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"Providing a safe, high quality, and efficient transportation system"
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June 3, 2016

Lusk Wyoming Flood Study
Flood Date: June 3 and 4, 2015
WYDOT

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Background

A large storm occurred over the Niobrara River watershed in the evening hours of June 3, 2015, and lasting into the early morning hours of June 4. The storm tracked from southwest to northeast over the entire 73 square mile watershed. Doppler radar images indicate the storm lasted approximately 4 hours. Figure 1 shows the Niobrara River watershed at Lusk. The storm lead to serious flooding in Lusk, including the failure of the bridge over the railroad on US85. According to the National Weather Service, precipitation varied from 4.69 inches in the northern parts of Niobrara County to 7.11 inches south-southeast of Lusk.

The objective of this study is to estimate the flood frequency (return period) of the June 4, 2015 flood and to show the possible error in return period estimates depending on methodology used. This also illustrates the complexity in estimating the peak discharge.

Hydrology

The Flood Insurance Rate Map (FIRM) shows an area of Zone A. Zone A floodplain delineation are rough estimates. The map is dated March 18, 1986. A Flood Insurance Study (FIS) with estimates of hydrology was not located on the FEMA website. The FIRM is shown in Figure 2.

Hydrology calculation estimates from 1982 for the bridge over the Niobrara River were found. Using equations from Water-Resources Investigations 76-112, values using a weighted average of Region 2 and 3 were estimated. These estimates are shown in Table 1. At that time, a value of 2180 cfs for the 100-year flood was obtained from FEMA. This value was used in the design of the bridge.

The USGS Regression equations from Floodflow Characteristics of Wyoming Streams (10) and Peak Flow Characteristics of Wyoming Streams (39) were used. For the 1988 study, the drainage area is located in the Plains region with a geographic factor of 1.0, a precipitation index of 14, and a basin slope of 287 feet per mile. The 2003 equations were computed using a composite soil index of 2.61. These flood frequency estimates are shown in Table 1.

A log Pearson type III and Gumbel flood frequency analysis was performed using the stream gage near the Wyoming border approximately 30 miles east of Lusk. The drainage area for the stream gage is 445 square miles. The results are listed in Table 1. The flood frequency from the stream gage analysis is substantially less than those estimated using the USGS Regression equations. This is unexpected due to the much larger drainage area at the stream gage. This might be due to a number of factors such as land use or the analysis of base flow conditions. The Gumbel distribution produces higher estimates than the log Pearson III analysis.

Table 1 - Hydrology Estimates from Regression Equations

Frequency	1976 eqns weighted avg	1988 equations	2003 equations	IPIII gage	Gumbel
2	440	329	206	20	17
5	1180	845	700	77	65
10	2070	1310	1320	162	156
25	3600	2130	2570	373	469
50	5180	3170	3940	652	1063
100	7150	3980	5790	1093	2389
200		5700	8228	1775	5344
500		8121	12730	3235	15401
1000		10613	15358	4463	

Note:
The log Pearson III (IPIII) and Gumbel analysis are not area adjusted to the site. The gage drainage area is 455 square miles making gage area adjustments unreliable. The drainage area at Lusk is 73 square miles.

The Community Collaborative Rain, Hail & Snow Network (CoCoRaHS) indicates there is a site southwest of Lusk that received 2.62 inches of precipitation on June 3. Figure 3 shows the location of the gage in relation to the Niobrara River drainage area. The gage is not located in the watershed area.

The drainage area was broken into 9 subareas using the Watershed Modeling System (WMS) software. The areas were roughly broken into subareas where changes in soil types occurred. A HEC-1 model was created as shown in Figure 4. Several different strategies were used to estimate discharges.

An NRCS type II rainfall distribution with a 100-year 24 hour rainfall of 3.8 inches from NOAA Atlas II was used. SCS curve number show a range for each soil type. For this reason a range of curve numbers were used for comparison in a sensitivity analysis. Curve numbers of 61 for NRCS type B soil and 80 for type D soil produced a discharge estimate of 4050 cfs. Another analysis utilized the same model, only changing the curve number to 65 for type B soils and 75 for type D soils produced a discharge estimate of 4740 cfs.

The total rainfall of 2.62 inches from the CoCoRaHS data using the NRCS type II rainfall distribution, curve numbers of 65 for type B soils and 75 for type D soils produced a discharge estimate of 1850 cfs.

A HEC-1 model of the drainage area without being divided into subbasins was also created. Using the NRCS type II rainfall distribution with a total storm precipitation of 3.8 inches yielded a discharge of 3330 cfs. A curve number of 65 for type B soils and 75 for type D soils were used.

Radar imagery from Weather Underground (www.wunderground.com) was obtained approximately every 30 minutes for the duration of the storm. The images were geo-referenced in WMS, showing a background radar image under the drainage subareas. Figure 5 shows a radar image from June 3 at 11:12PM under the subareas used in the HEC-1 model. The colors of the radar are only categorized as light to heavy rainfall. An arbitrary amount of inches of rainfall was used for each color. A composite amount of rainfall was determined for each radar image over each subarea. This was then converted to the amount of inches over each watershed for each time step. The radar data was scaled to a total rainfall of 3.8 inches. The discharge at Lusk was estimated to be 7390 cfs. The radar data was also scaled to the CoCoRaHS rainfall of 2.62 inches, which resulted in a discharge of 2960 cfs.

The rainfall intensities from Doppler radar do not necessarily measure the rainfall the hits the ground thus introducing input data error.

All the different methods and the subsequent discharges are shown in Table 2. The table indicates there can be a large range of values when using rainfall runoff methods.

Table 2 - Hydrology Estimates using Rainfall Runoff Methods

Method	Discharge cfs
100-yr 24 hour type II, NOAA=3.8 in CN=61 B soil, CN=80 D soil, w/ subbasins	4050
100-yr 24 hour type II, NOAA=3.8 in CN=65 B soil, CN=75 D soil, w/ subbasins	4740
24 hour type II, CoCoRaHS=2.62 in CN=65 B soil, CN=75 D soil, w/ subbasins	1850
radar data, 3.8 in. total storm precip. CN=65 B soil, CN=75 D soil, w/ subbasins	7390
radar data, 2.62 in. total storm precip. CN=65 B soil, CN=75 D soil, w/ subbasins	2960
100-yr 24 hour type II, NOAA=3.8 in CN=65 B soil, CN=75 D soil, no subbasins	3330

USGS Flood Peak Estimate

The USGS was requested to estimate the peak discharge of the flood. An indirect determination was completed about 1.5 miles downstream of the bridge, along Wasserburger Road. The total peak discharge was computed as the sum of separate road overtopping and culvert computations. The discharge was estimated to be 9300 cfs.

Aerial Reduction Factor

Aerial reduction factors are used to adjust point rainfall to spatially distributed rainfall depths over the entire watershed. The 1972 NOAA atlas provides a generalized ARF for large regions of the United States. The radar images were also used to develop the aerial reduction factor (ARF) for this storm. This is useful in comparing the local ARF to the ARFs presented in the NOAA Atlas. Figure 6 compares the ARF calculated for this storm and the ARF presented in the NOAA Atlas. The June 4, 2015 storm has more reduction than the generalized NOAA atlas indicating a smaller discharge peak than what is produced for a rainfall runoff analysis. If the storm was distributed like the NOAA ARF then the flood peak would have been larger. The ARF must be used in estimating the return period of the storm over the watershed. The ARF suggests that the return period of the point rainfall is larger than the return period averaged over the watershed.

Storm Return Period

The return period at rain gages provide point rainfall return periods. The ARF is used to adjust the total rain fall and duration to estimate the averaged return period of the storm over the watershed.

The rain gage at Harrison, Nebraska has the best available record and intensity duration frequency. The 100-year 6 hour event is 3.37 inches, 500-year is 4.28 inches and the 1000-year is 4.69 inches.

The rainfall hyetograph from Doppler radar average over the watershed is 2.7 inches for the storm duration of 4 hours. This indicates the averaged storm rainfall return period is 50 years.

The entire 4 hour storm was broken into several smaller durations, such as 30 minutes, 1 hour, 2 hours, and 3 hours. Table 3 shows the average rainfall for several smaller durations within the entire storm and their corresponding frequency using the Harrison, Nebraska rain gage.

Table 3 - Storm Frequency for Small Storm Durations

storm length	avg rainfall (in)	frequency (yr)
30 minutes	3.86	1000+
	2.69	500
	1.84	100
	2.76	1000
1 hour	3.52	1000+
	3.81	1000+
	2.28	100
	3.90	1000+
2 hours	3.09	200
	3.45	500
	3.60	500
	3.34	500
3 hours	3.25	200
	2.93	100

Conclusion

The flood of June 3 and 4, 2015, was estimated to be 9300 cfs by the USGS. According to the 1976 regression equations, this flood was greater than the 100-year frequency. The 1988 regression equations show this flood to be approximately a 700-yr flood. The 2003 equations indicate the Niobrara River flood to be approximately a 220-year flood. Figure 7 compares the regression equation values to the USGS estimated flood flow.

The June 4, 2015 flood peak of 9300 cfs would exceed the 200-year flood event for Gumbel distribution and greater than the 1000-year event using the log Pearson III distribution. These estimates were made assuming there are no watershed conditions that cause significant attenuation of peak flows.

This study illustrates the complexities of estimating the return period of an event. The return period of the event can not be estimated using the return period of the rainfall depth. The return period of the storm and the return period of peak are different due to antecedent soil condtions, spatial and temporal distributation of the storm cell.

The range of return period estimates produced in this study suggests that the June 3 and 4, 2015 floood event exceeds the 100-year return period and is possibly much greater.

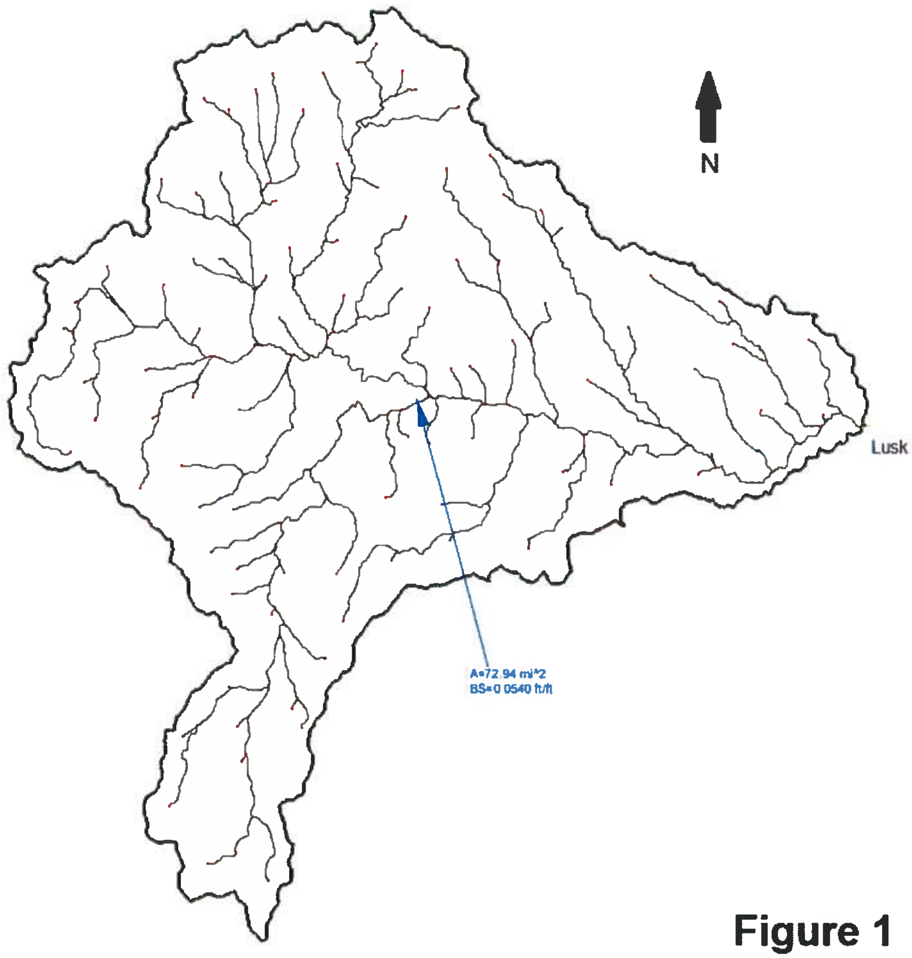
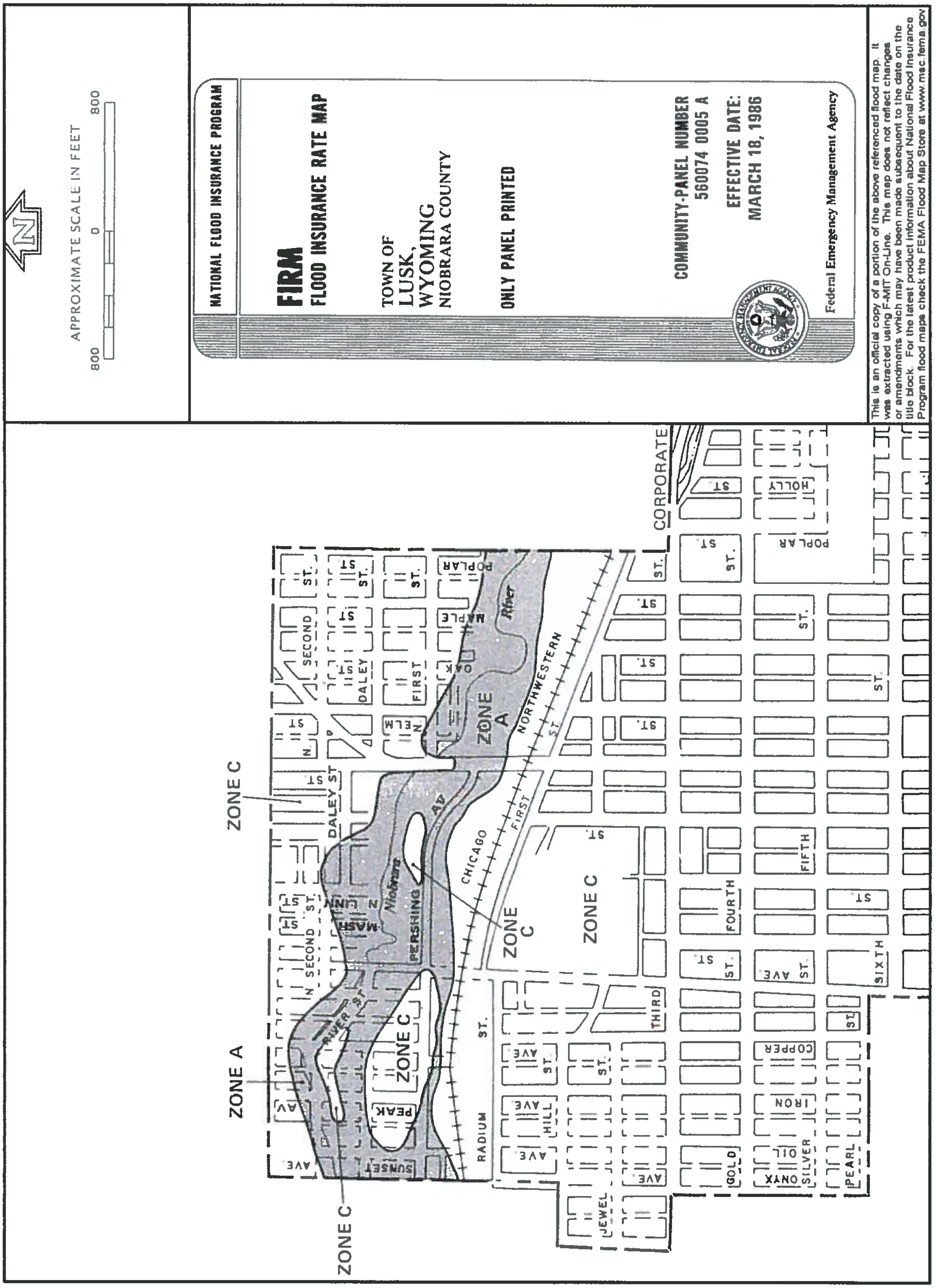


Figure 1


APPROXIMATE SCALE IN FEET
800 0 800
NATIONAL FLOOD INSURANCE PROGRAM
FIRM
FLOOD INSURANCE RATE MAP
TOWN OF LUSK, WYOMING
NIOBRARA COUNTY
ONLY PANEL PRINTED
COMMUNITY-PANEL NUMBER
560074 0005 A
EFFECTIVE DATE:
MARCH 18, 1986
Federal Emergency Management Agency
This is an official copy of a portion of the above referenced flood map. It was extracted using F-MIT On-Line. This map does not reflect changes or amendments which may have been made subsequent to the date on the title block. For the latest product information about National Flood Insurance Program flood maps check the FEMA Flood Map Store at www.msc.fema.gov
ZONE A
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Niobrara River
CHICAGO NORTHWESTERN
CORPORATE

Figure 2

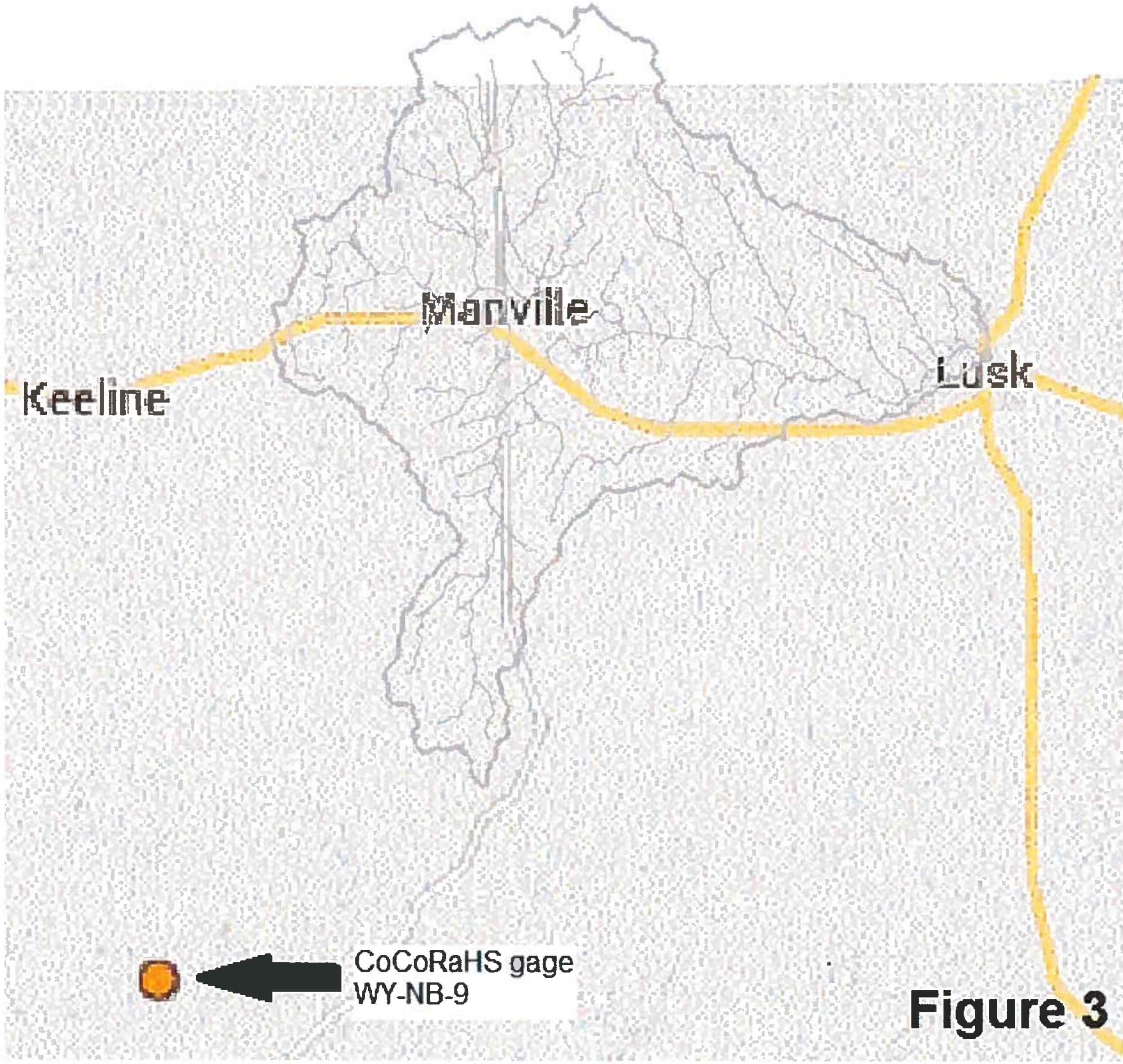
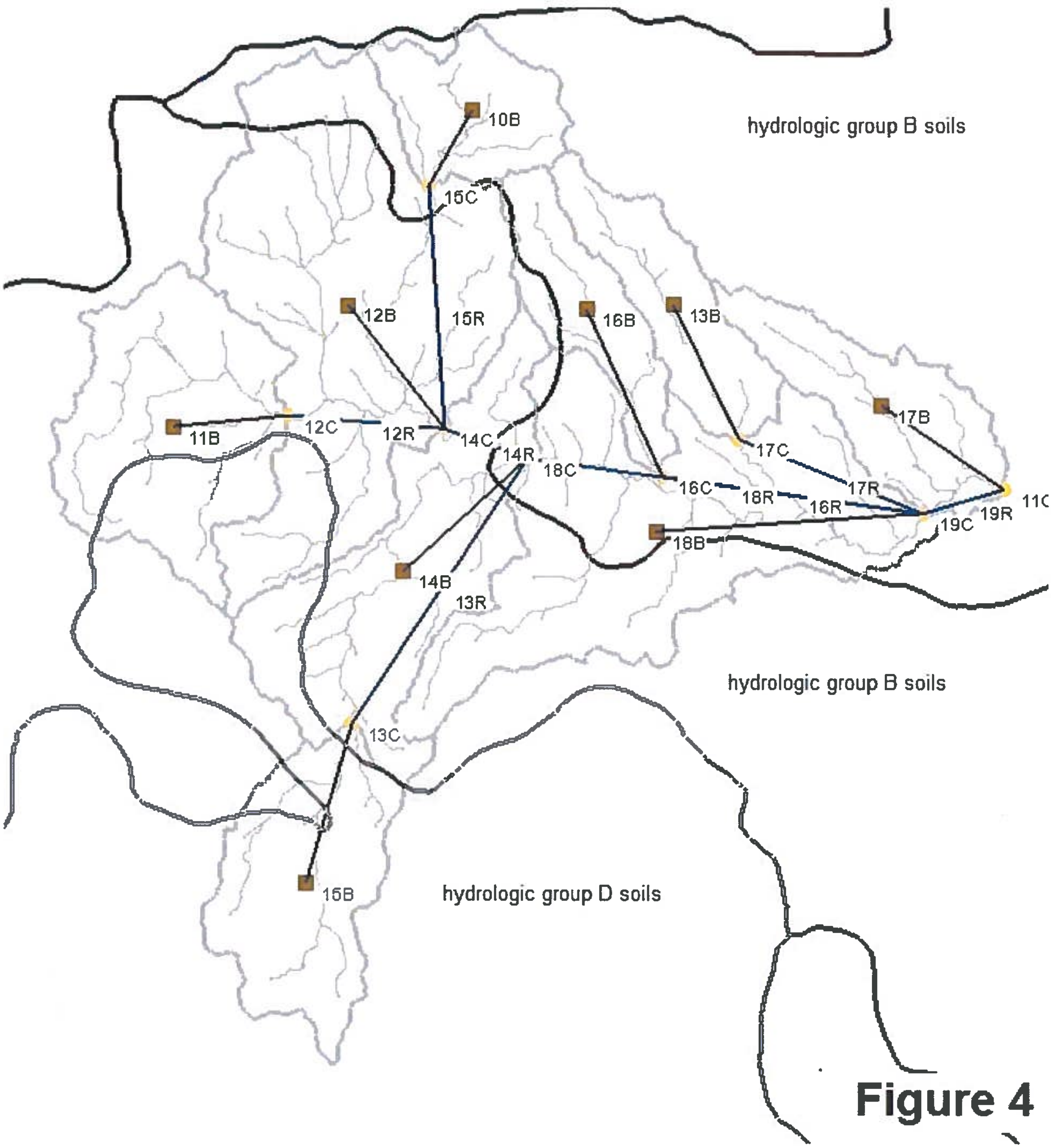


Figure 3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15C
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11B
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14C
14R
18C
17C
16C
18R
16R
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13R
hydrologic group B soils
13C
15B
hydrologic group D soils

Figure 4

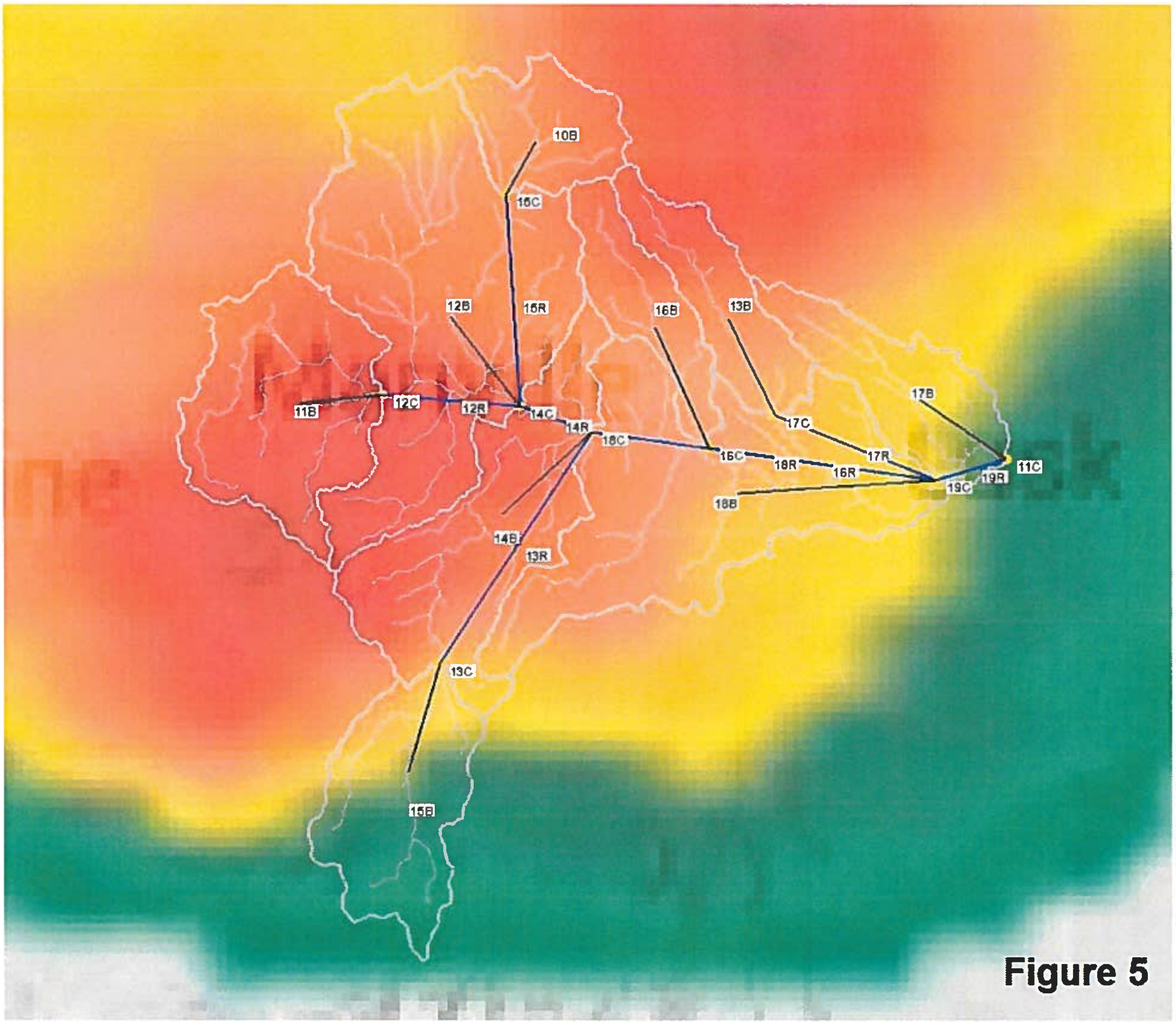
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Figure 5

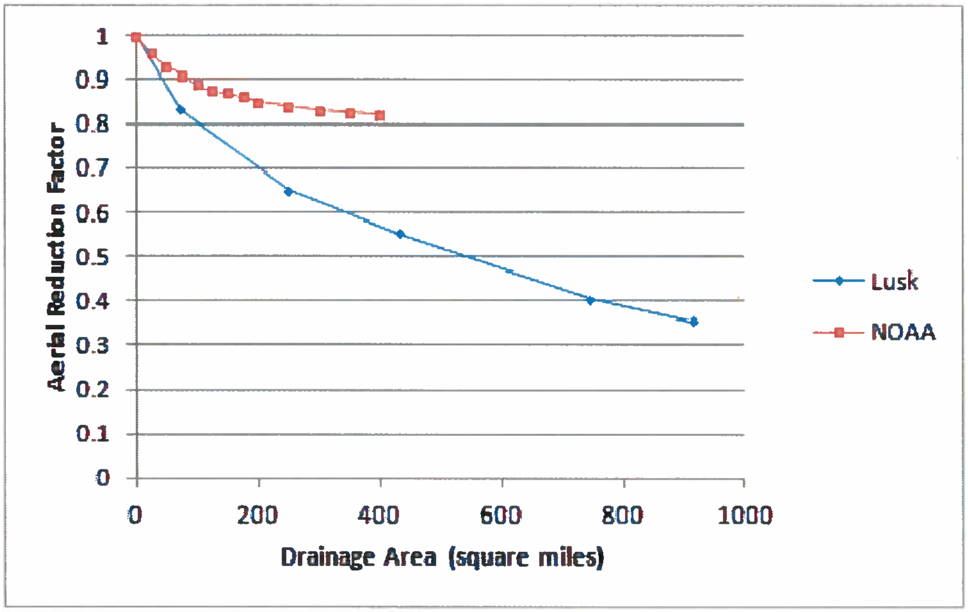

Figure 6

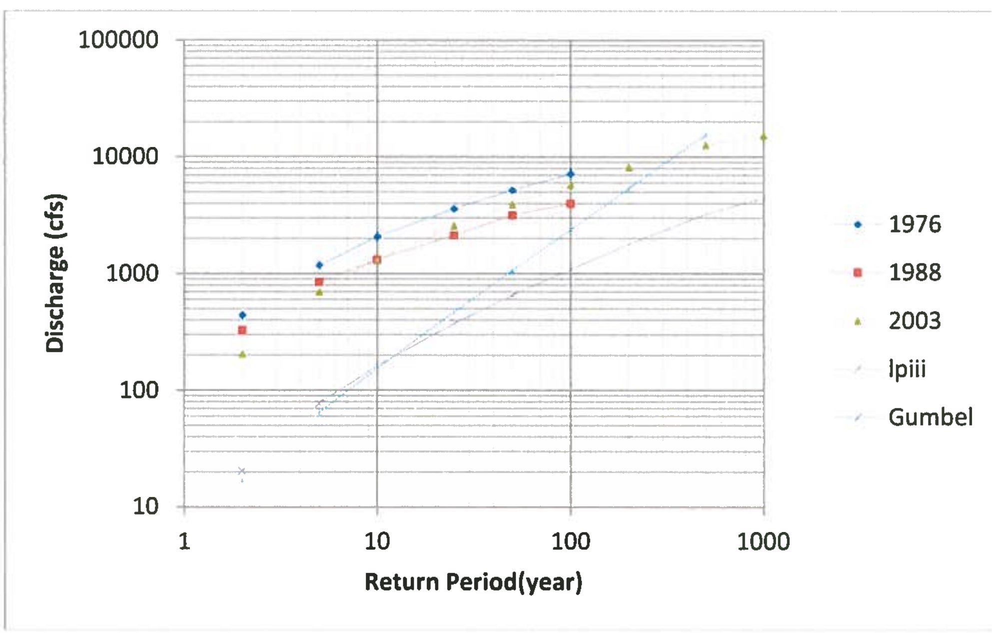

Figure 7

The USGS estimate of 2450 cfs flood peak through the railroad bridge opening is considered accurate if the bridge super structure was not collapsed prior to or during the peak discharge, or that the railroad bridge opening was not blocked by other debris.

The design of the Niobrara Highway US 85 Bridge was approximately 2180 cfs. It was blocked with lots of drift making it difficult to estimate the discharge through the bridge. The addition of the railroad bridge discharge of 2450 cfs and the Niobrara River Bridge design discharge of 2180 cfs produces a total discharge of 4630 cfs. That discharge does not include the portion of the discharge that diverted through the town south of the railroad bridge.

LUSK Flood Sensitivity Analysis

The rainfall runoff model parameters are subject to a range of values that are selected by the user.

A high and low curve number for each sub basin was input into the model to compute a range of flood estimates such that the most probable flood discharge lies within the range of estimates.

Hydrologic soils for pasture or range land

B soils CN 61 to 79

D soils CN 80 to 89

The June 3-4, 2015 hyetograph from the Doppler radar aerial distribution study

Low discharge estimate 2136 cfs

High discharge estimate 7072 cfs

Average estimate 4604 cfs.

Sensitivity Analysis Frequencies for Different Methods

	frequency				
method	1976	1988	2003	lplII	Gumbel
low estimate 2136 cfs	11	25	20	270	90
high estimate 7072 cfs	n/a	390	150	1000+	250
avg estimate 4604 cfs	40	130	68	1000	180

Extreme Events and Climate Change

A trend analysis was made to give insight as to the potential effects of climate change. The term climate change is widely used by not well defined such that communication regarding extreme events and climate change is difficult. This study is not intended to endorse or refute anthropogenic effects of the climate or that the climate may be significantly changing. The trend analysis suggests that flood peaks are not increasing but appear to be decreasing.

One may ask if the Lusk flood event was a result of climate change. The fact that extreme events occur in all climates and events larger than the June 4, 2015 event have likely occurred in historic period, the June 2015 is not necessarily attributed to a change in climate. However if the climate has changed then all weather events large or small are a result of climate change. This paradox is not possible to resolve with current technology. This trend analysis suggests that large events are not increasing in occurrence. A rigorous stationarity analysis may prove otherwise. A rigorous stationarity analysis is beyond the scope of this study.

A true significant climate change would have a significant change in the flood frequency estimates. As shown in this study, a wide range of flood frequency estimates can be made using various methods. The rainfall runoff methods may have variables that would respond to changes in climate. For instance the rainfall hyetograph could be climate adjusted if the rainfall frequency due to climate change can be estimated. The USGS regression equations and the stream gage analysis methods are not readily adaptable to estimate changes in peak discharges due to change in global average temperature.

It is difficult to accurately estimate a flood frequency curve for any climate, even with extensive data. The most impact to man will be in the lower frequency ranging from 10 to 100-year since they occur more frequently.

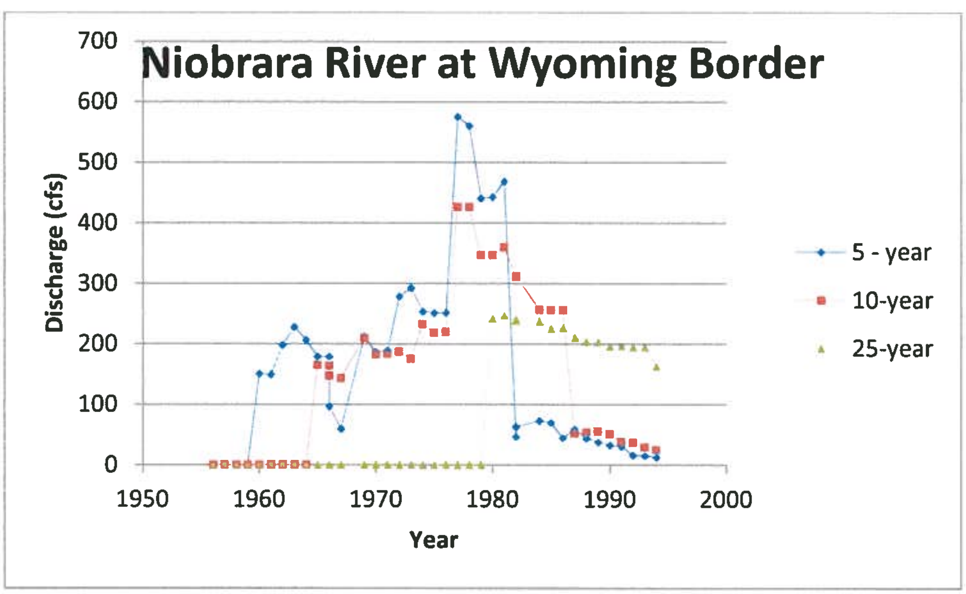

Figure 8 – Niobrara River Near Wyoming Border

A trend analysis of the Niobrara River gage was made using the 5, 10 and 25 year moving averages as shown in Figure 8. The rise in global average temperatures began in about 1970. There has been no global increase in temperature in the last 15 years (2000- 2016).

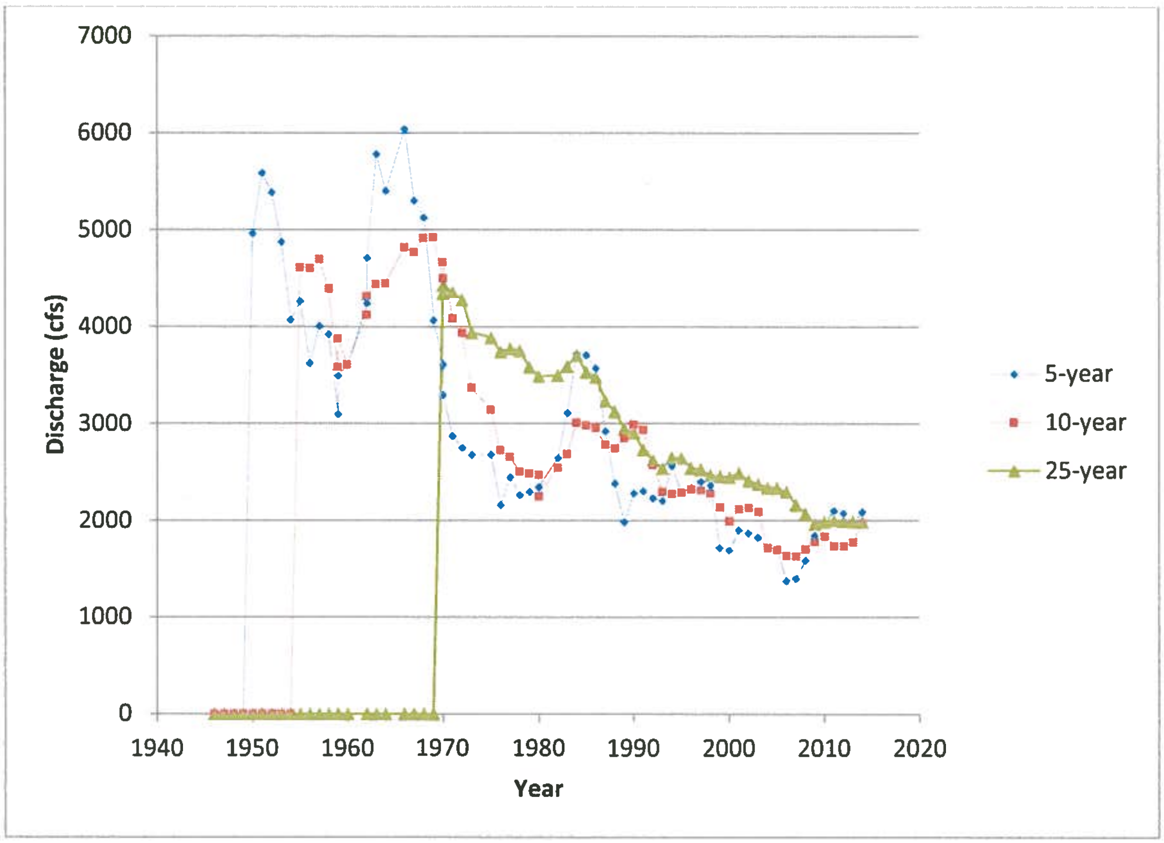

Figure 9 – Niobrara River near Sparks Nebraska

The trend analysis of the 5, 10 and 25 year moving averages shows no increased trend in peak runoff or extreme events. The decrease could be attributed to climate change, watershed conditions or random variation in flood events over a long period of time.

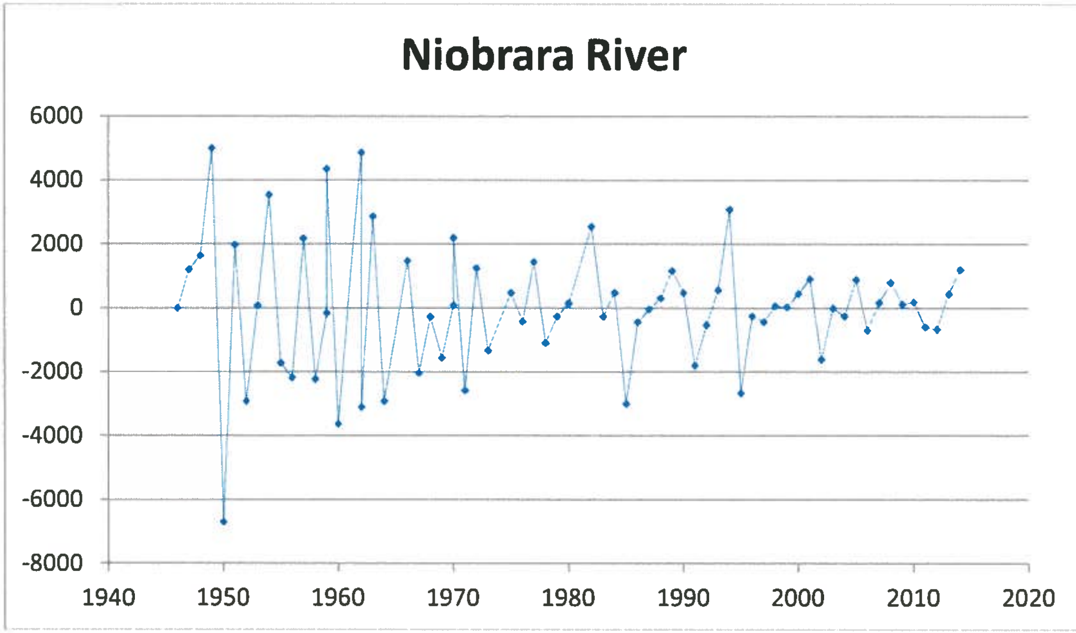

Figure 10 Random Walk Difference Data

A random walk through the data showing the difference in yearly change in discharge Dy = $(y_t\text{-}y_{t-1})$. Visually the yearly differences in peak fluctuations appear to be decreasing with time. The 2015 flood however is not included in the data. There appears to be a larger fluctuation in yearly peak differentials from 1945 to 1965.

A regression of the difference data does not show an upward or downward trend. There appears to be a downward trend in the fluctuation of peak discharges. The trends may be attributed to land use changes and possibly “climate change”.

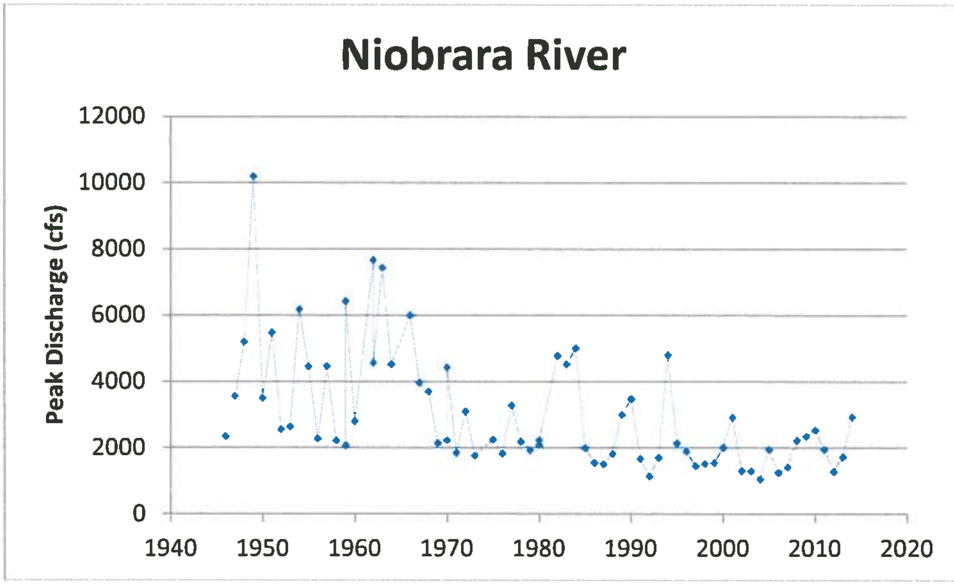

Figure 11 – Niobrara River Yearly Peak Discharges, Sparks gage

The 2015 flood peak is not shown on the graph. The Niobrara River stream gage at Sparks Nebraska has a drainage area of 7150 square miles.

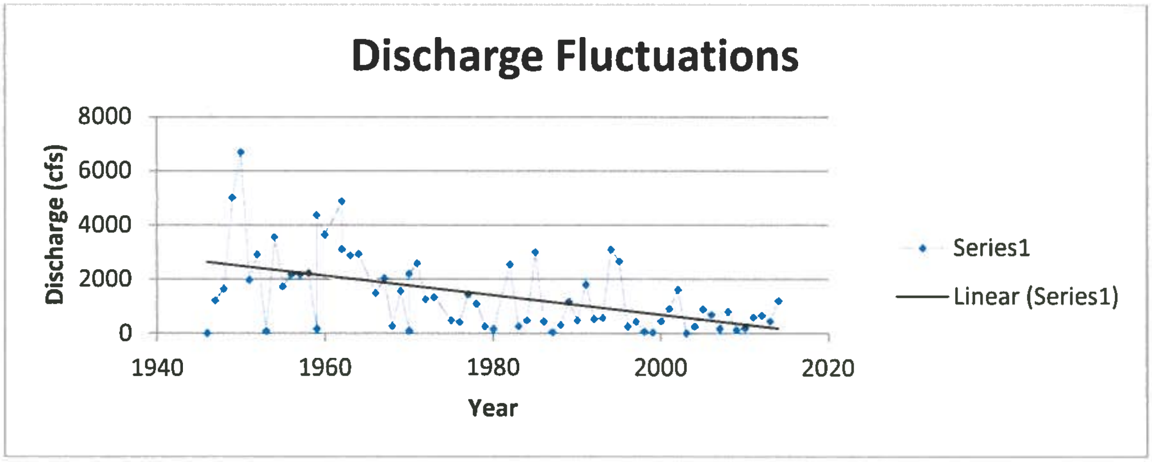

Figure 12 - Trend in Yearly Discharge Fluctuations

The 2015 flood peak was not included in the data since it is not yet available.