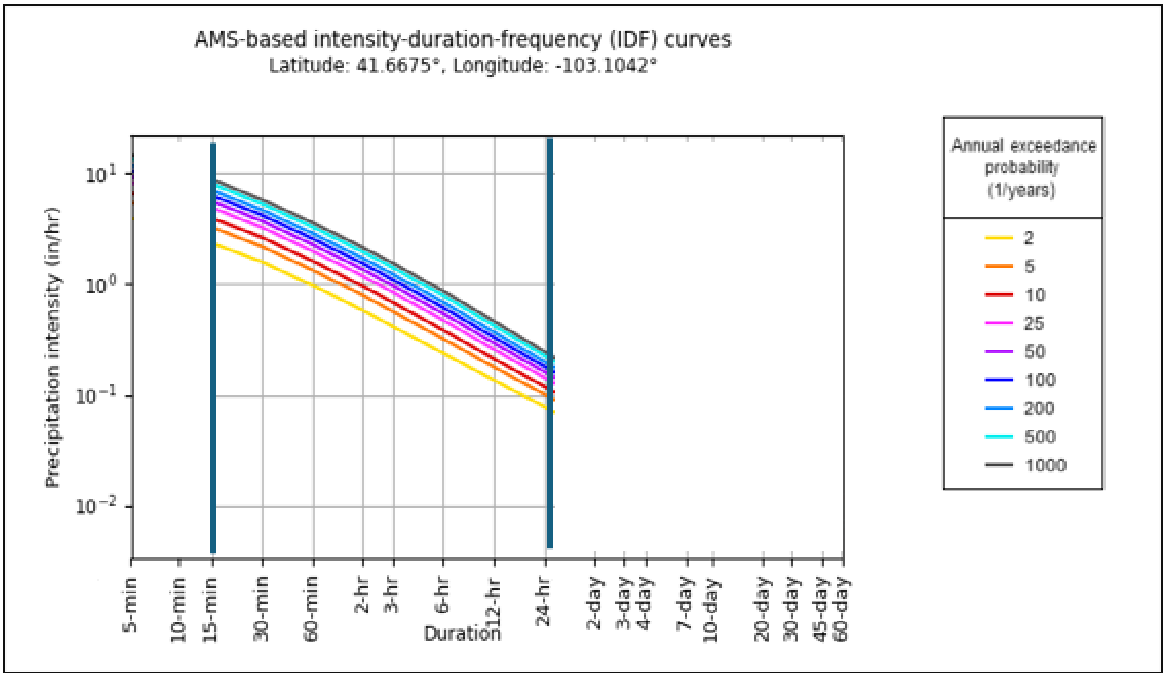
Return Period (Years)	NOAA-NCEI (in/hr)	PRISM (in/hr)
2	0.06	0.06
5	0.08	0.08
10	0.11	0.10
25	0.14	0.13
50	0.18	0.16
100	0.22	0.19

Figure A.3 Updated station data (1981-2010) and PRISM Raw Data (1981-2010) - Daily Precipitation.

Note: Further Verification and comparison: Two Stations in Zone A with Atlas 14 Data

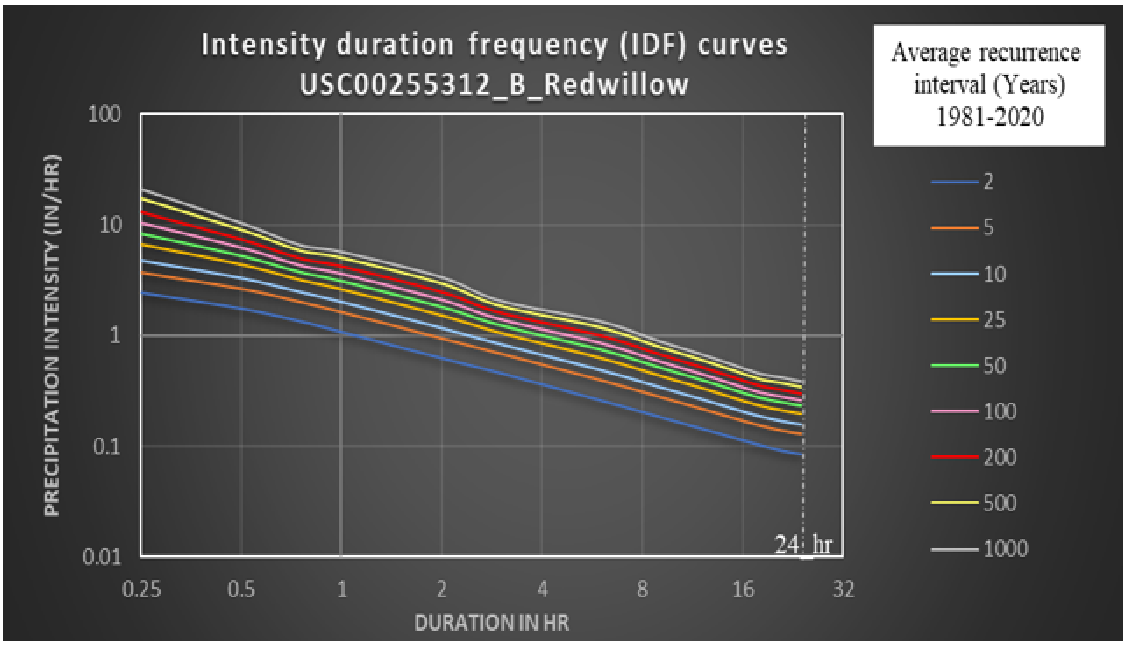


Updated IDF Curve
Jan-1981 to Dec-2020

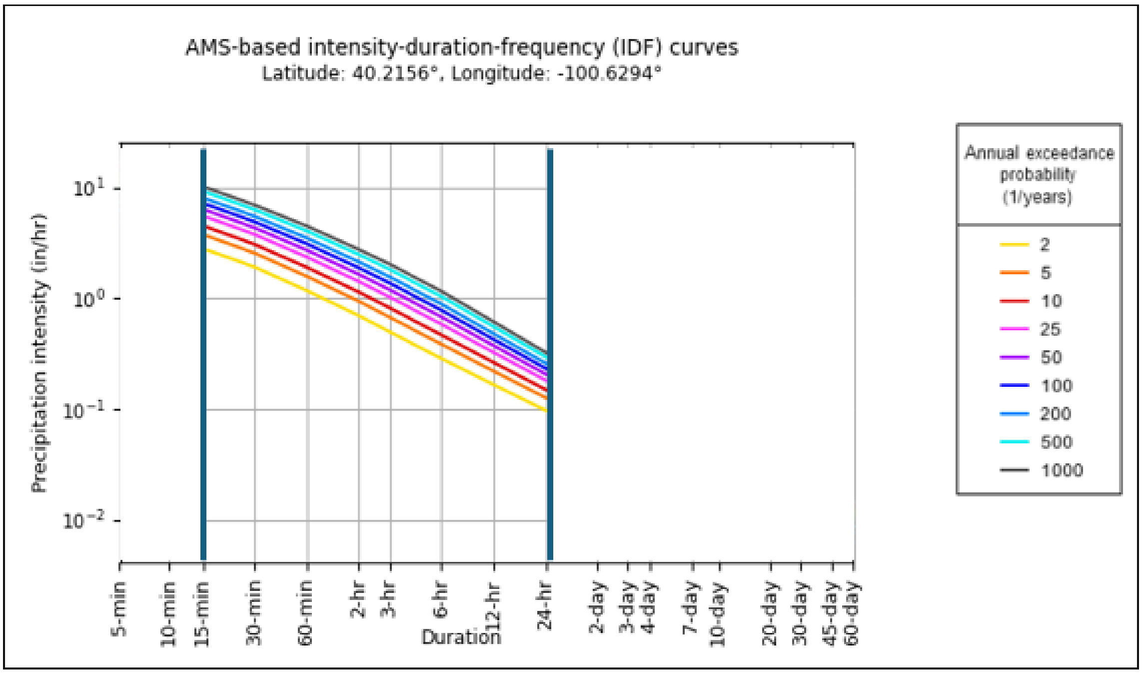


ATLAS-14 IDF Curve
May-1971 to Dec-2010

Figure A.4 Verification and comparison Between updated IDF (1981-2010) and Atlas 14 (May 1971 - Dec 2010) - Daily Precipitation for station USC00251145 Morrill. Note: 0.25 hours, and 0.5 hours are indicated 15 minutes and 30 minutes.



Updated IDF Curve
Jan-1981 to Dec-2020



ATLAS-14 IDF Curve
May-1971 to Dec-2010

Figure A.4 cont. Verification and comparison Between updated IDF (1981-2010) and Atlas 14 (May 1971 - Dec 2010) - Daily Precipitation for station USC00251145 Morrill. Note: 0.25 hours, and 0.5 hours are indicated 15 minutes and 30 minutes.

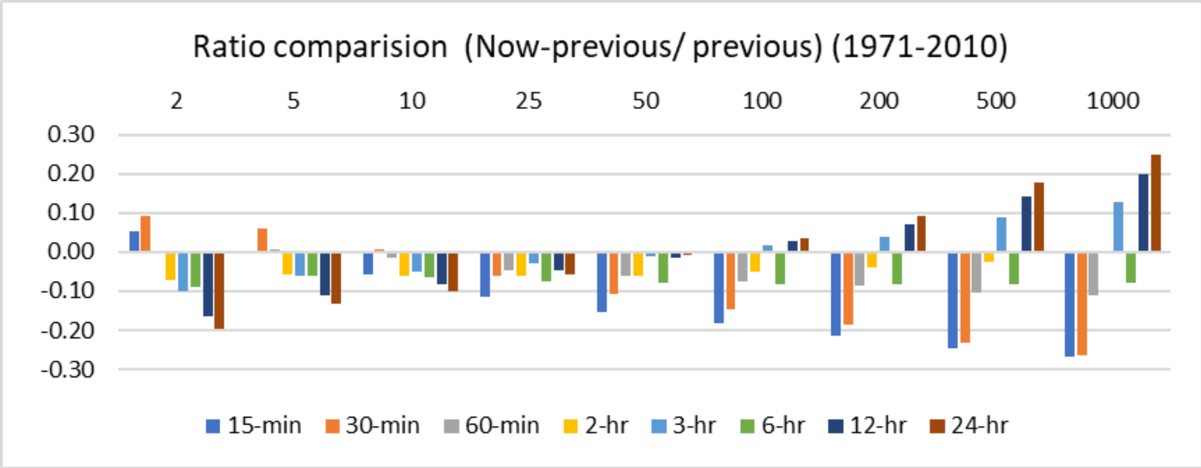


Figure A.5 Ratio Comparison (now represent: GHCN NOAA station data & Previous represent: ATLAS-14) from 1971-2010 period.

Note: Example of one station to show (USC00251145, Morrill) how we have done the verification and comparison with ATLAS-14

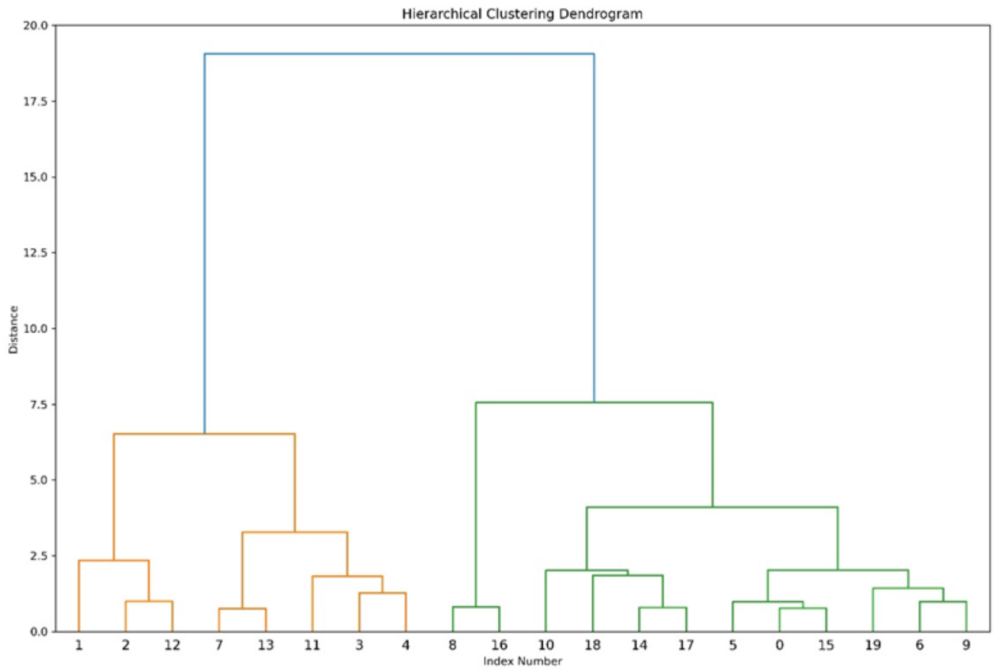


Figure A.6 Application of Hierarchical Clustering method. Index numbers represent the station ID and the dendrogram shows where the distance is about 19. If we put this distance value to find out the number of optimal clusters, it shows 2 which is not feasible. Therefore, we use k-means clustering for our further work from 1981-2020 period.