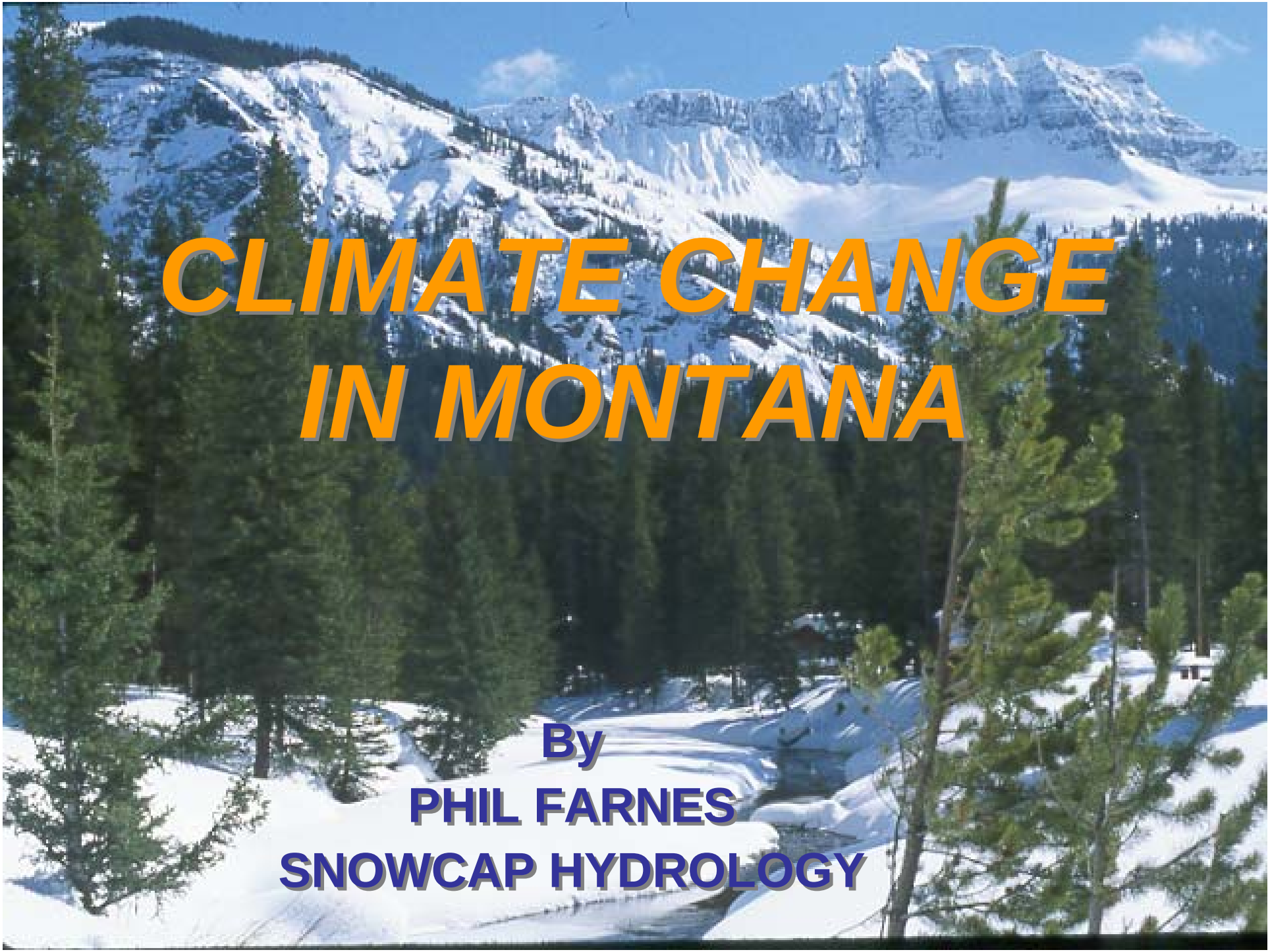
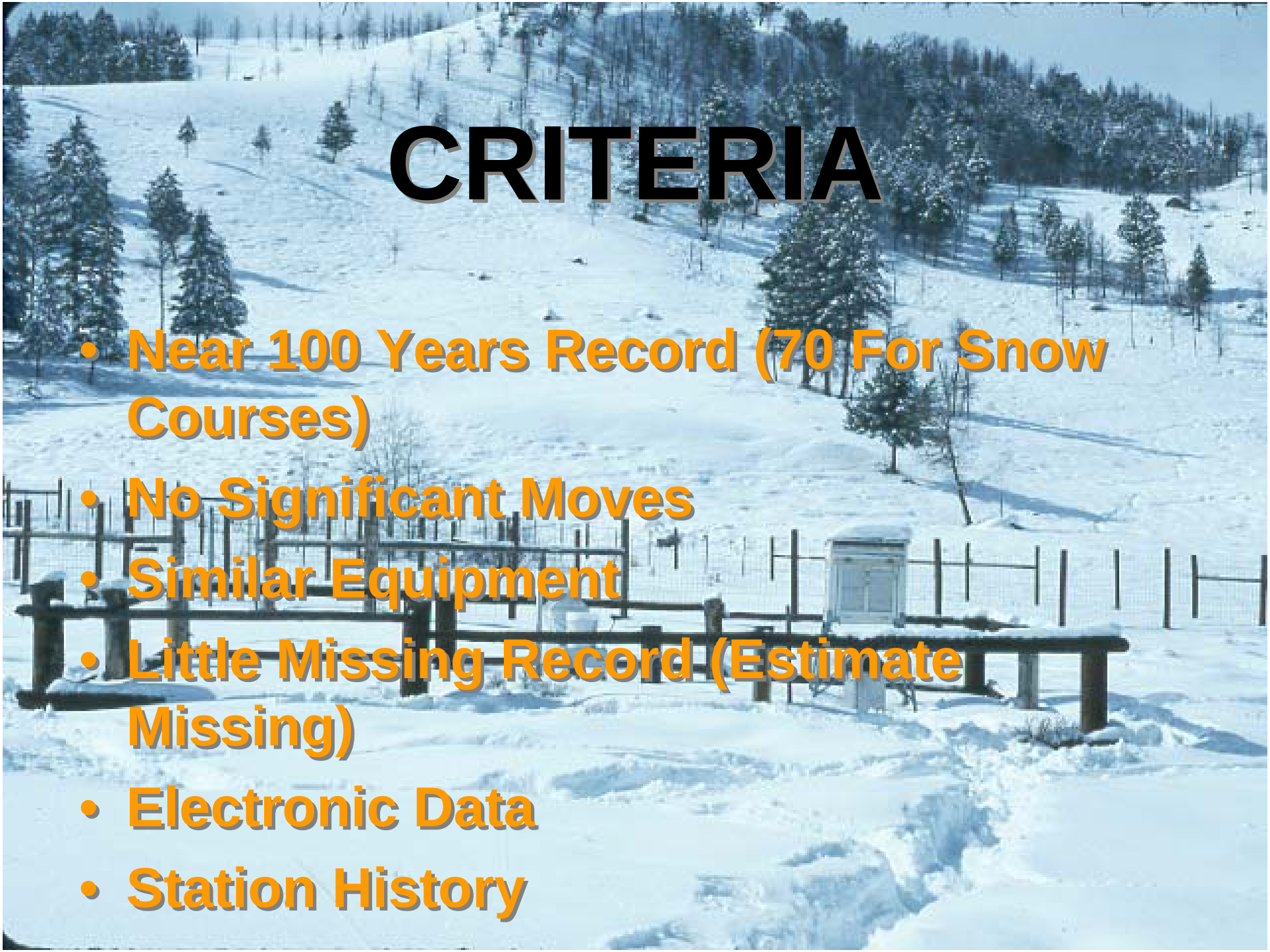
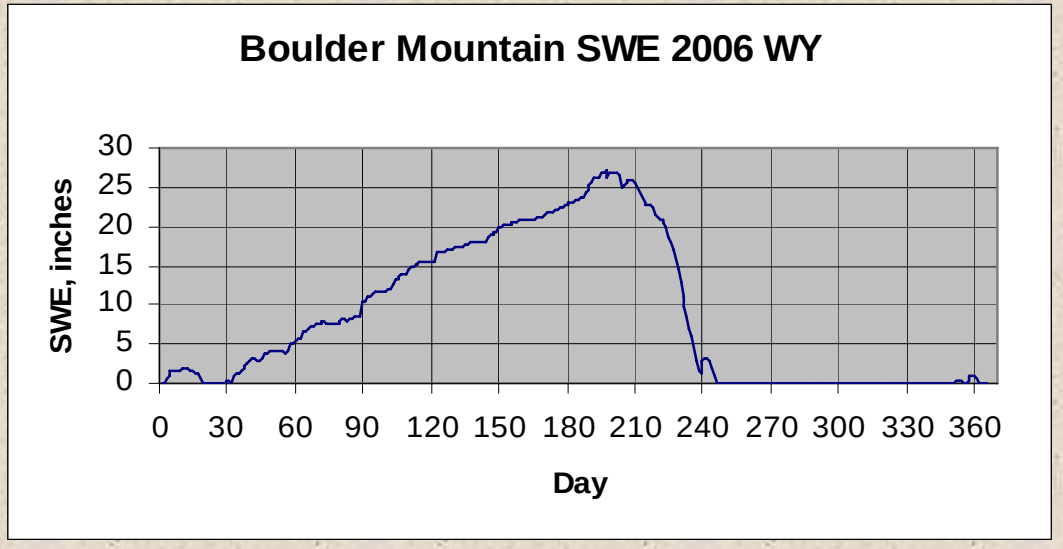

CLIMATE CHANGE
IN MONTANA
By
PHIL FARNES
SNOWCAP HYDROLOGY

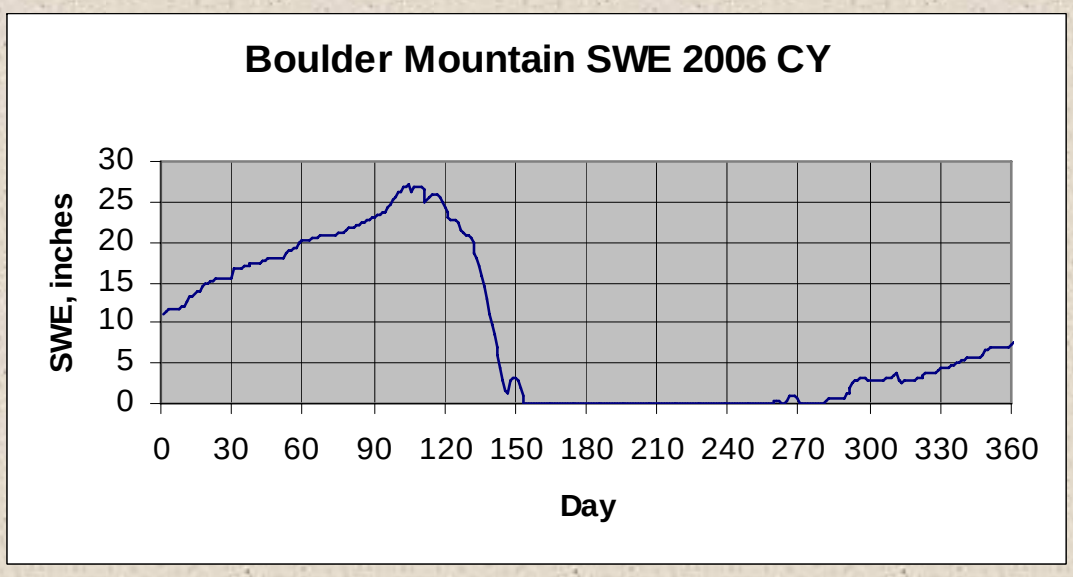


CRITERIA

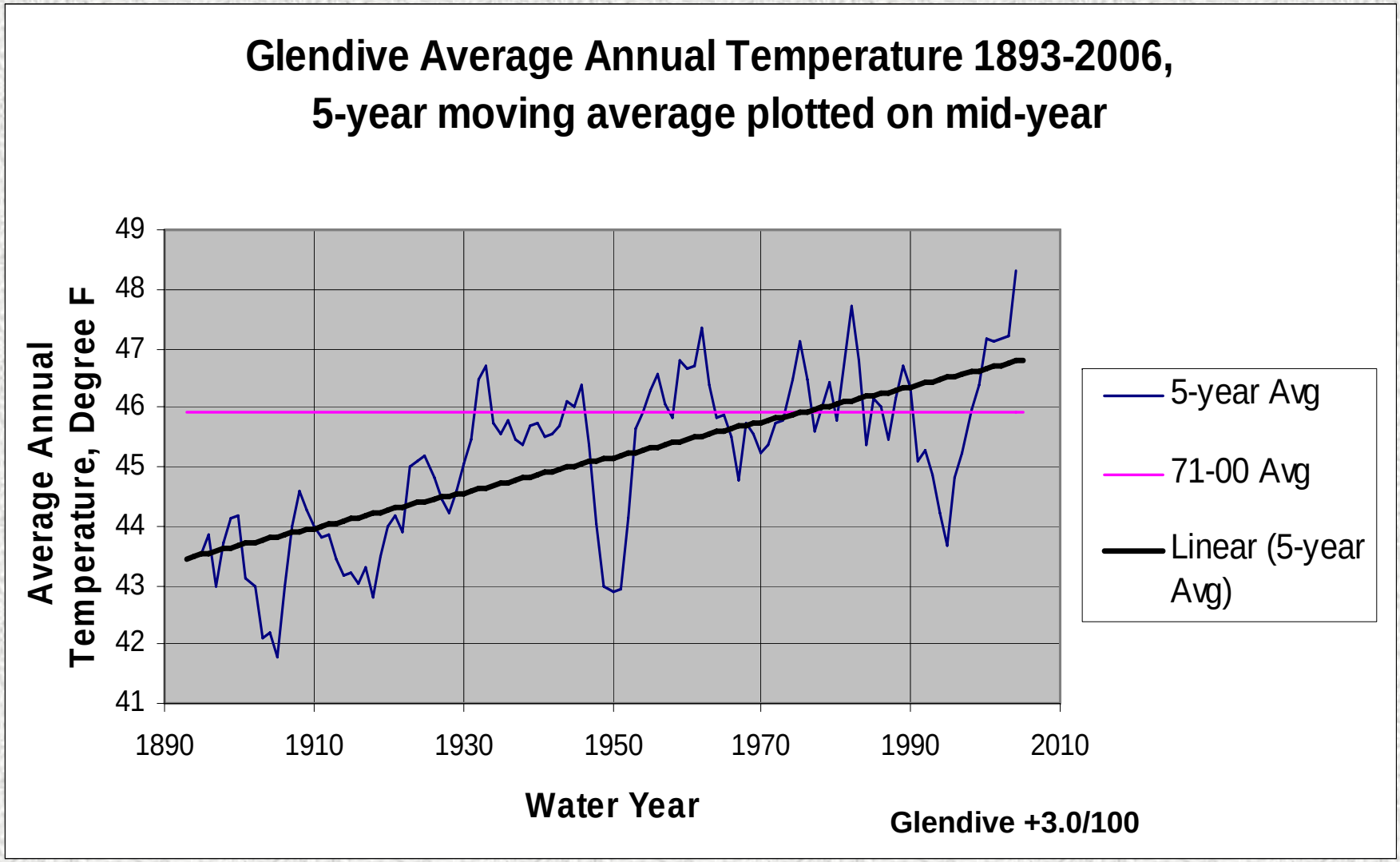
- Near 100 Years Record (70 For Snow Courses)
- No Significant Moves
- Similar Equipment
- Little Missing Record (Estimate Missing)
- Electronic Data
- Station History

WY vs CY

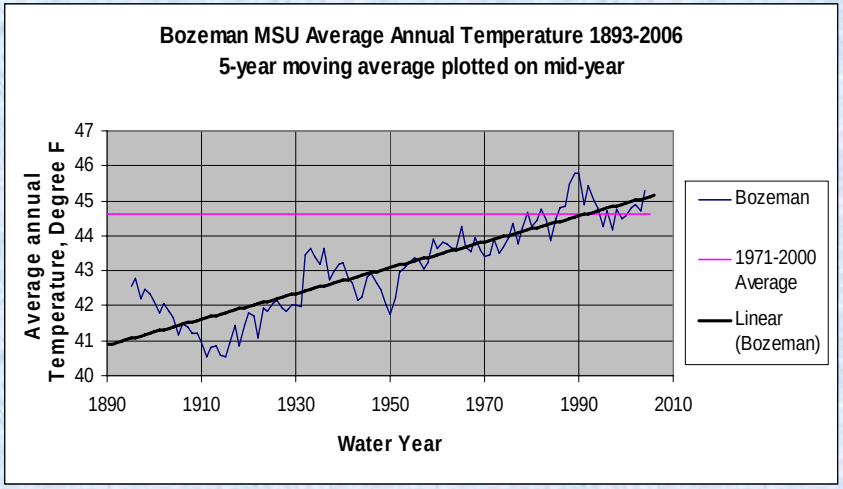

Boulder Mountain SWE 2006 WY
SWE, inches
30
25
20
15
10
5
0
0 30 60 90 120 150 180 210 240 270 300 330 360
Day

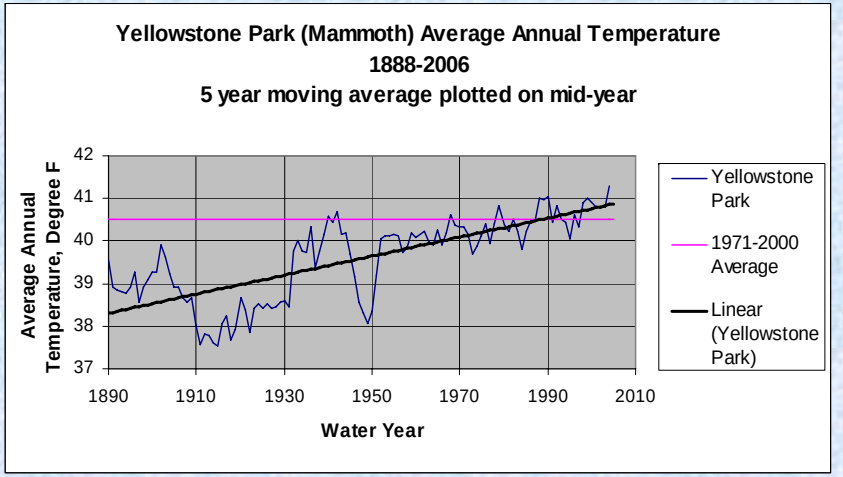

Boulder Mountain SWE 2006 CY
SWE, inches
30
25
20
15
10
5
0
0 30 60 90 120 150 180 210 240 270 300 330 360
Day

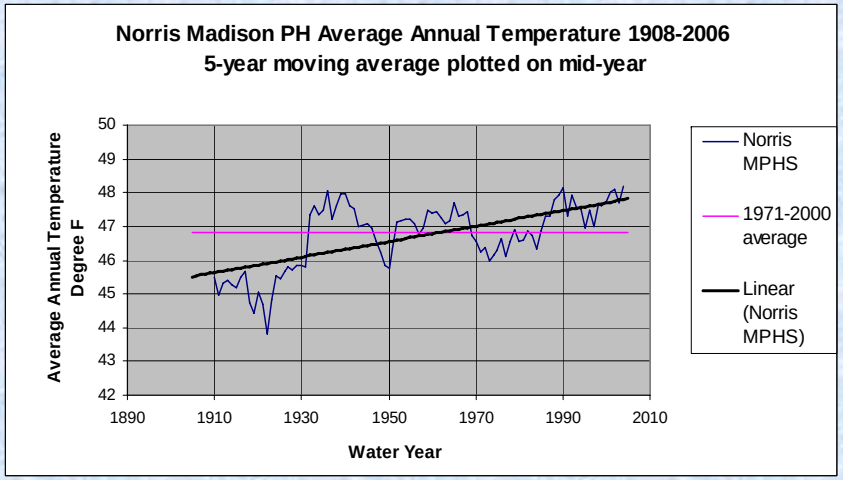
AVERAGE TEMPERATURES

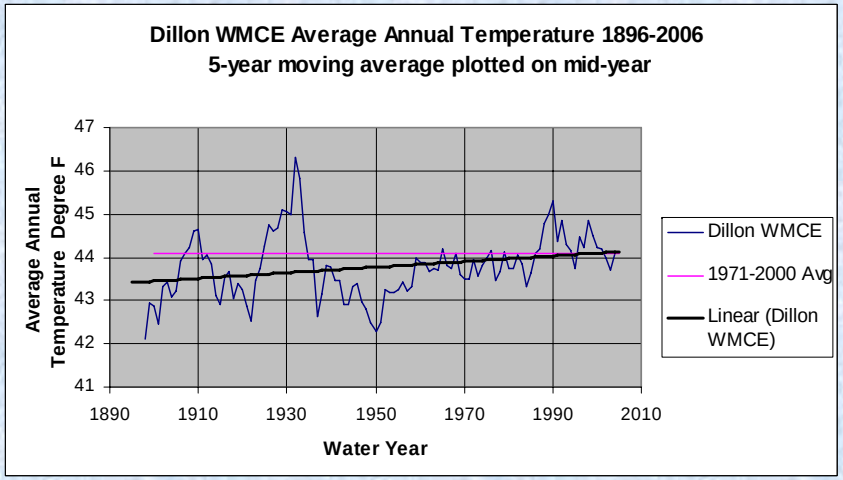


MORE AVERAGE TEMPERATURES



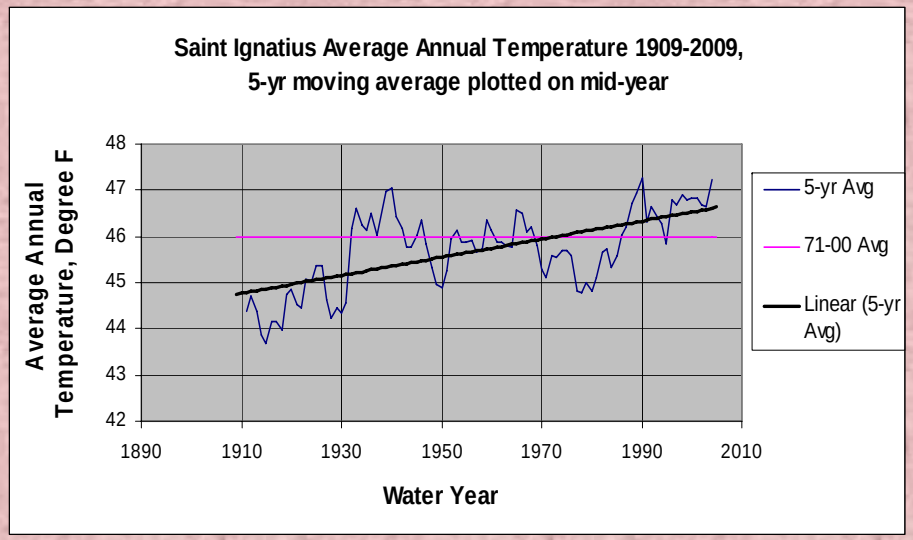


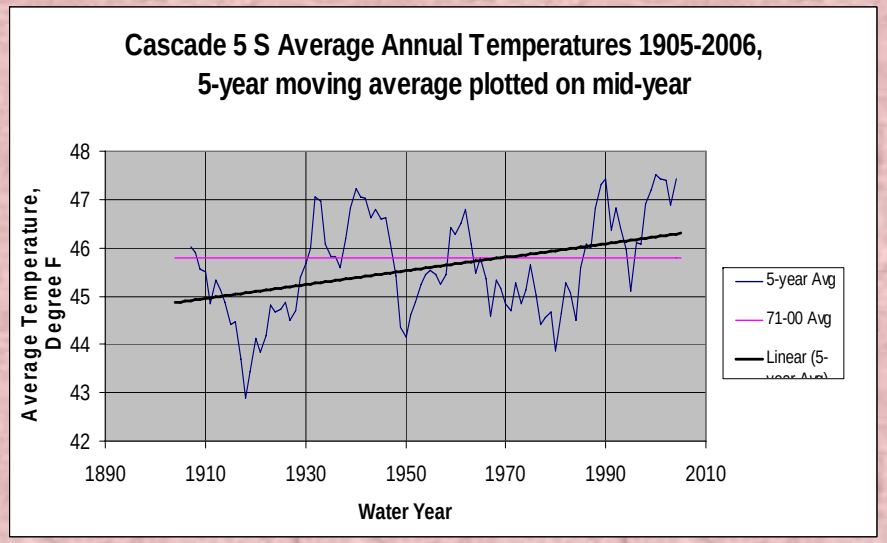


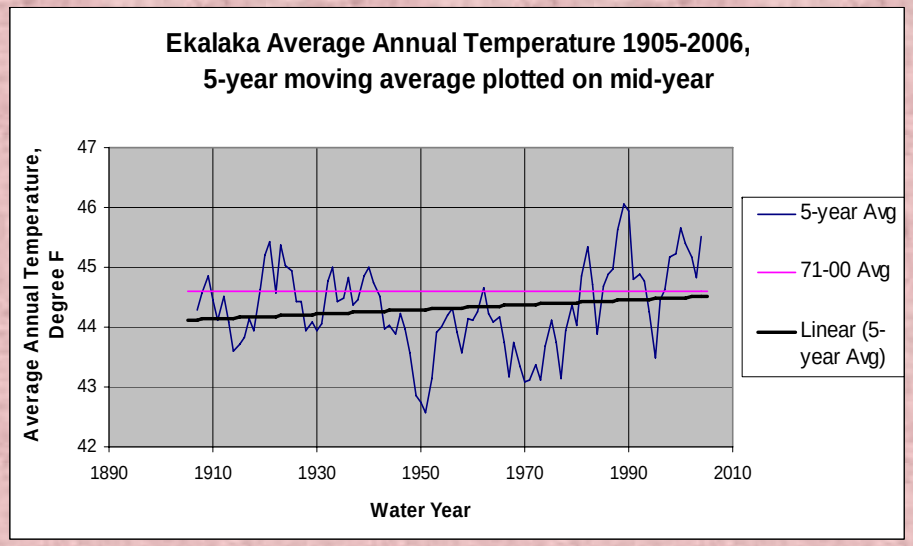


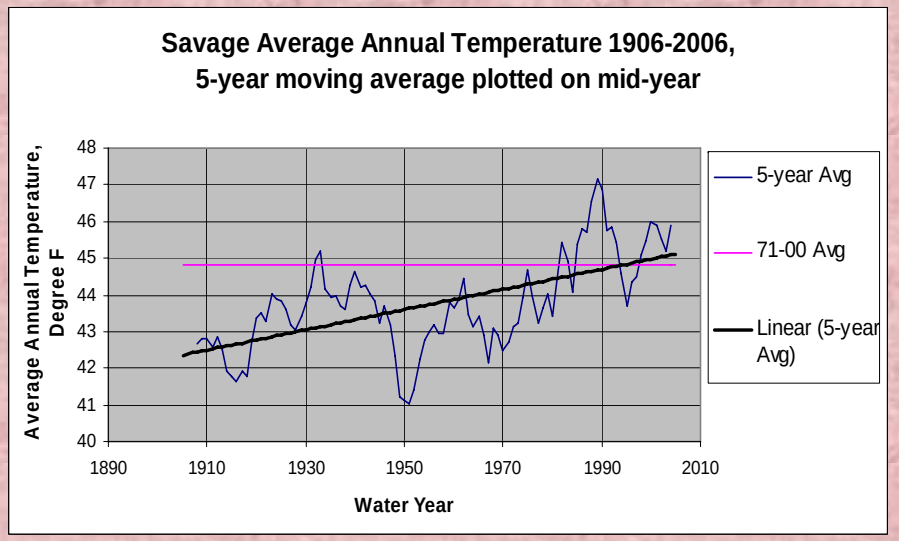
Boz +3.7 NMPH +2.3 Yel Pk + 2.2 WMCE +0.6

MORE AVERAGE TEMPERATURES

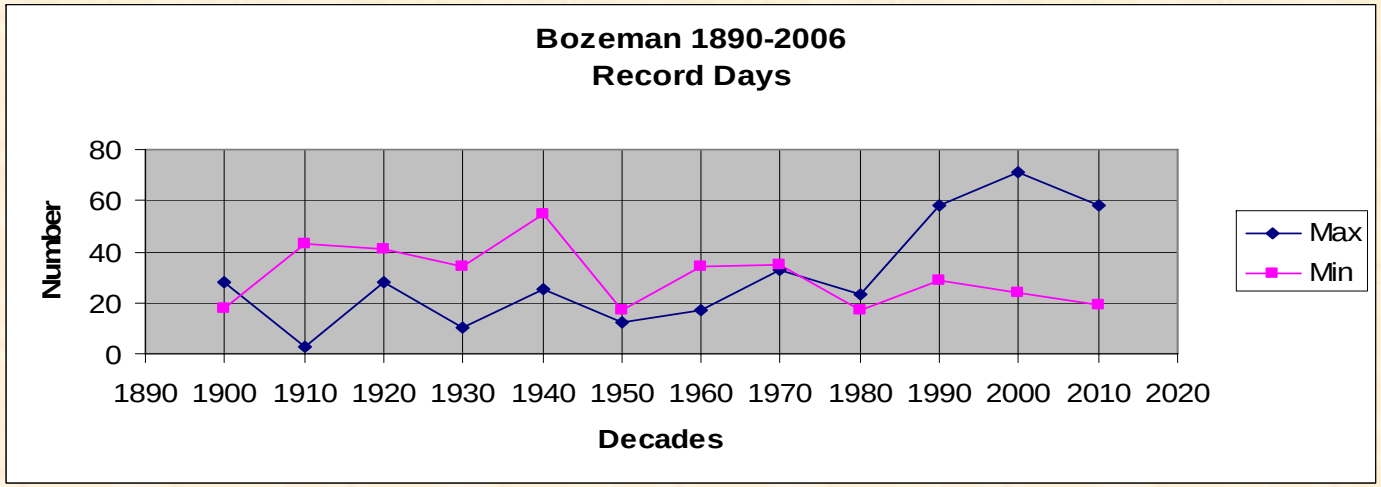








BOZEMAN MSU



Bozeman Year of max and min

1890-2006

Periods	Max	Min	Decades
1890-1899	1	28	18	1900
1900-1909	2	3	43	1910
1910-1919	3	28	41	1920
1920-1929	4	10	34	1930
1930-1939	5	25	55	1940
1940-1949	6	12	17	1950
1950-1959	7	17	34	1960
1960-1969	8	33	35	1970
1970-1979	9	23	17	1980
1980-1989	10	58	29	1990
1990-1999	11	71	24	2000
2000-2006	12	58	19	2010

Hottest 105 F 1892

(112 Aug 1875)

100 or above

1(?) 1875

4 in 1892

1 in 1931

3 in 2002

2 in 2007

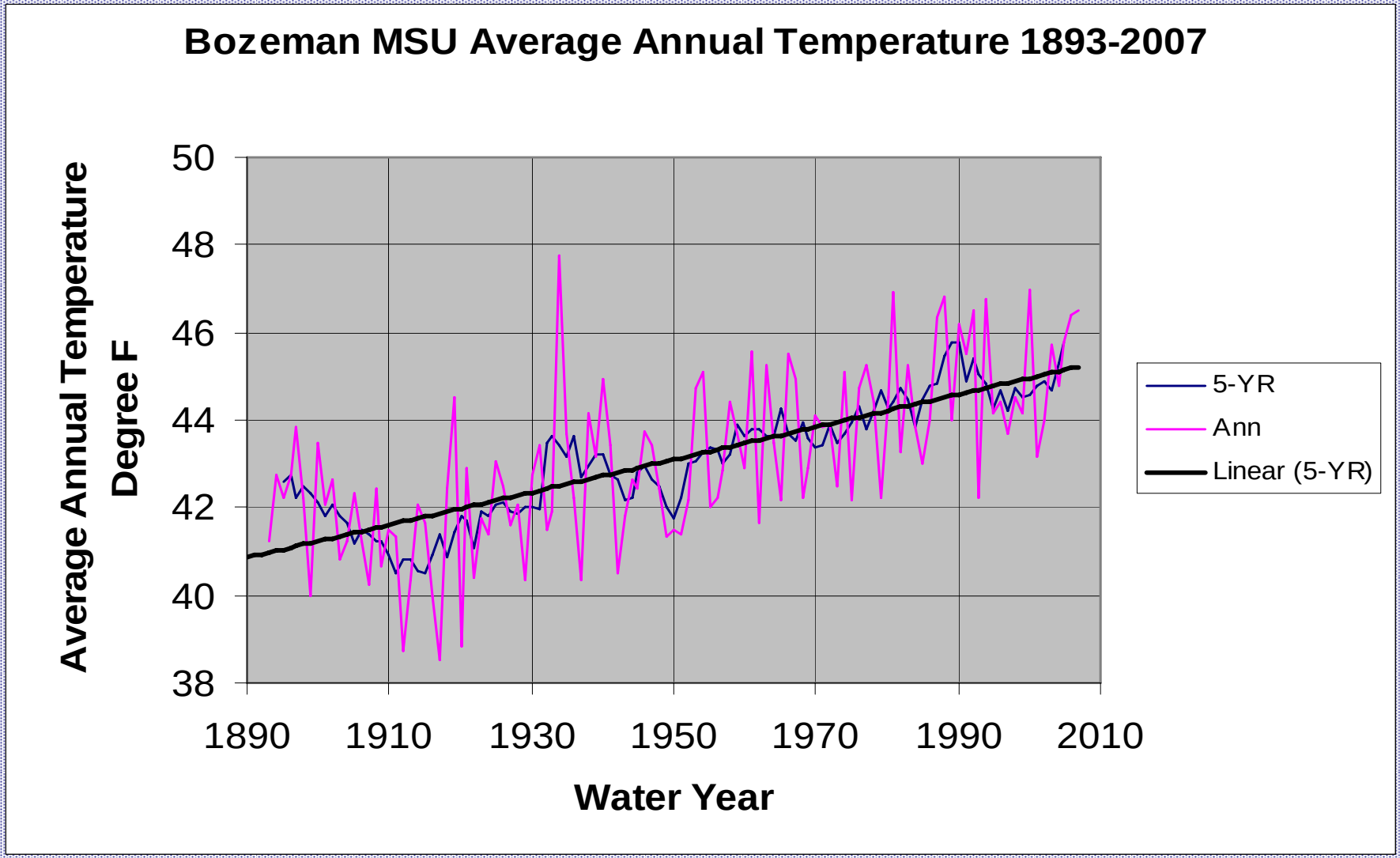
Coldest -44 F 1936 (-53?)

40 or below

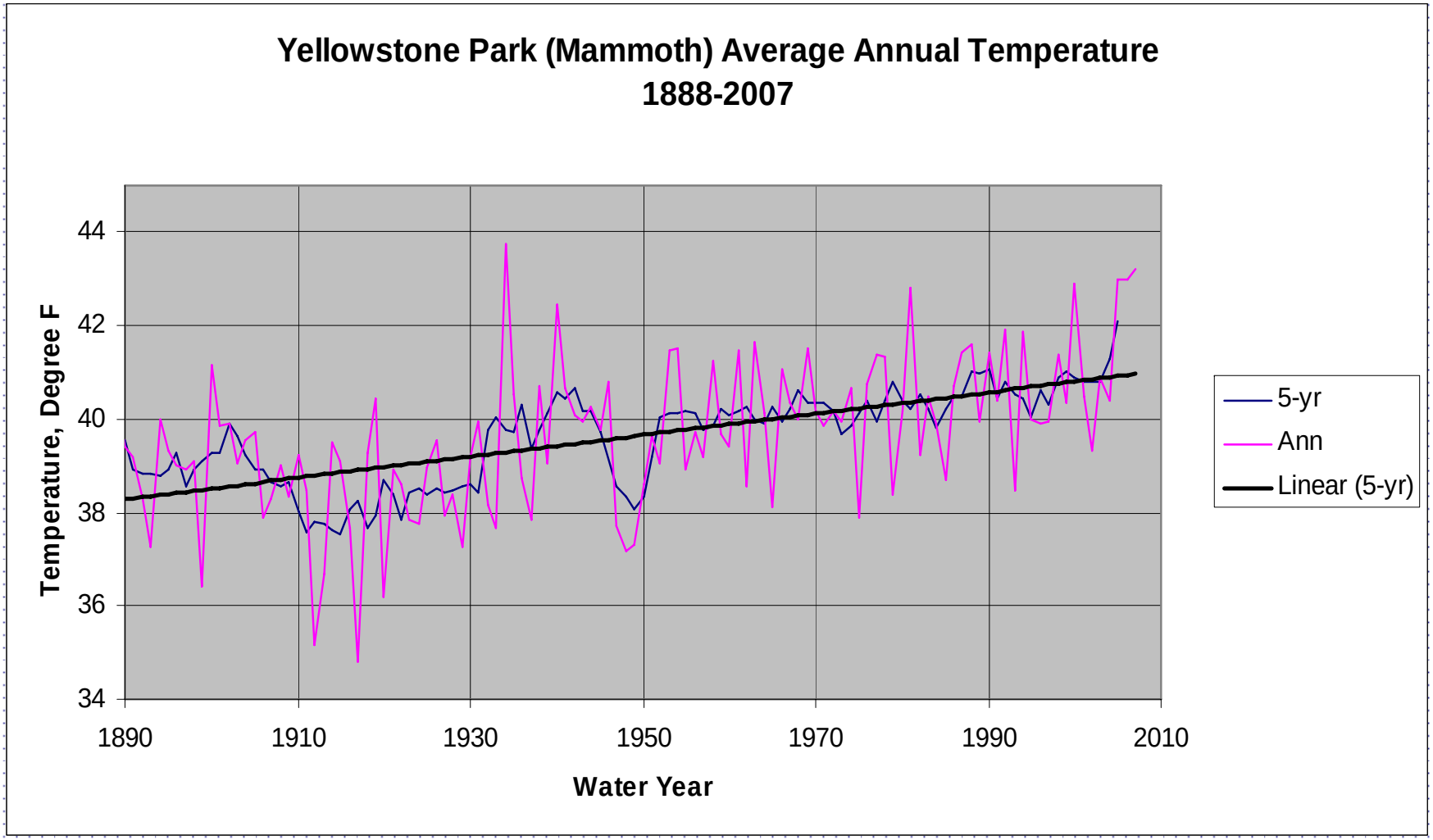
1 in 1893

1 in 1936

BOZEMAN MSU


Bozeman MSU Average Annual Temperature 1893-2007
Average Annual Temperature
Degree F
50
48
46
44
42
40
38
1890
1910
1930
1950
1970
1990
2010
Water Year
5-YR
Ann
Linear (5-YR)

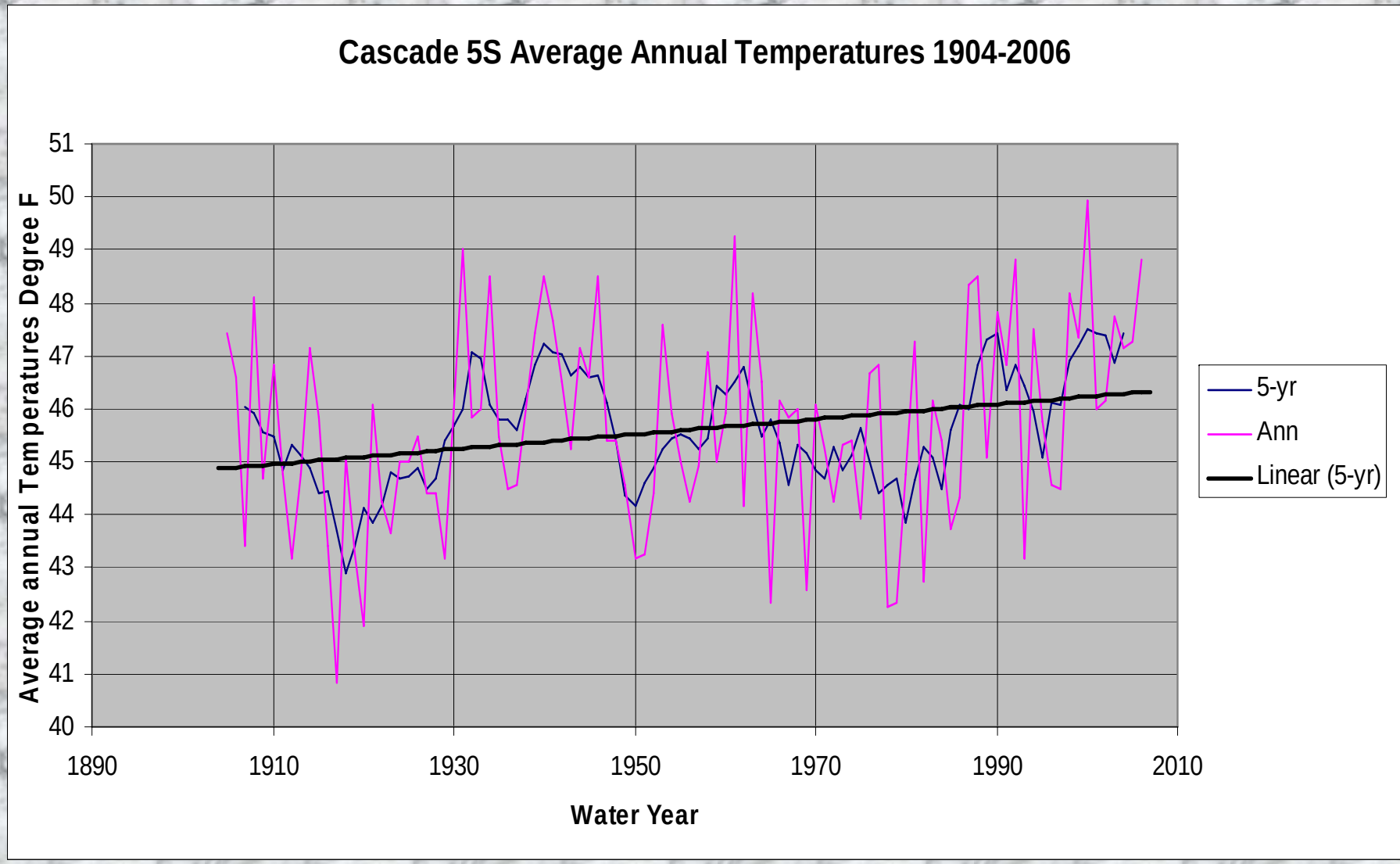
MAMMOTH (YELLOWSTONE PARK)



MAMMOTH (YELLOWSTONE PARK)

- MISSING 36 MONTHS 1948-2006
- FOUND 30 IN CHIEF RANGERS OFFICE
- NWS AVERAGE ANNUAL ESTIMATED TEMPERATURE 39.3 F
- DATA AVERAGE ANNUAL TEMPERATURE 40.5 F

CASCADE 5S

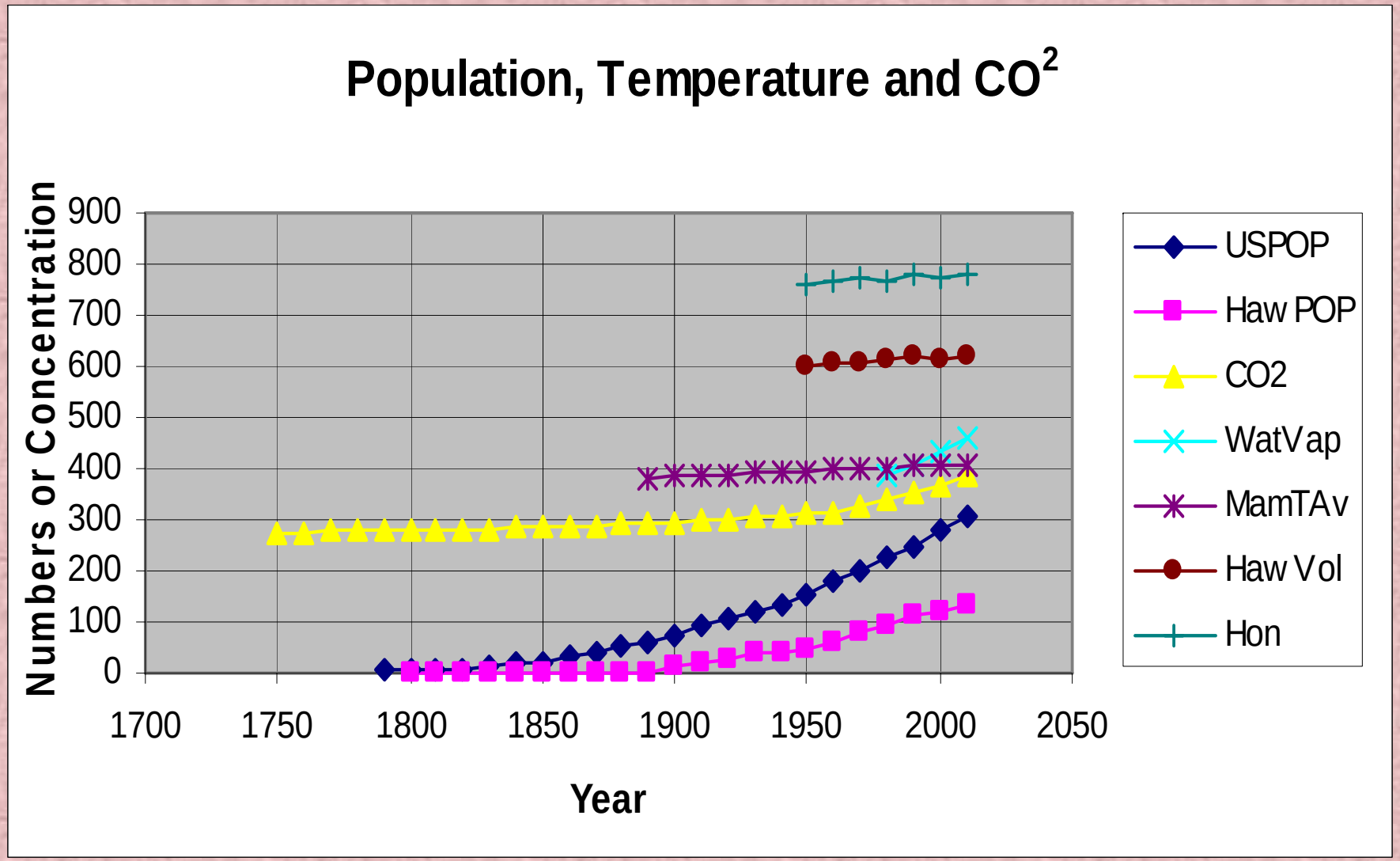

Cascade 5S Average Annual Temperatures 1904-2006
Average annual Temperatures Degree F
51
50
49
48
47
46
45
44
43
42
41
40
1890
1910
1930
1950
1970
1990
2010
Water Year
5-yr
Ann
Linear (5-yr)

Changes Over Past 100 Years

Increases in Degree F

• Augusta	3.4	Havre AP	5.4
• Big Timber	0.1	Libby RS	3.3
• Billings WP	3.5	Miles City AP	1.9
• Bozeman MSU	3.7	Norris MPH	2.3
• Cascade 5 S	1.4	Saint Ignatius	1.9
• Ekalaka	0.4	Savage	2.7
• Glendive	3.0	Valier	3.0
• Moran 5 WNW	3.8	YP Mammoth	2.2

TRENDS


Population, Temperature and CO2
Numbers or Concentration
900
800
700
600
500
400
300
200
100
0
1700
1750
1800
1850
1900
1950
2000
2050
Year
USPOP
Haw POP
CO2
WatVap
MamTAv
Haw Vol
Hon

Average Annual Temperature

- Temperatures Have Increased About 2.5 Degrees F Statewide Over Past 100 Years (NCDC 1.7)
- Annual Variability Has Decreased
- Rate Of Change Does Not Appear To Have Accelerated In Recent Years
- All Seasons Have Increased
- Maximum Temperatures Increased Less Than Minimum Temperatures
- Still Have Considerable Variability During The Year

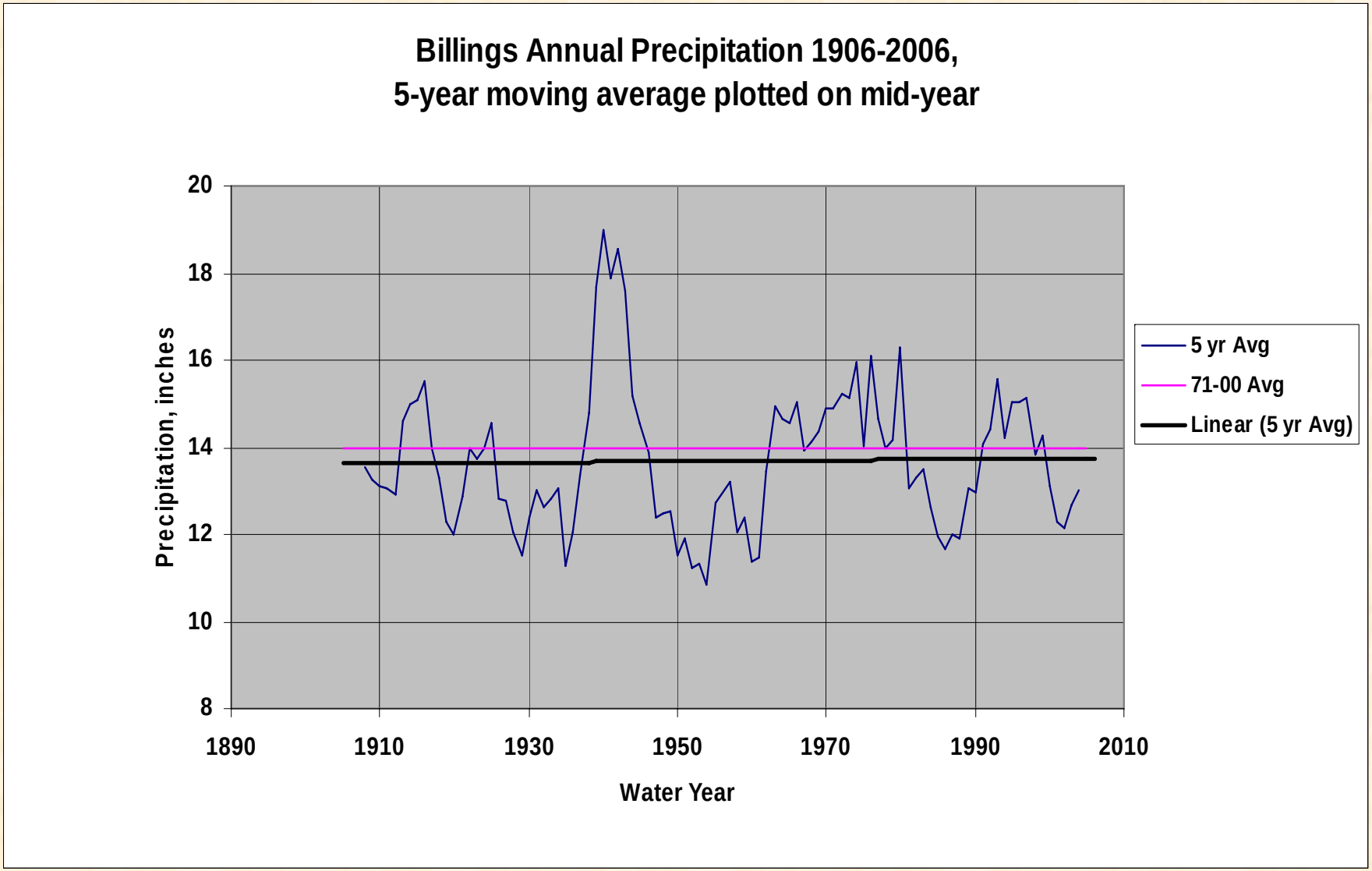
FYI

Difference in Average Annual Temperature Between City and Airport Degree F

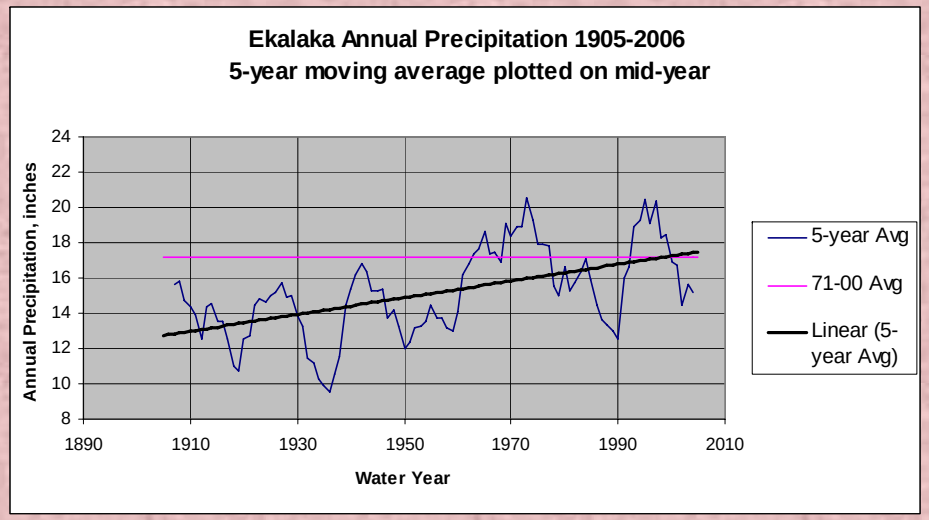
- Bozeman +2.5
- Billings +1.5
- Dillon +1.1
- Glasgow +2.0
- Havre +2.6
- Kalispell +2.2
- Livingston +1.6
- Miles City +1.0

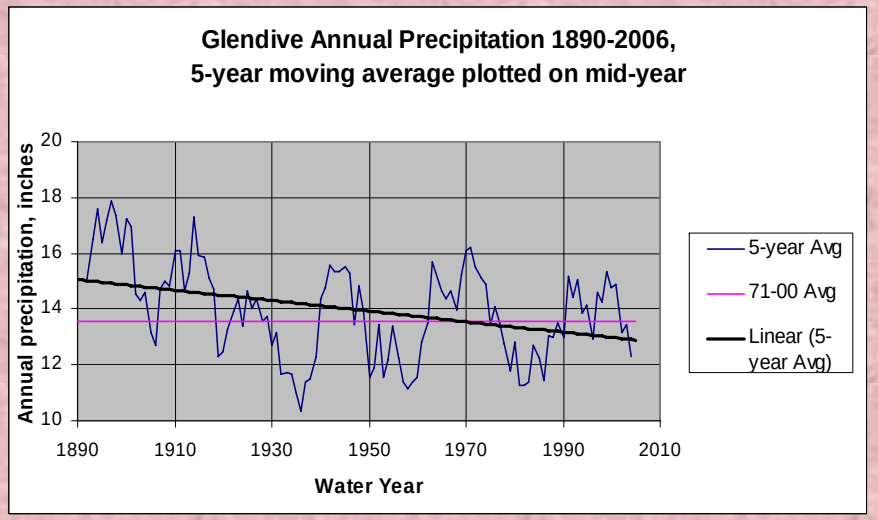
- Average +1.8

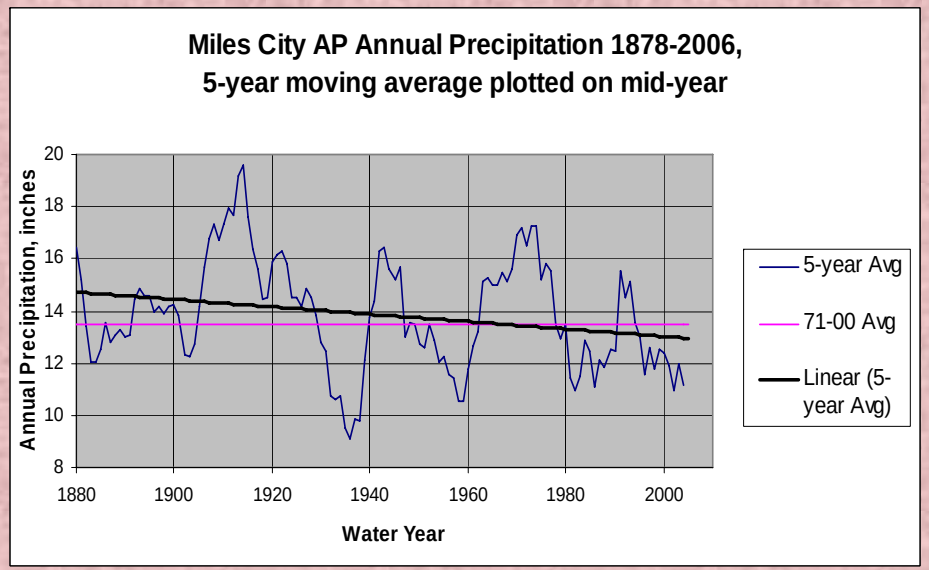
AVERAGE ANNUAL PRECIPITATION

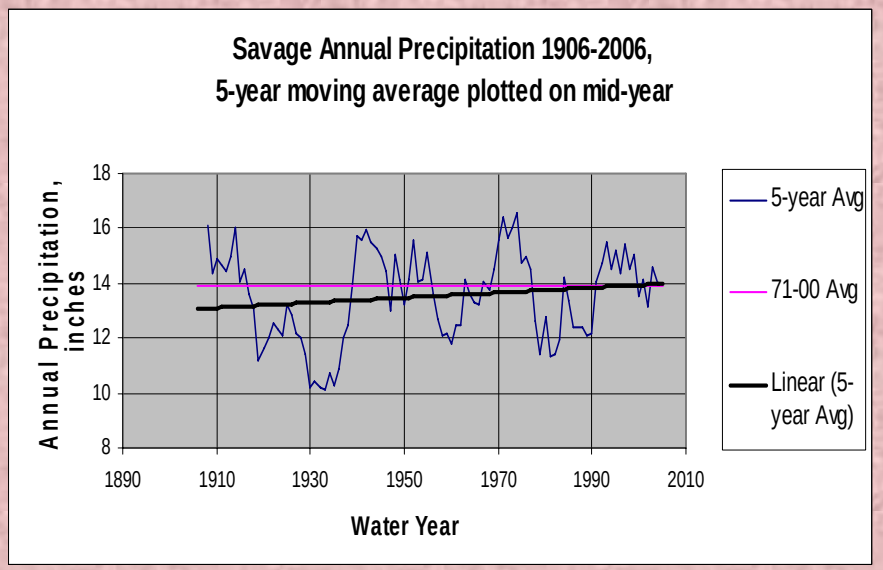


More Annual Precipitation

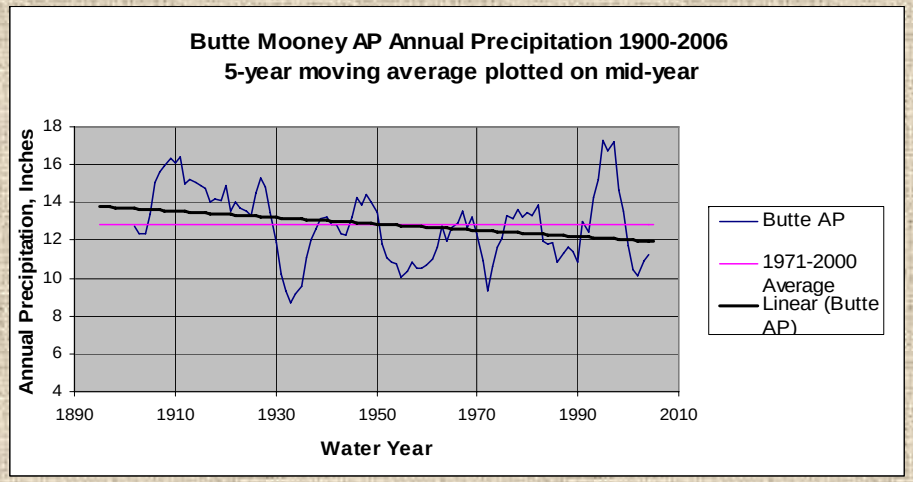


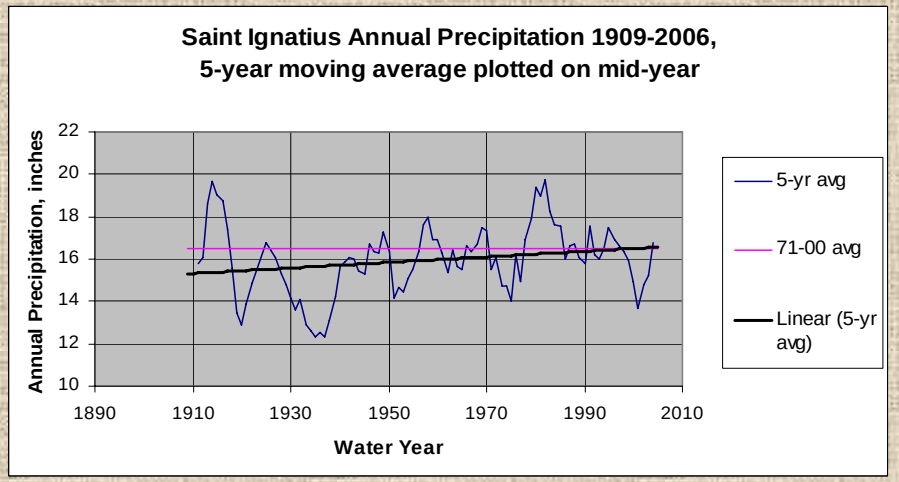


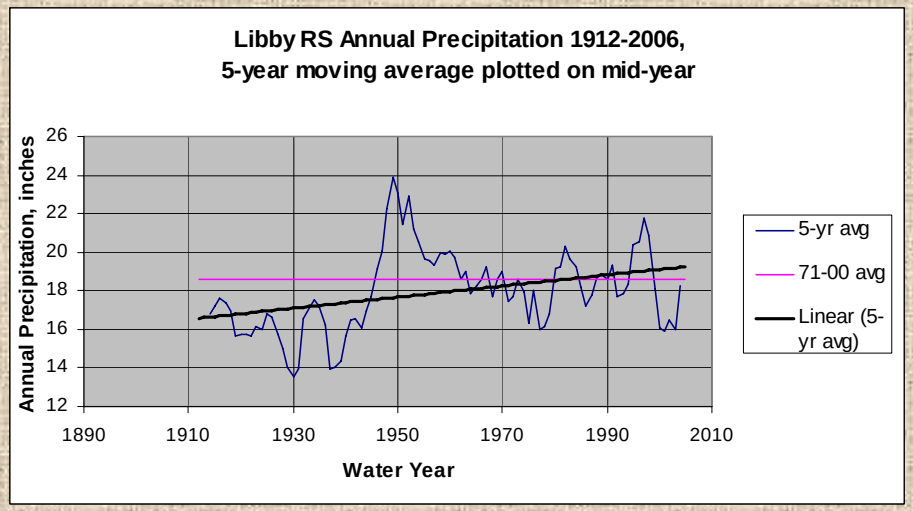


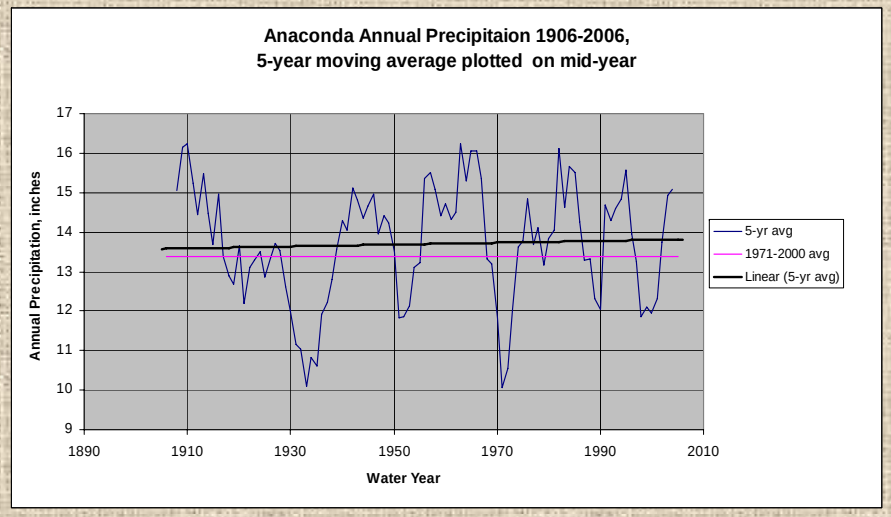


More Annual Precipitation







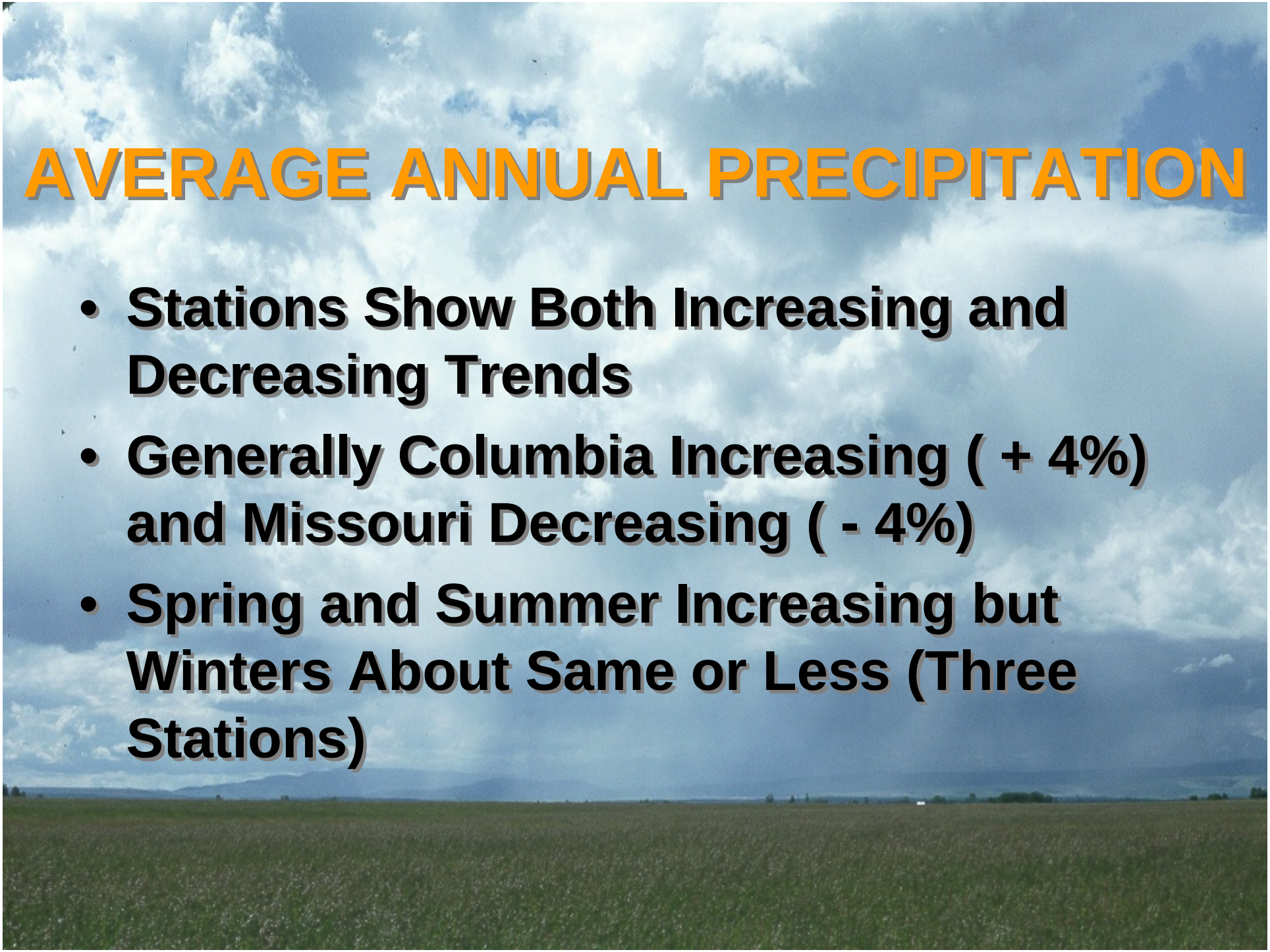


But - 1.6 Lib + 2.8 St I + 1.2 Anac + 0.3

Changes Over Past 100 Years

Percent Change in Annual Precipitation

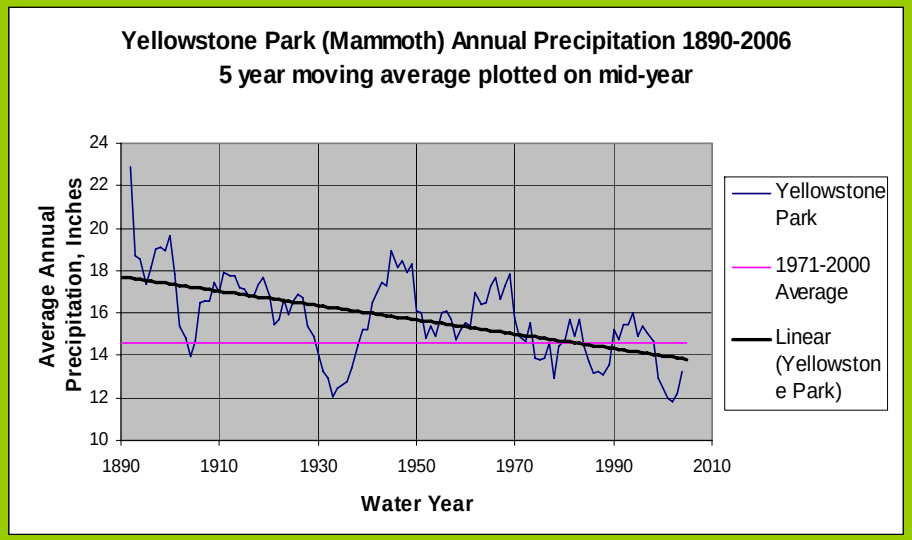
Augusta	– 10	Libby RS	+ 15
Big Timber	+ 7	Miles City AP	- 11
Billings WP	+ 1	Norris MPH	- 1
Bozeman MSU	+ 11	Saint Ignatius	+ 7
Cascade 5 S	- 2	Savage	+ 6
Ekalaka	+ 28	Virginia City	+ 27
Fort Assinniboine	+ 10	Valier	- 5
Glendive	- 13	Moran	+ 10
Havre	- 6	YP Mammoth	- 23
Holter Dam	- 18		

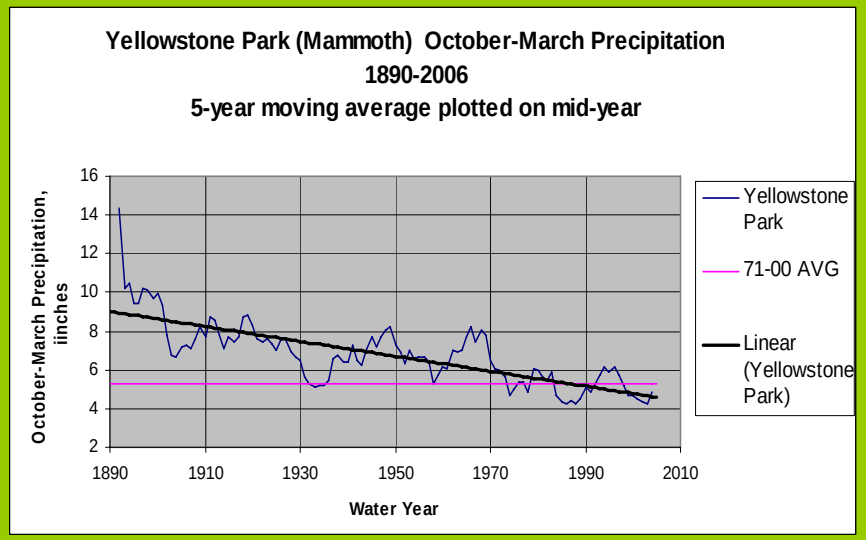


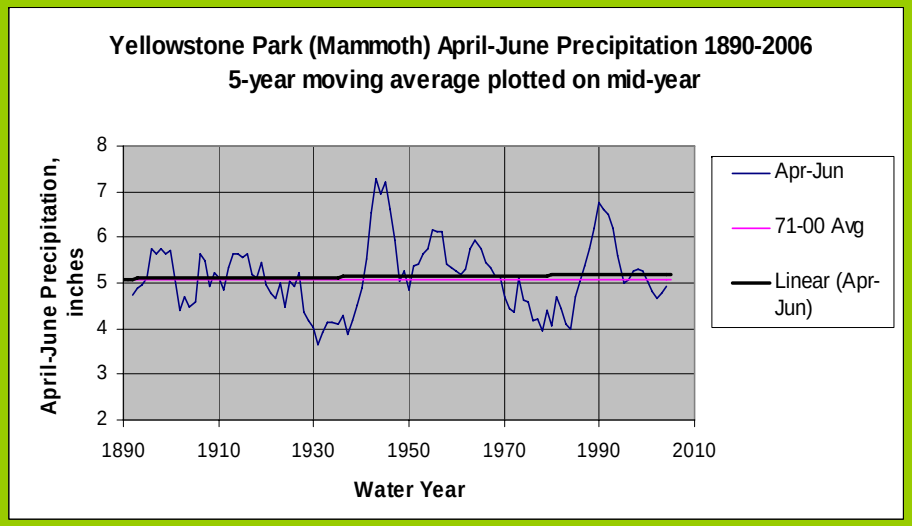
AVERAGE ANNUAL PRECIPITATION

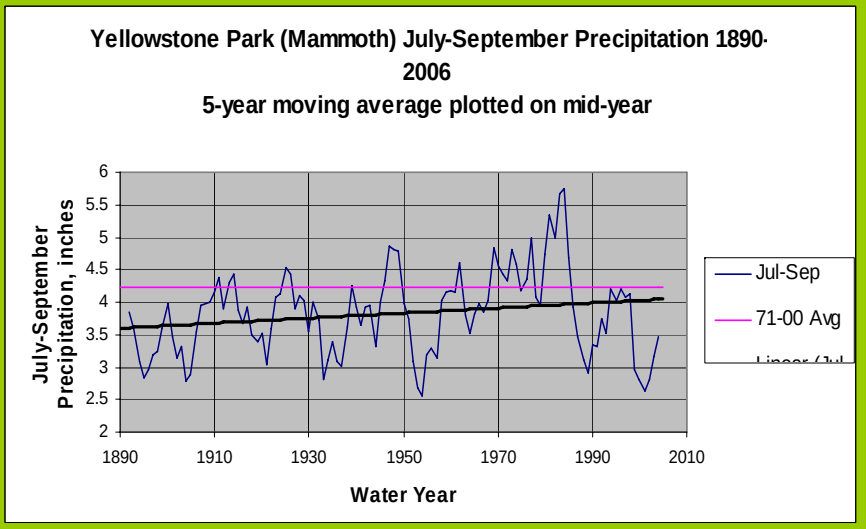
- Stations Show Both Increasing and Decreasing Trends
- Generally Columbia Increasing (+ 4%) and Missouri Decreasing (- 4%)
- Spring and Summer Increasing but Winters About Same or Less (Three Stations)

SEASONAL PRECIPITATION

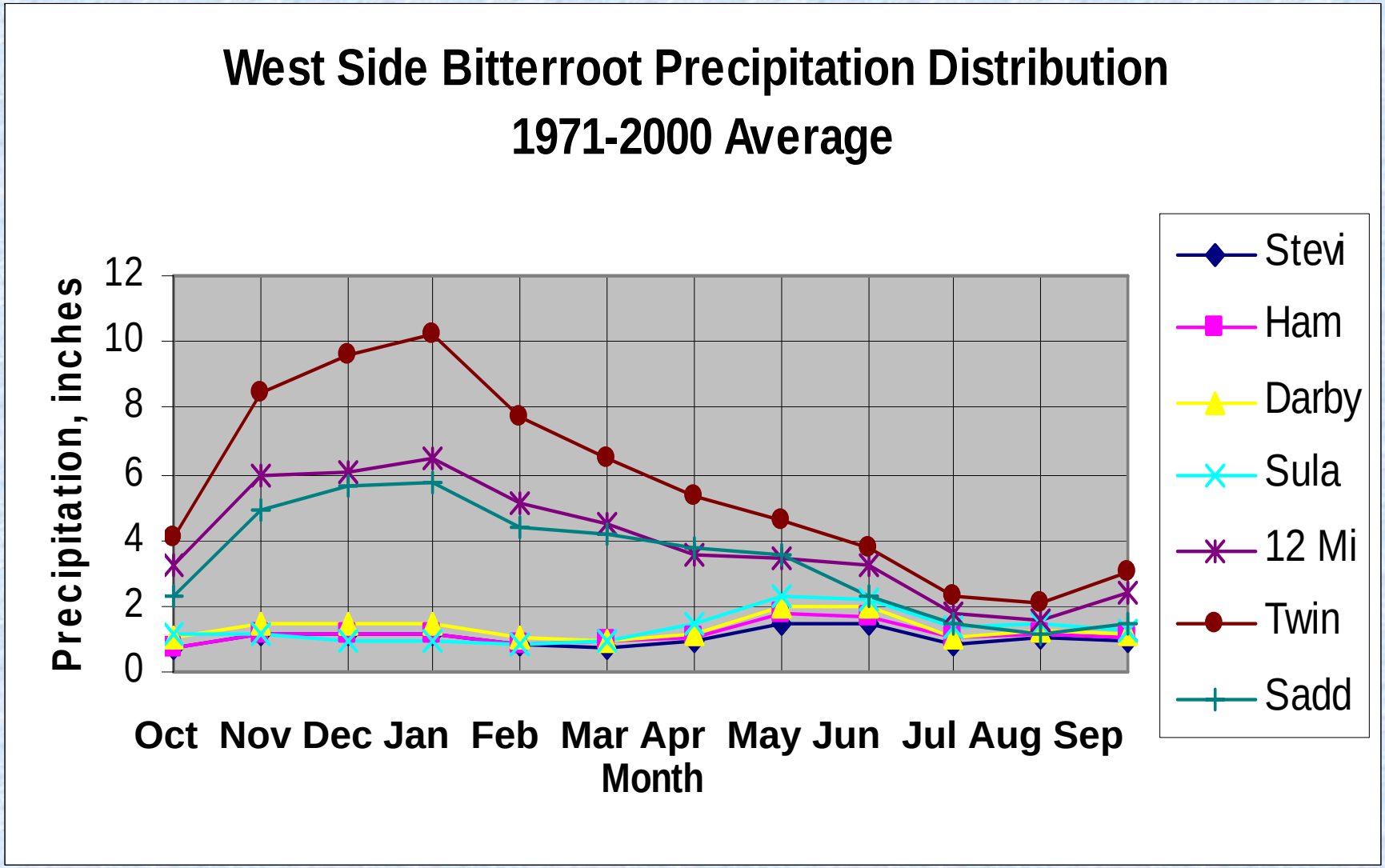




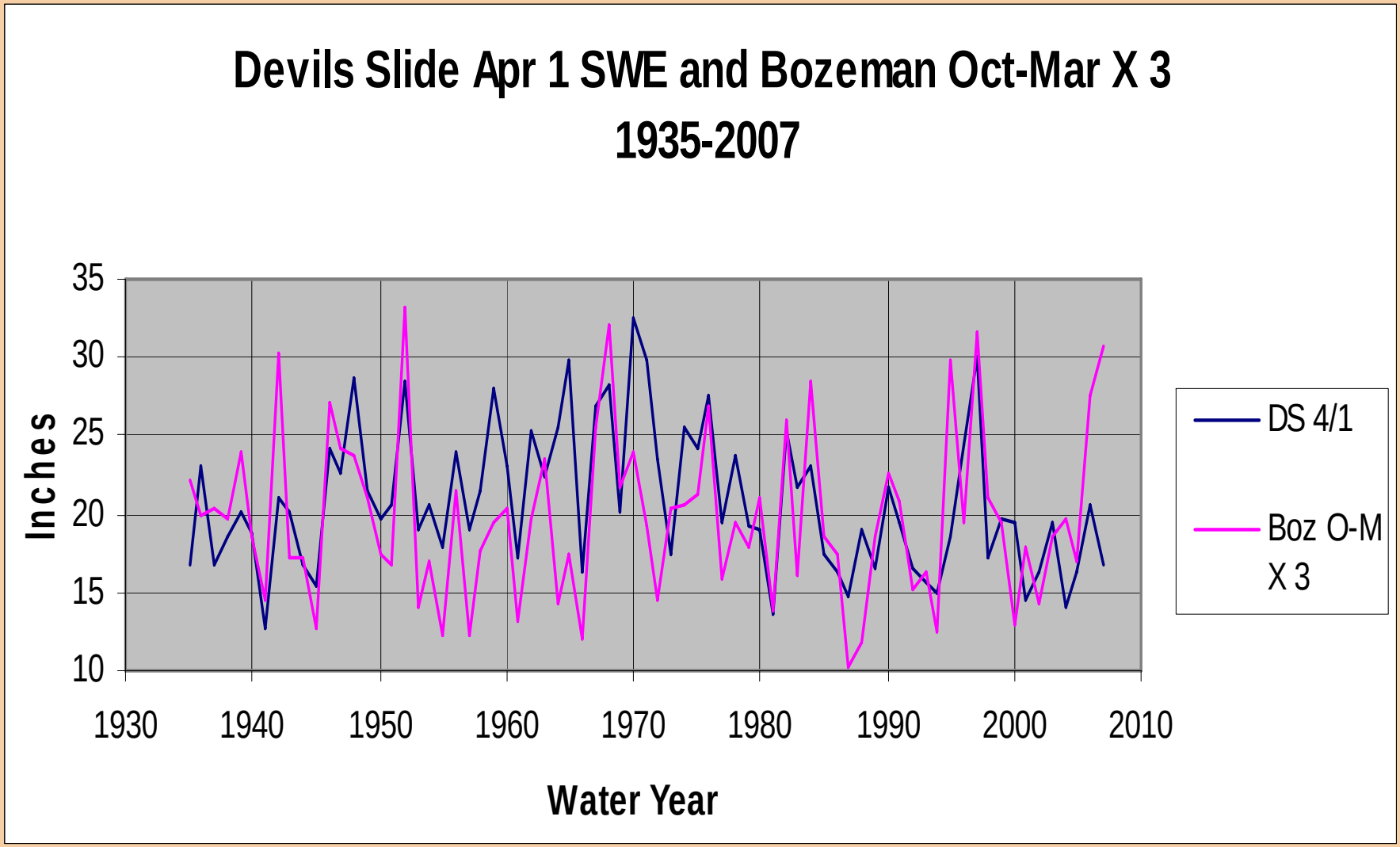




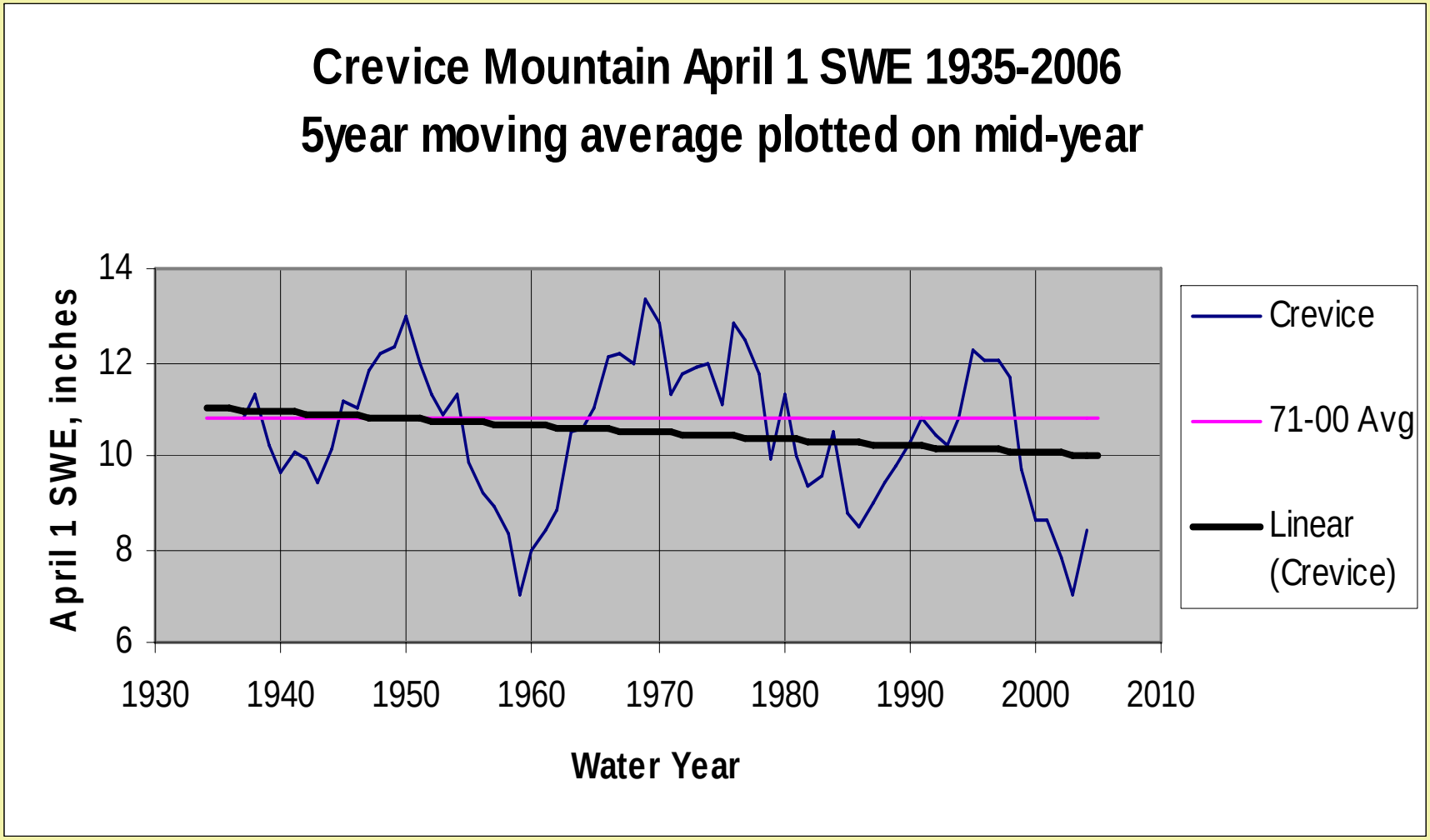
PRECIPITATION DISTRIBUTION



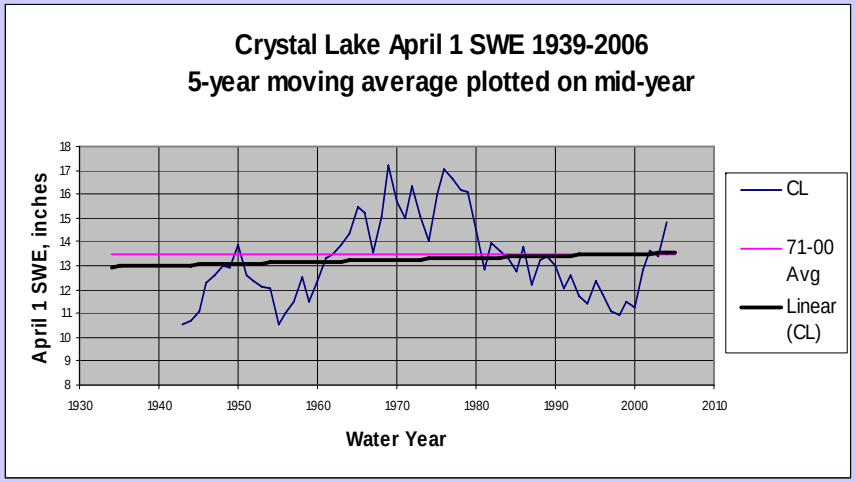
MOUNTAIN vs VALLEY

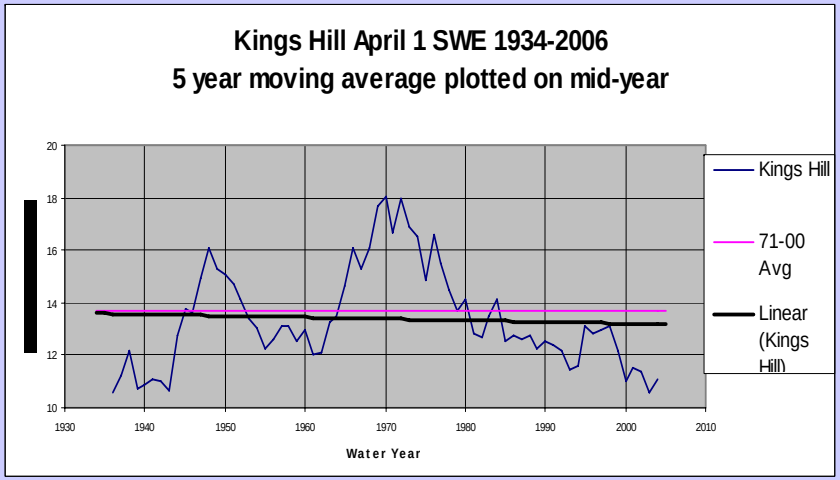


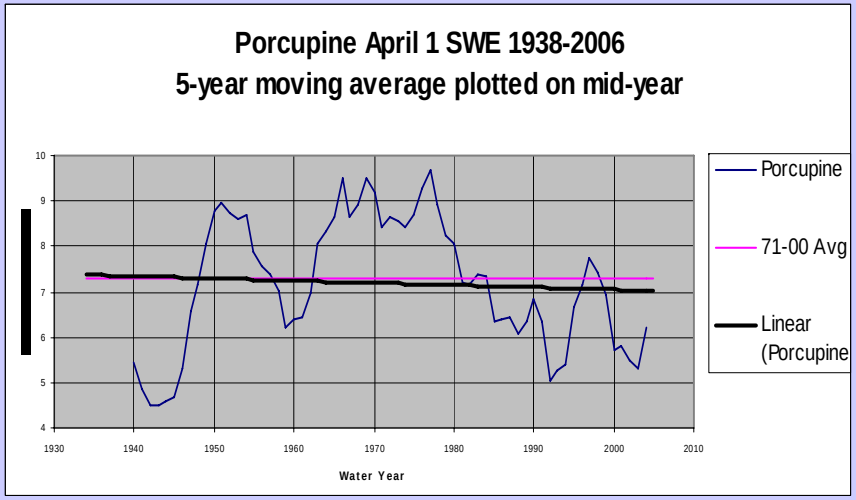
Snow Water Equivalent

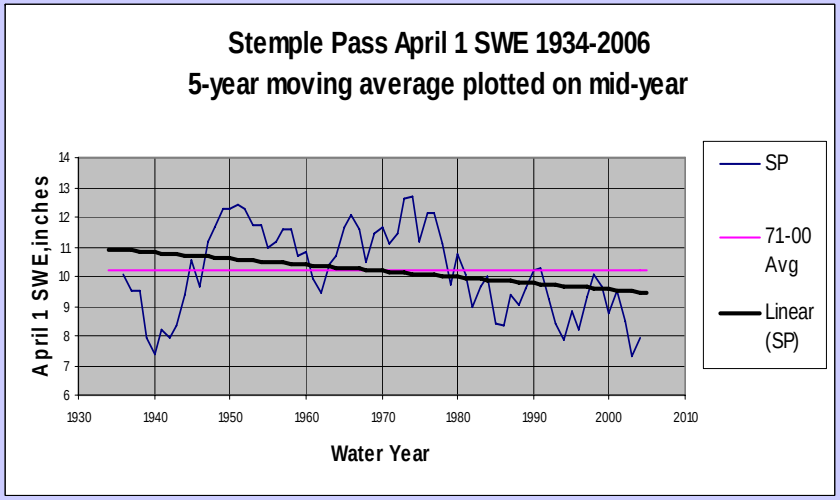


More SWE







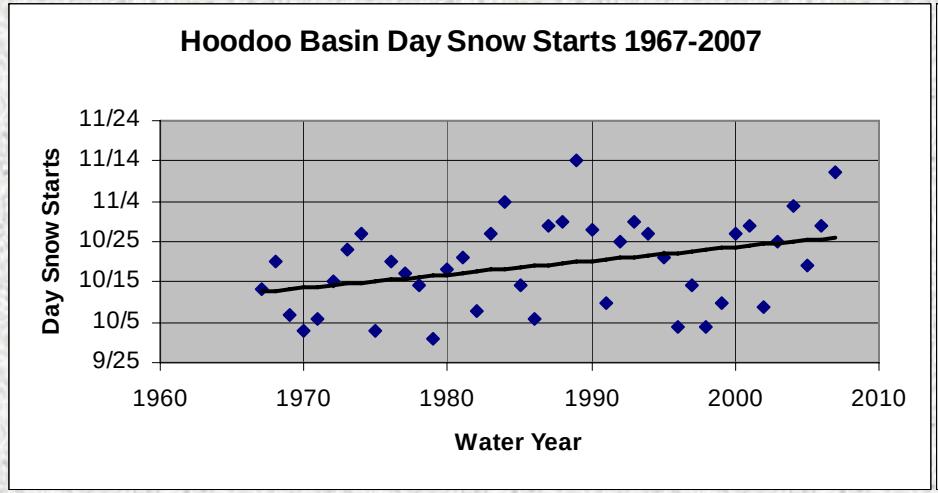


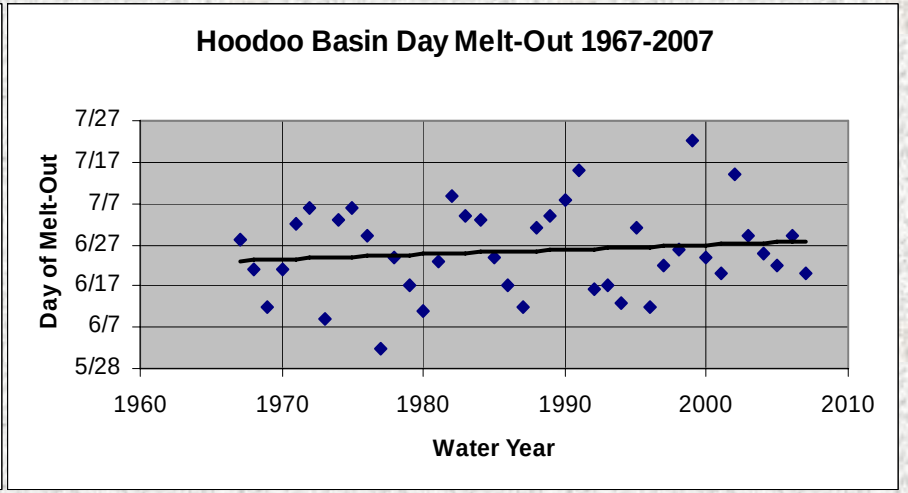
CL + 4% PP - 2% KH - 1% SP - 15%

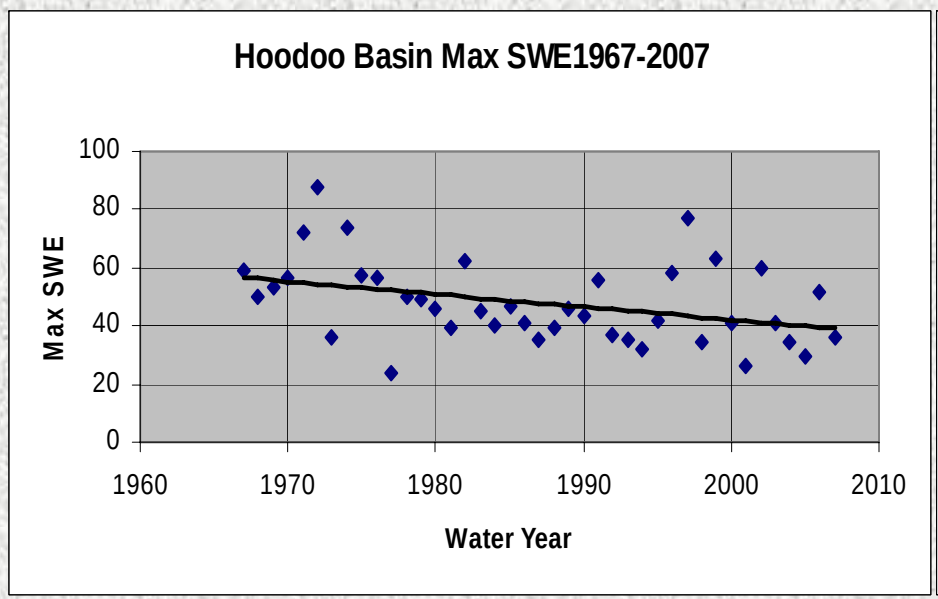
Changes Over Past 70 Years

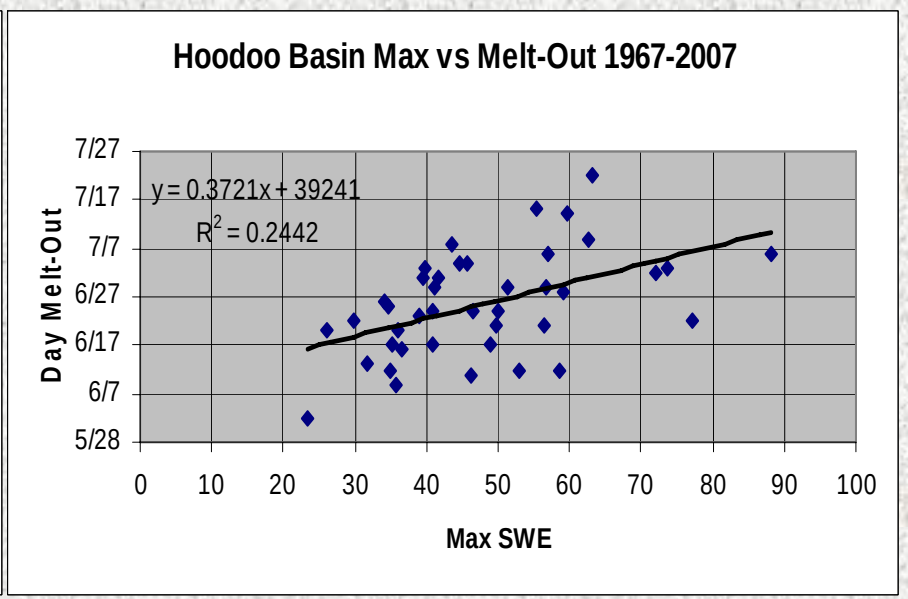
- **Most Snow Courses Have Been Replaced With SNOTEL (manual measurements discontinued)**
- **Limited Number Are Still Manual Stations**
- **Most Snow Courses Show Decreasing Trends**
- **Some Show Small Increases**
- **Some Show Large Decreases**
- **Effects of Canopy Growth**
- **Statewide – 19%**
  Columbia -25% Missouri -16% Hudson Bay -2%

HOODOO BASIN

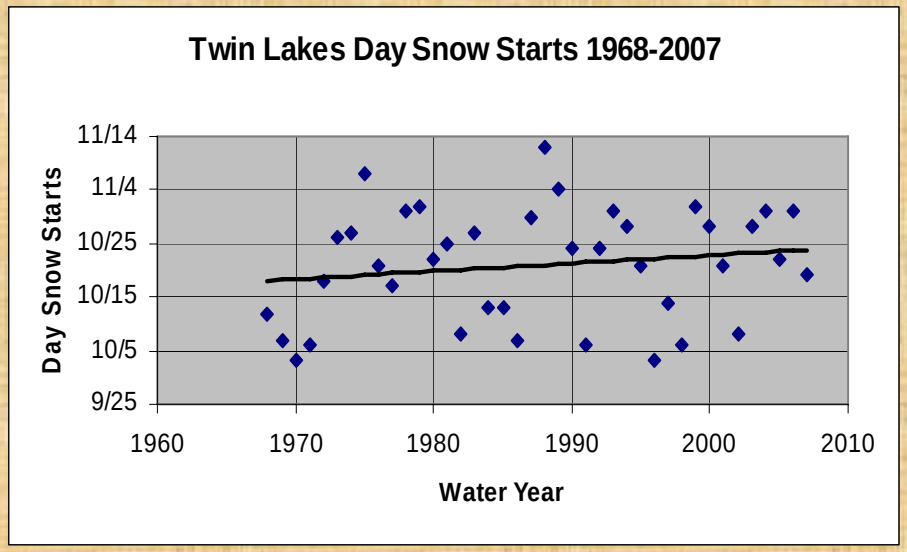


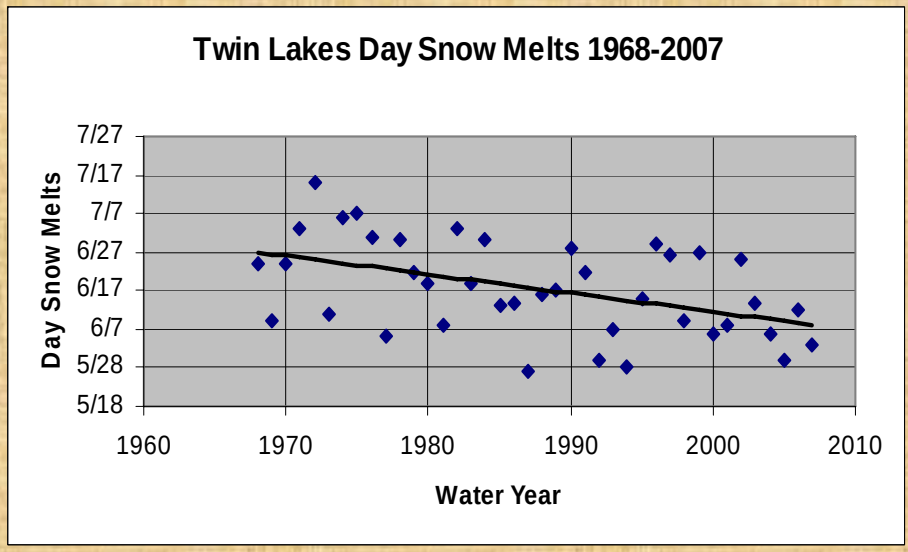


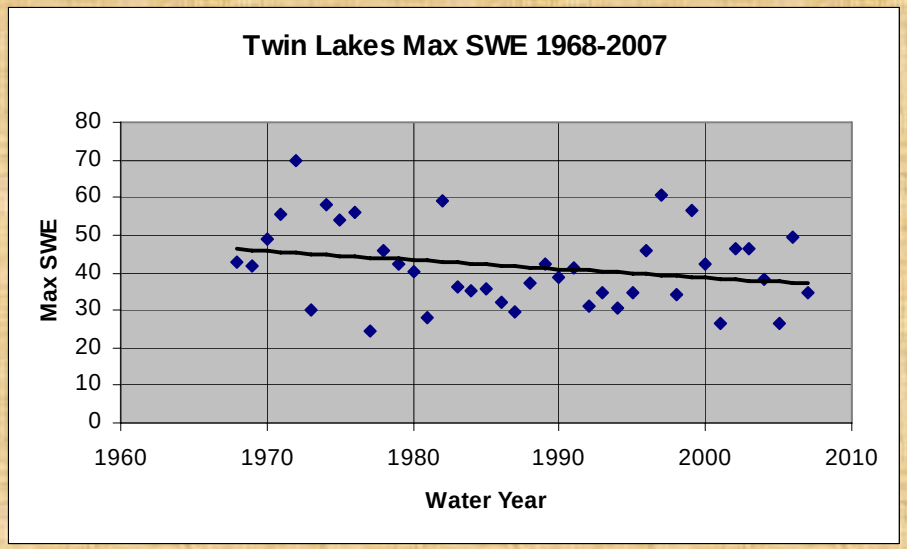


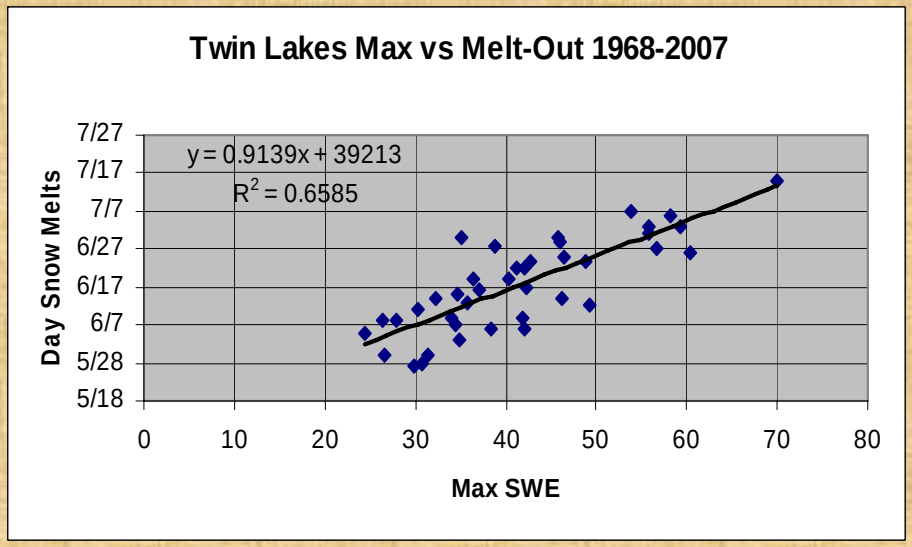


TWIN LAKES


Twin Lakes Day Snow Starts 1968-2007
Day Snow Starts
11/14
11/4
10/25
10/15
10/5
9/25
1960
1970
1980
1990
2000
2010
Water Year


Twin Lakes Day Snow Melts 1968-2007
Day Snow Melts
7/27
7/17
7/7
6/27
6/17
6/7
5/28
5/18
1960
1970
1980
1990
2000
2010
Water Year

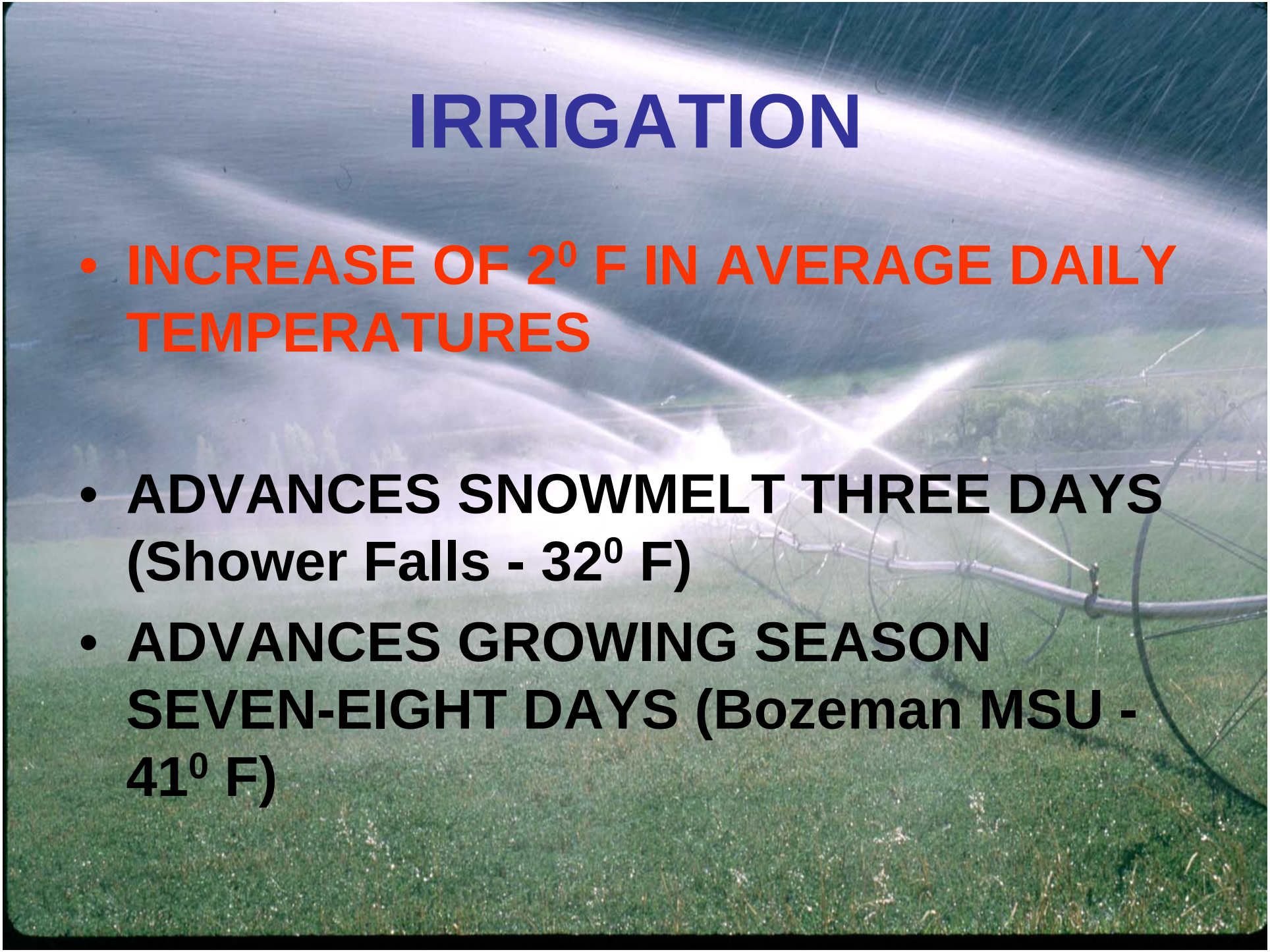

Twin Lakes Max SWE 1968-2007
Max SWE
80
70
60
50
40
30
20
10
0
1960
1970
1980
1990
2000
2010
Water Year


Twin Lakes Max vs Melt-Out 1968-2007
y = 0.9139x + 39213
R2 = 0.6585
Day Snow Melts
7/27
7/17
7/7
6/27
6/17
6/7
5/28
5/18
0
10
20
30
40
50
60
70
80
Max SWE

MOUNTAIN SNOWPACK

- OVER PAST 40 YEARS AT 5 SNOTEL SITES-

- **Accumulation Starting Later (About 10 days)**
- **Maximum SWE Trending Less (25%)**
- **Melt-Out Coming Earlier (9 days)**
- **Melt-Out related to Max SWE**
- **Start of Accumulation and Melt-Out Vary by Six Weeks**
- **Older Sites Started During Wet Periods**

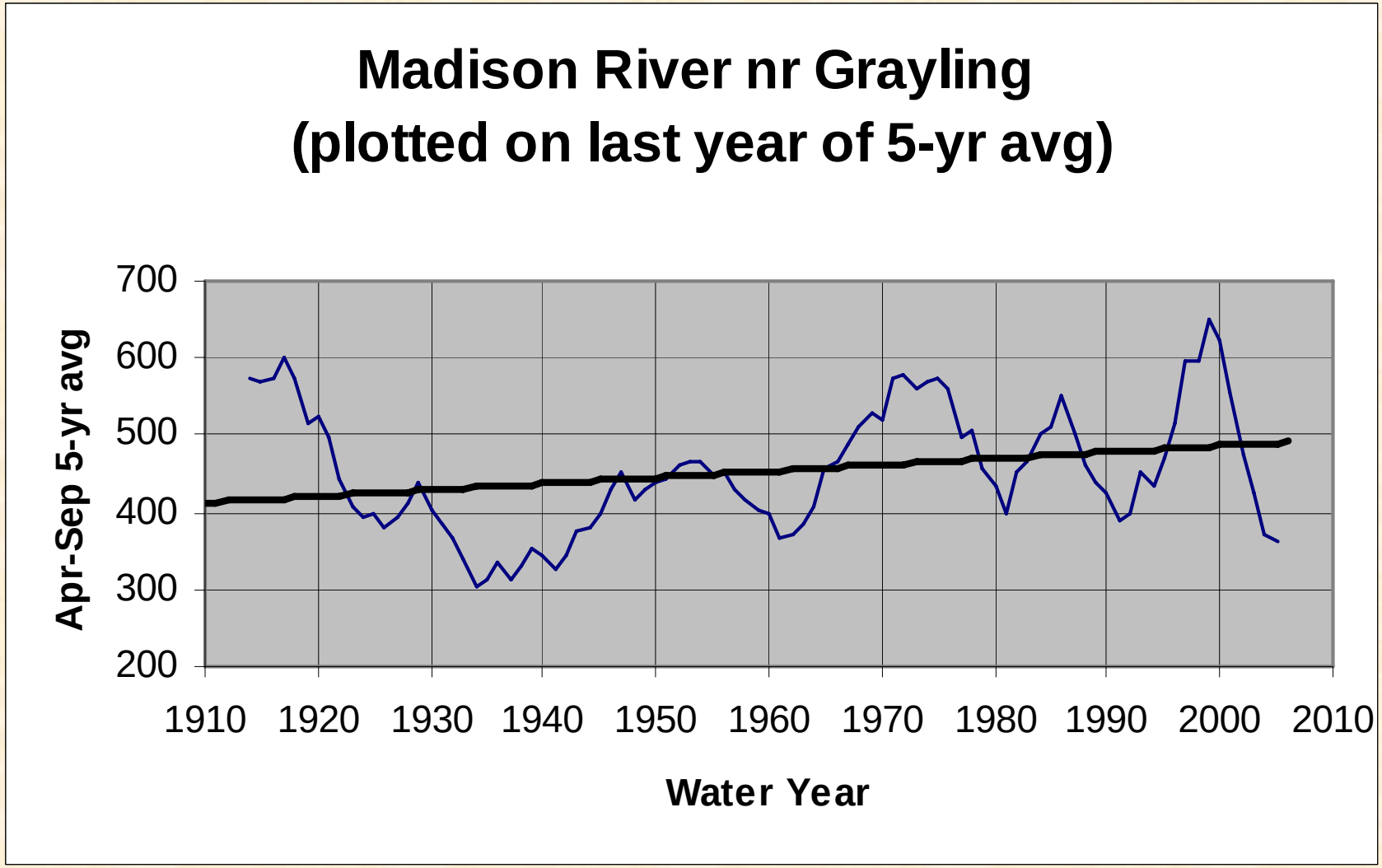


IRRIGATION

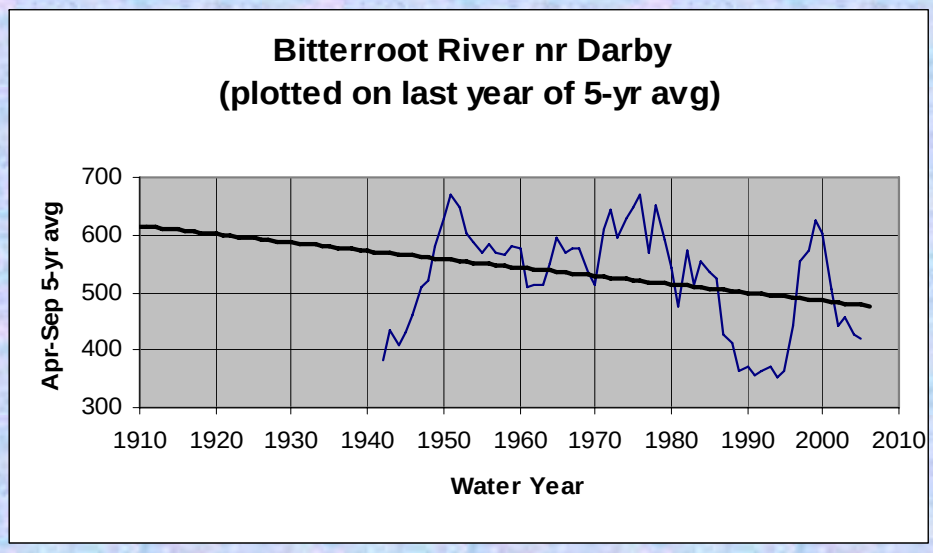
- **INCREASE OF 2^0 F IN AVERAGE DAILY TEMPERATURES**

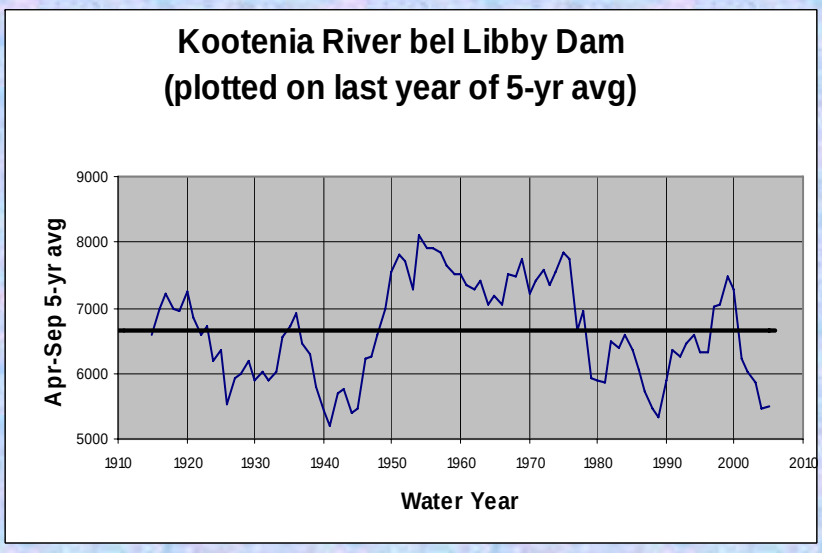
- **ADVANCES SNOWMELT THREE DAYS (Shower Falls - 32^0 F)**
- **ADVANCES GROWING SEASON SEVEN-EIGHT DAYS (Bozeman MSU - 41^0 F)**

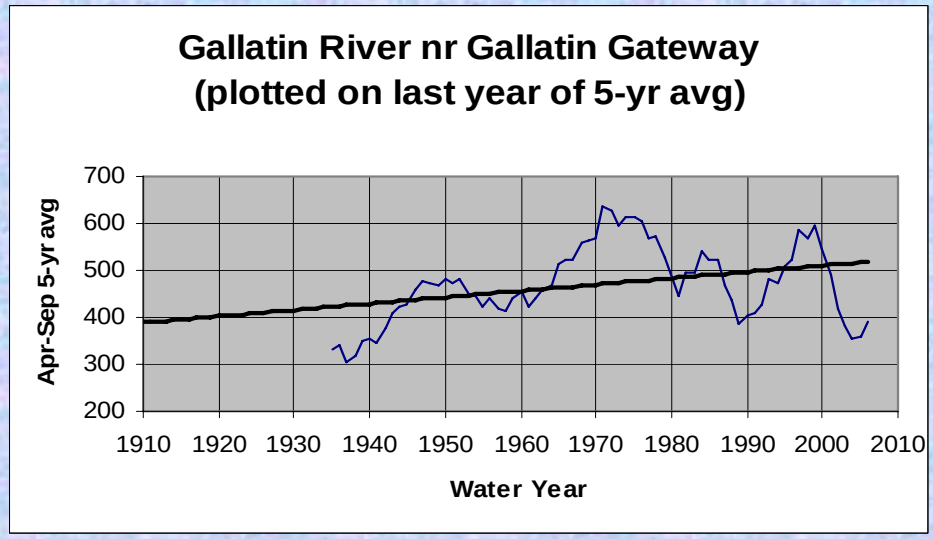
HISTORIC RUNOFF

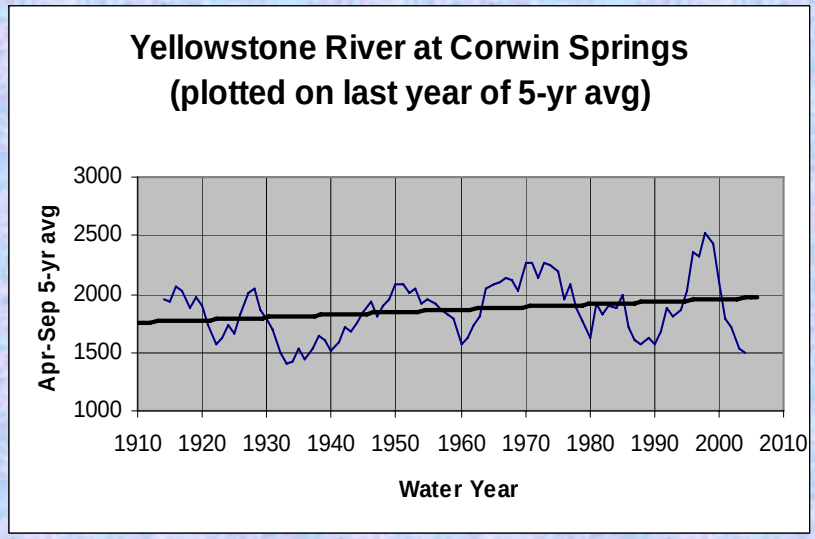


RUNOFF

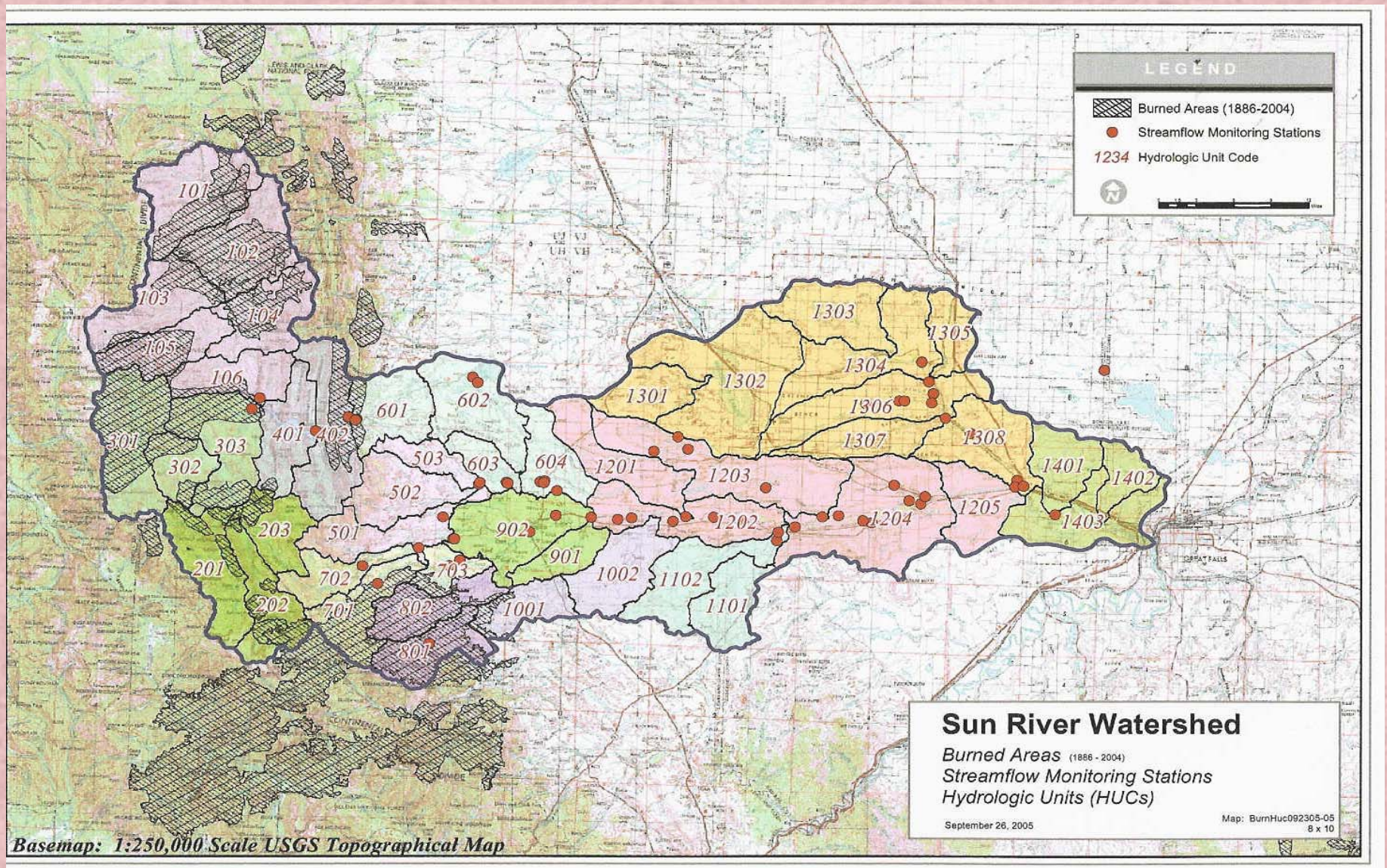

Bitterroot River nr Darby
(plotted on last year of 5-yr avg)
Apr-Sep 5-yr avg
700
600
500
400
300
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
Water Year


Kootenia River bel Libby Dam
(plotted on last year of 5-yr avg)
Apr-Sep 5-yr avg
9000
8000
7000
6000
5000
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
Water Year

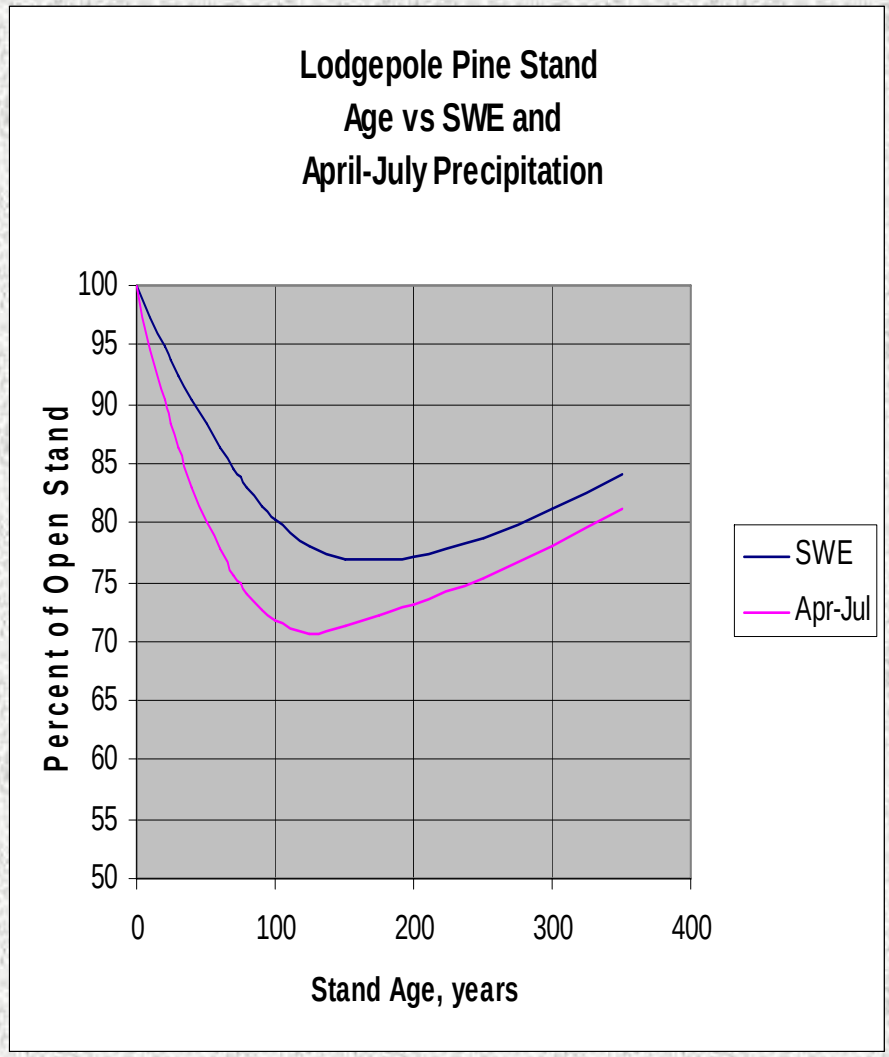

Gallatin River nr Gallatin Gateway
(plotted on last year of 5-yr avg)
Apr-Sep 5-yr avg
700
600
500
400
300
200
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
Water Year

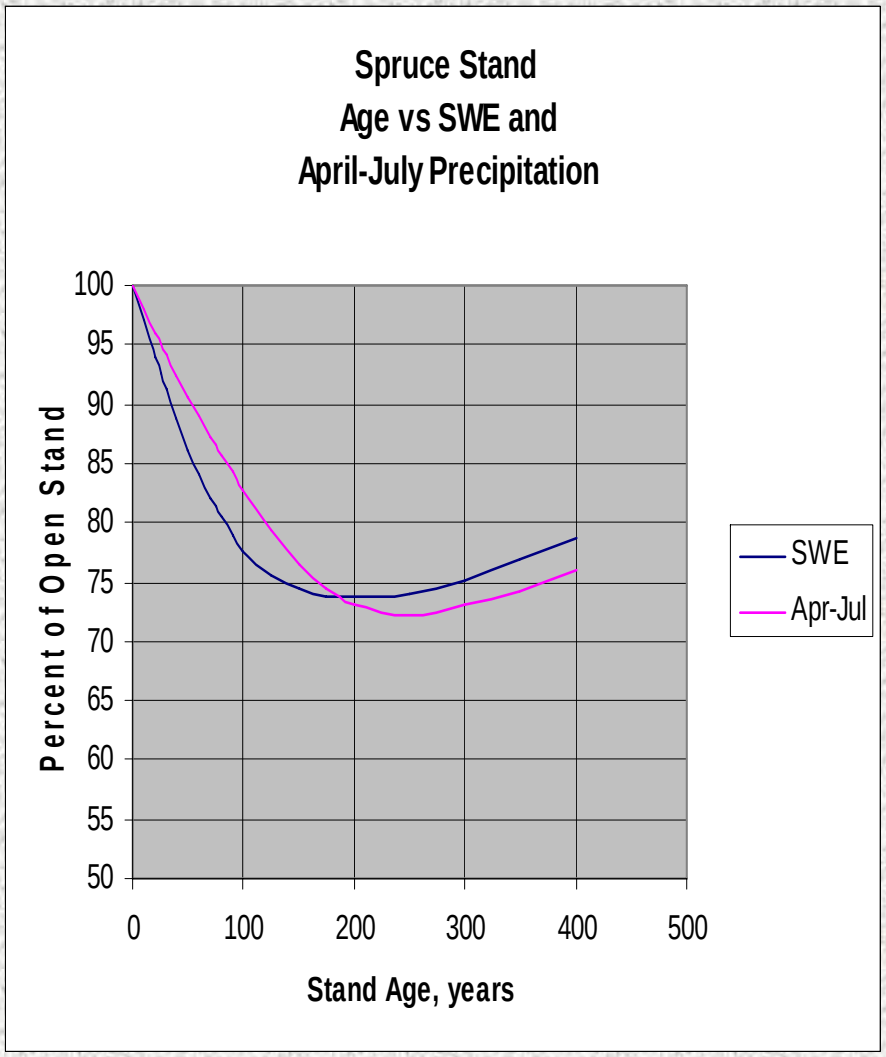

Yellowstone River at Corwin Springs
(plotted on last year of 5-yr avg)
Apr-Sep 5-yr avg
3000
2500
2000
1500
1000
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
Water Year

FIRE HISTORY MAPS

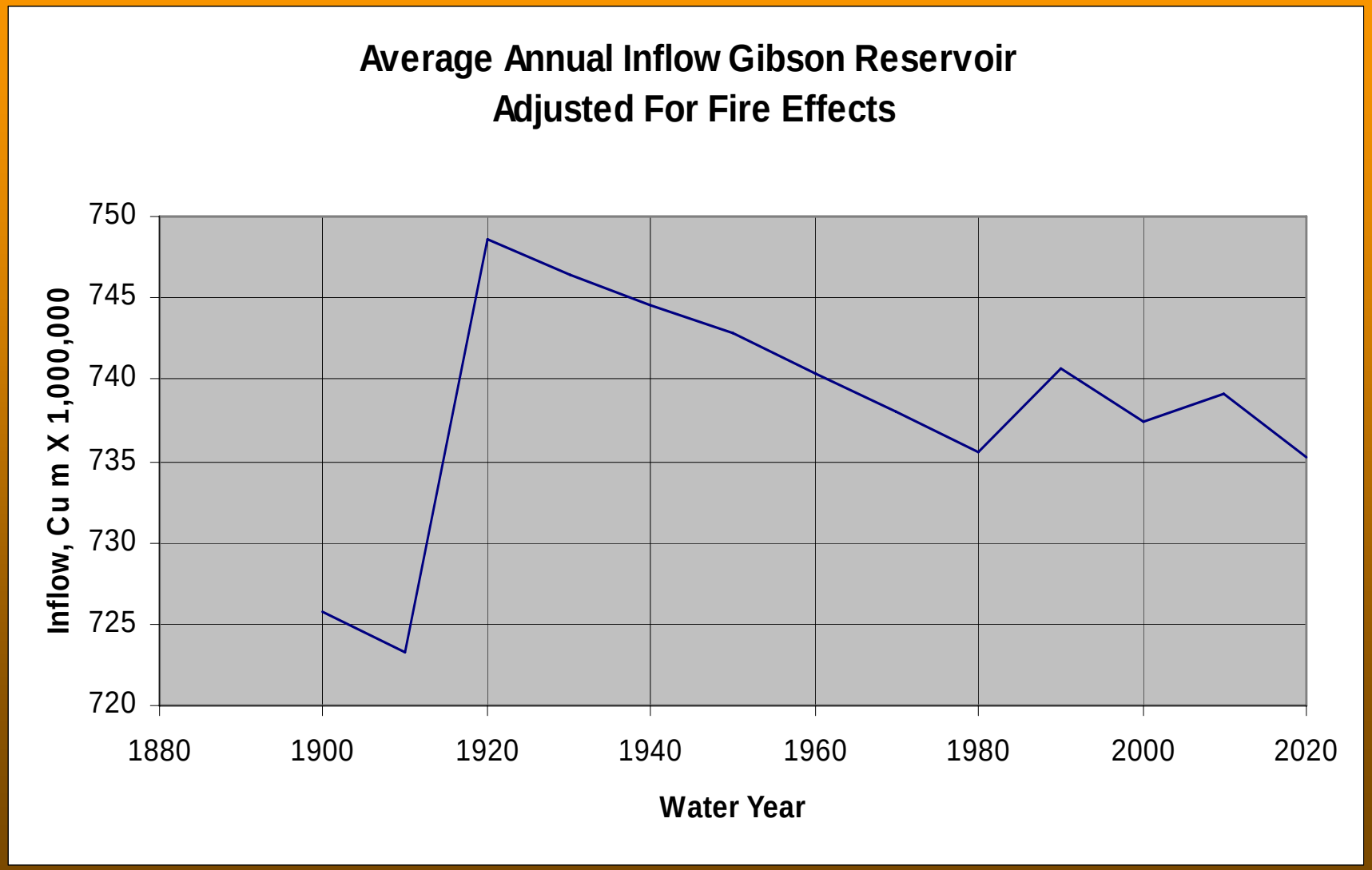


COVER TYPES

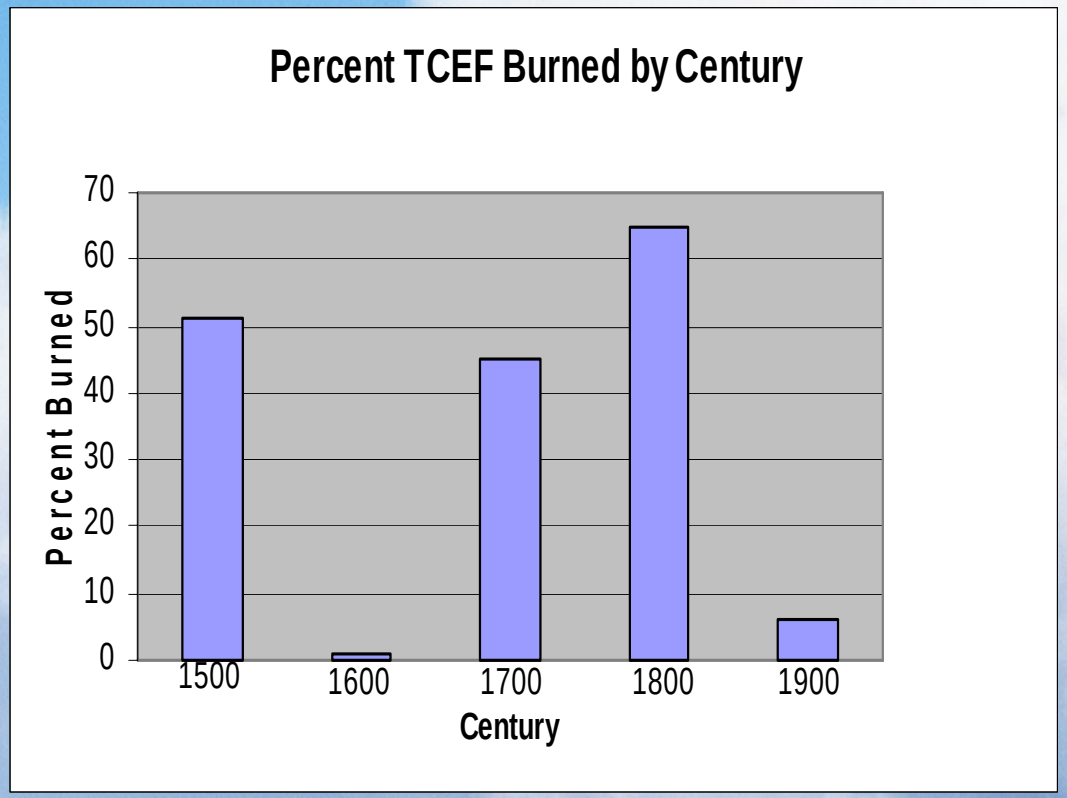

Lodgepole Pine Stand
Age vs SWE and
April-July Precipitation
Percent of Open Stand
100
95
90
85
80
75
70
65
60
55
50
0
100
200
300
400
Stand Age, years
SWE
Apr-Jul


Spruce Stand
Age vs SWE and
April-July Precipitation
Percent of Open Stand
100
95
90
85
80
75
70
65
60
55
50
0
100
200
300
400
500
Stand Age, years
SWE
Apr-Jul

RUNOFF TRENDS



FIRE TCEF



TENDERFOOT CREEK EXPERIMENTAL FOREST

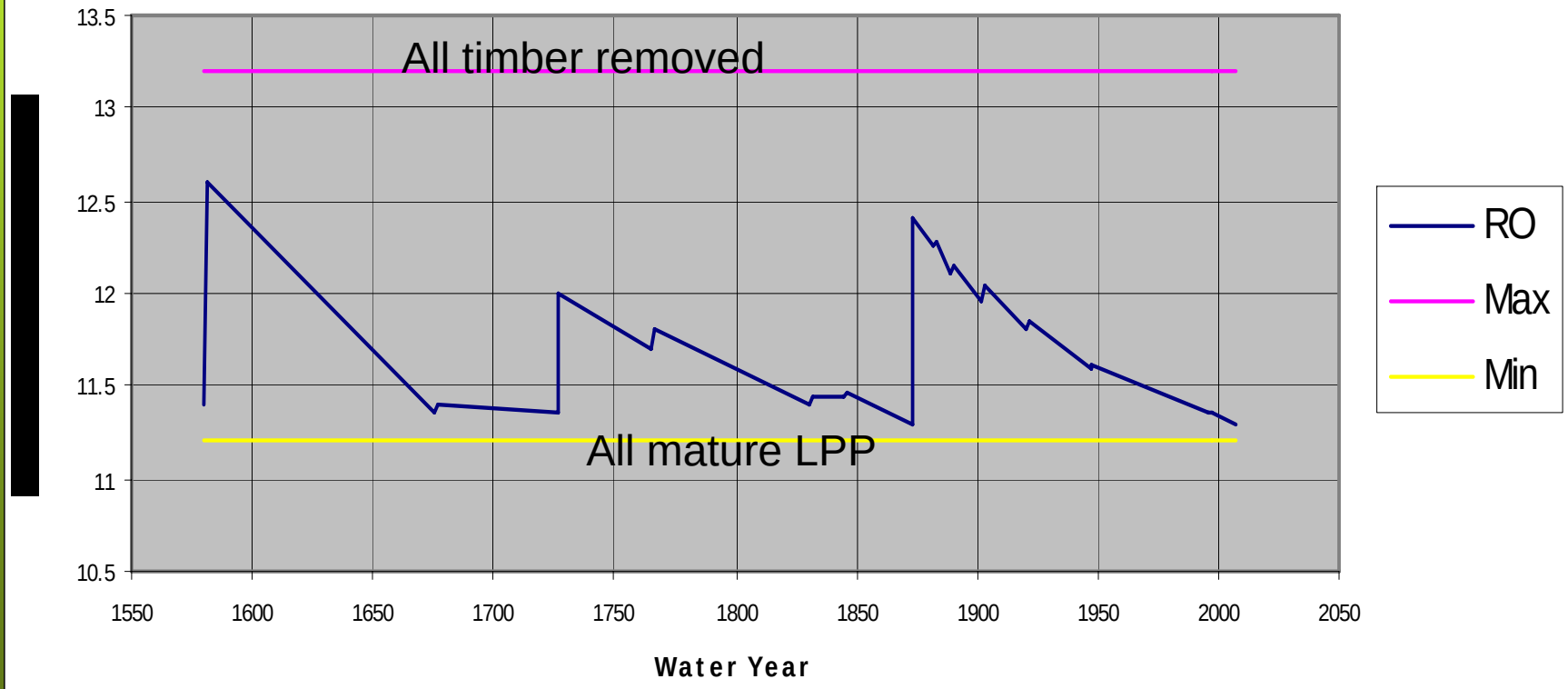
Central Montana

PERIOD	PERCENT BURNED
1500's	51
1600's	1
1700's	45
1800's	65
1900's	6
Avg/100 yr	34

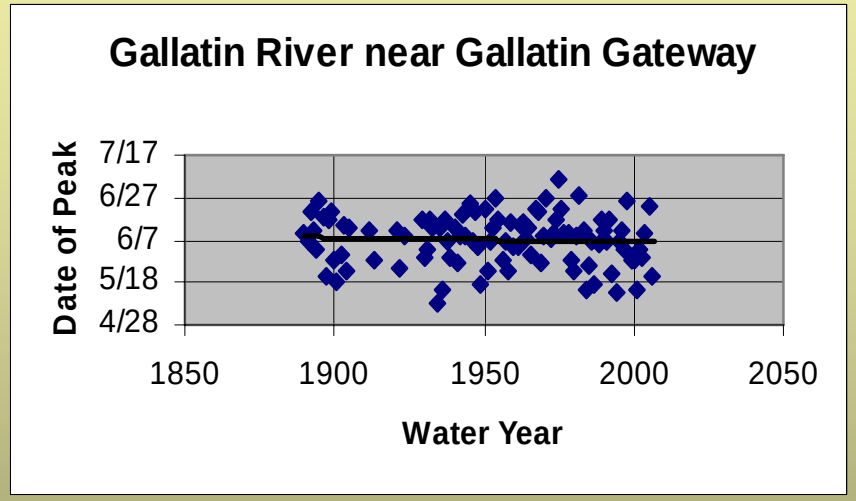
49% LPP are two-aged stands

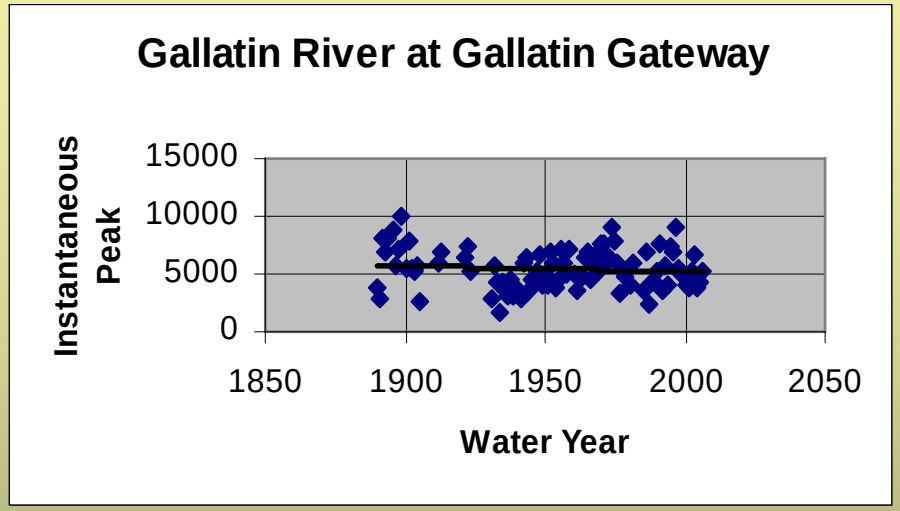
TCEF FIRE RUNOFF

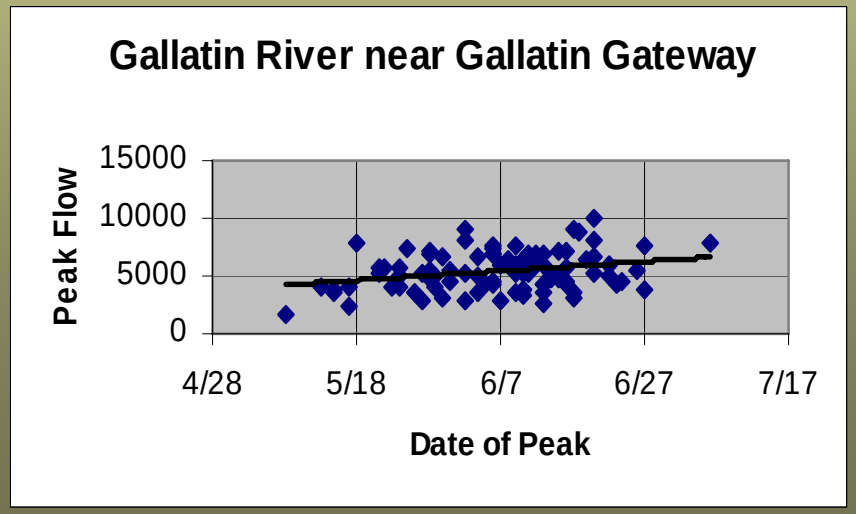
Estimated Average Annual Runoff TCEF
Based on Burn Area and CT 1590-2007



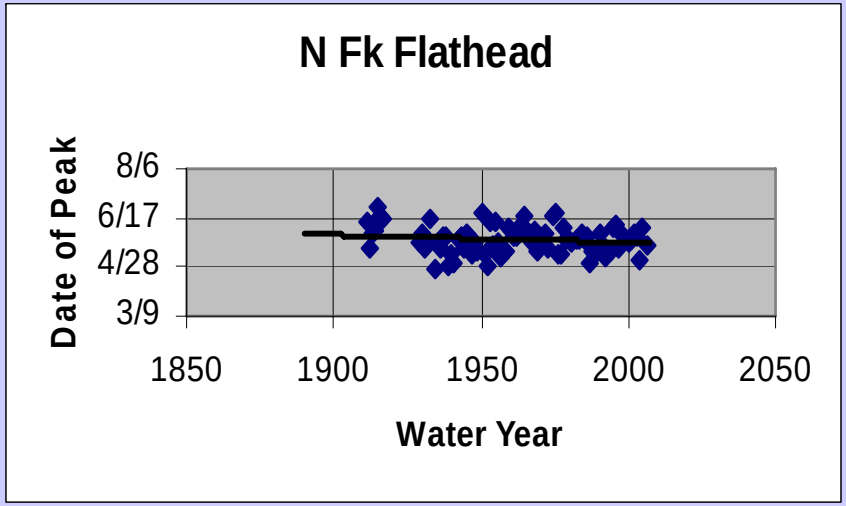
GALLATIN PEAK FLOW

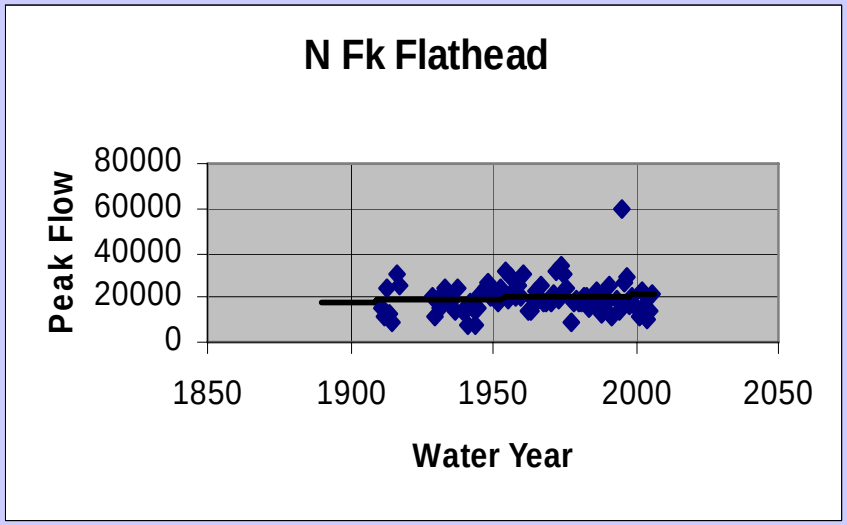


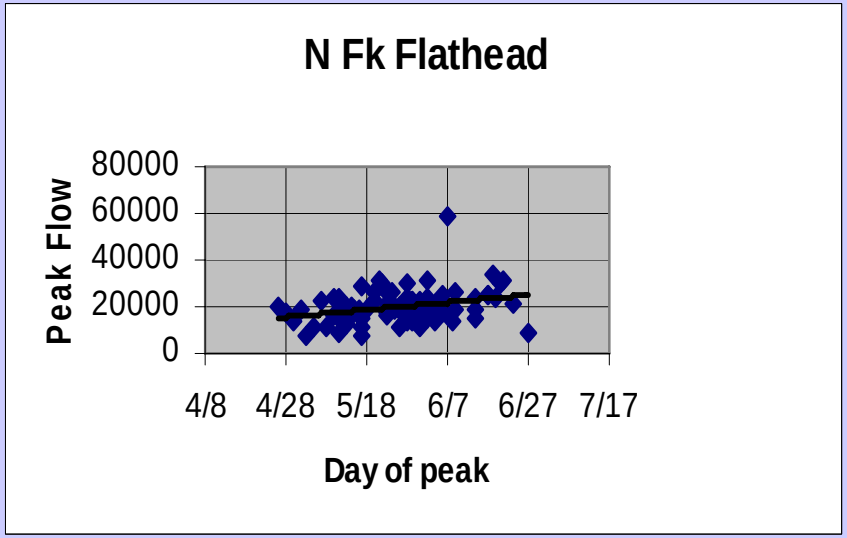




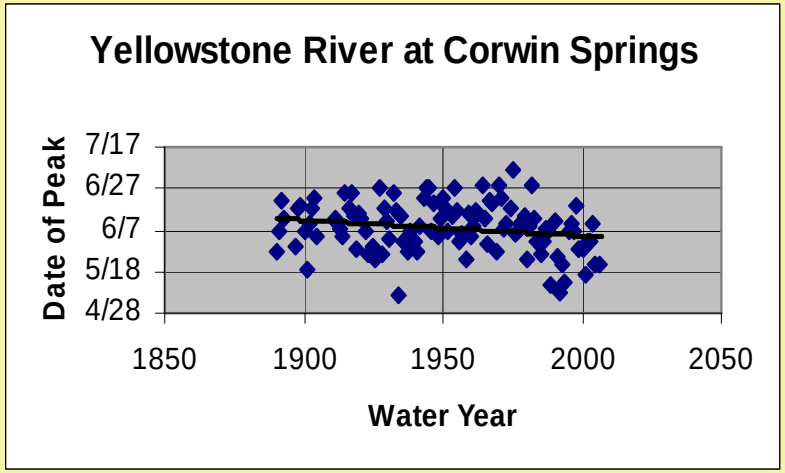
N FK FLATHEAD PEAK FLOW

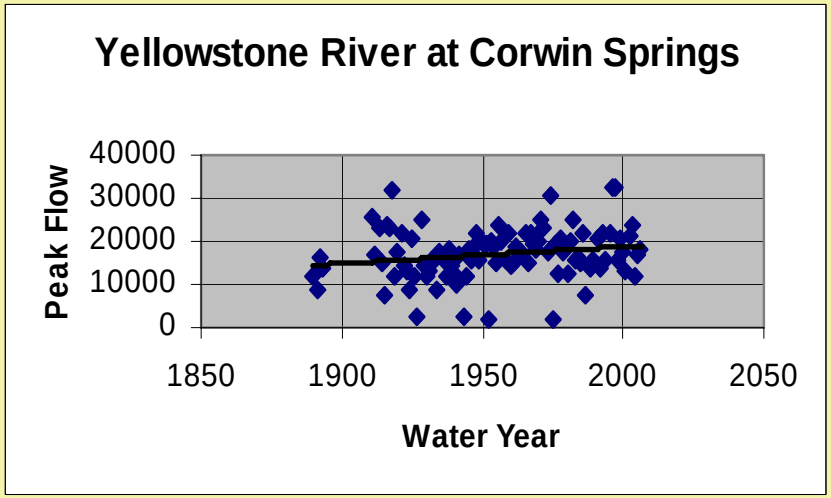


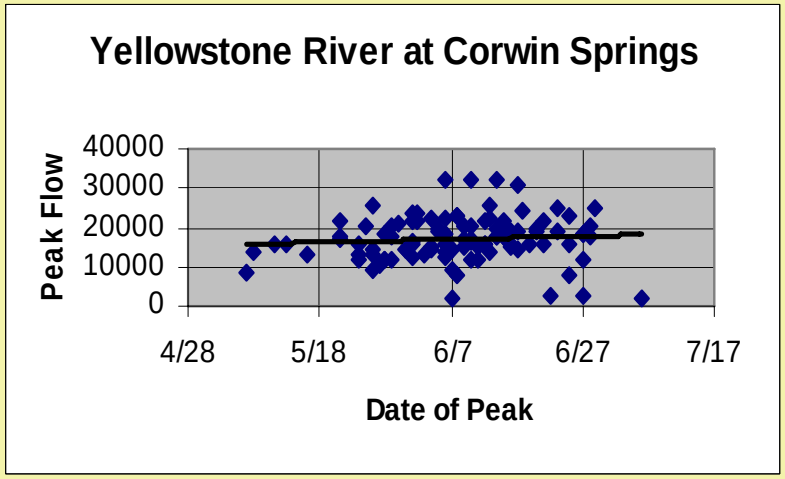




YELLOWSTONE PEAK FLOW

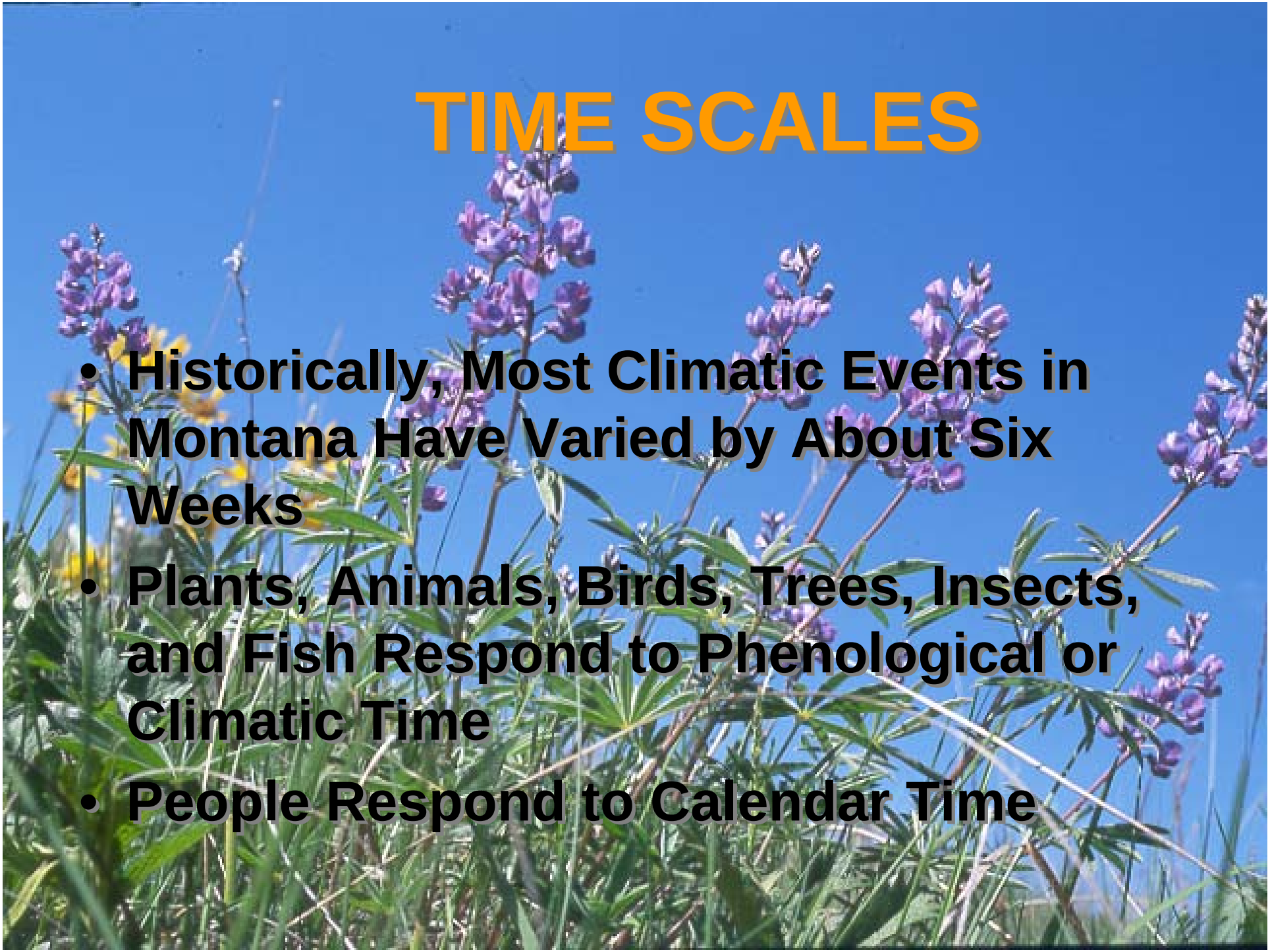






PEAK FLOW

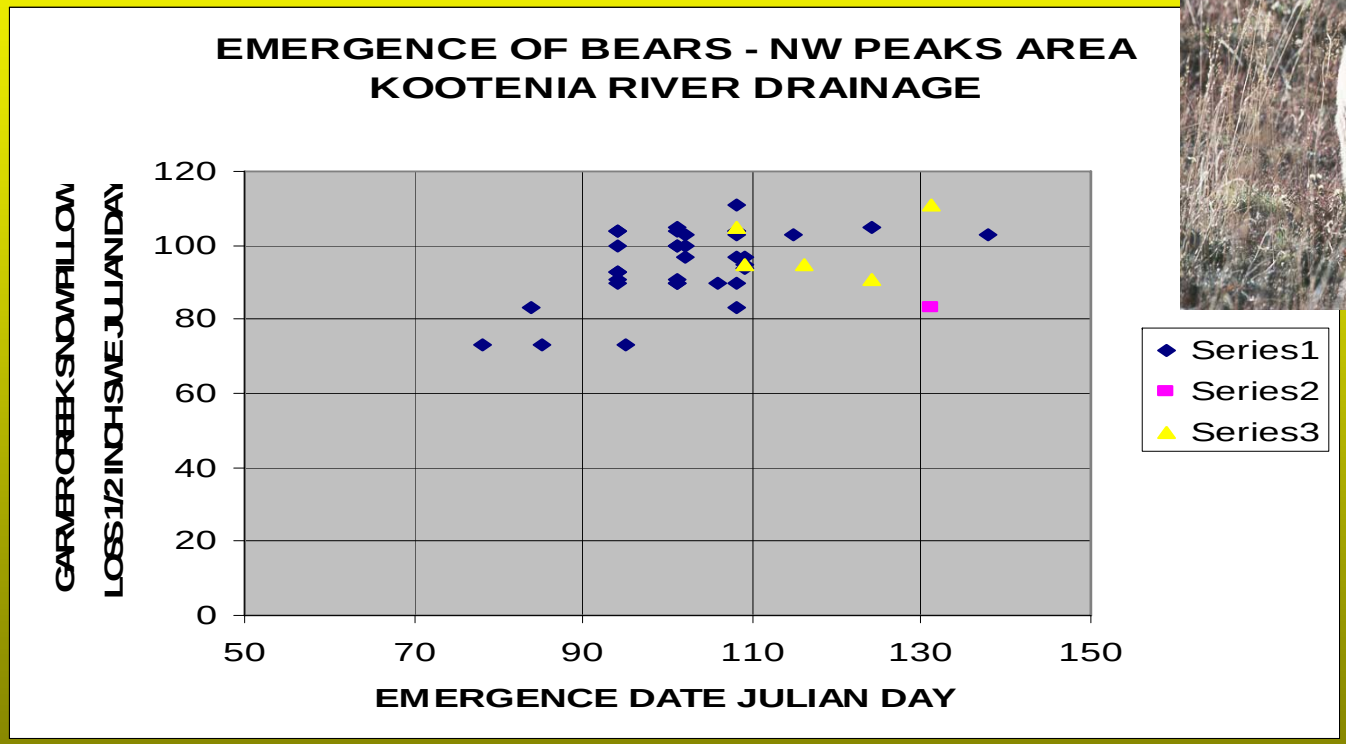
- Date of Peak about Same or a Little Earlier
- Size of Peaks Unchanged
- Higher the Peak, The Later the Date of Peak Flow
- Date of Peak Determined by Snow-Melt and Rainfall
- Date of Peak May Vary by Six Weeks



TIME SCALES

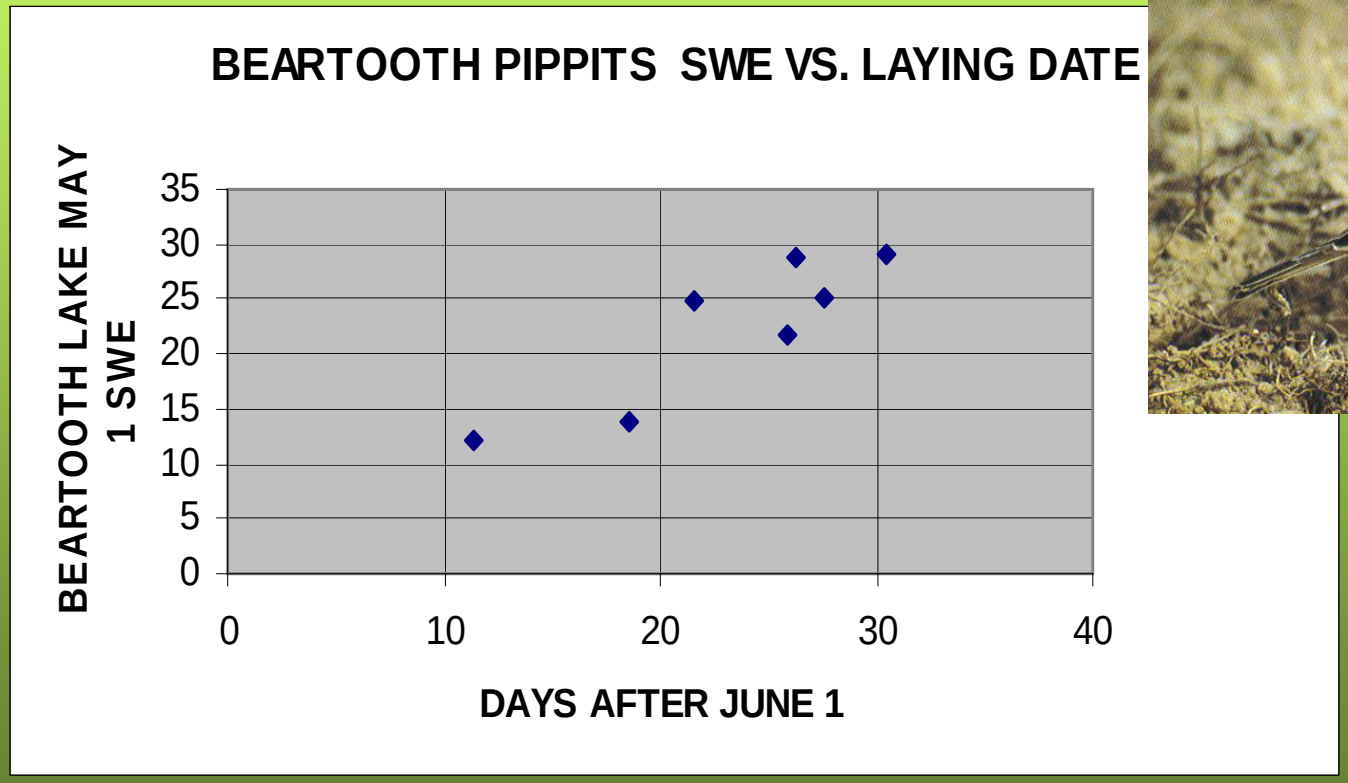
- Historically, Most Climatic Events in Montana Have Varied by About Six Weeks
- Plants, Animals, Birds, Trees, Insects, and Fish Respond to Phenological or Climatic Time
- People Respond to Calendar Time

BEAR EMERGENCE



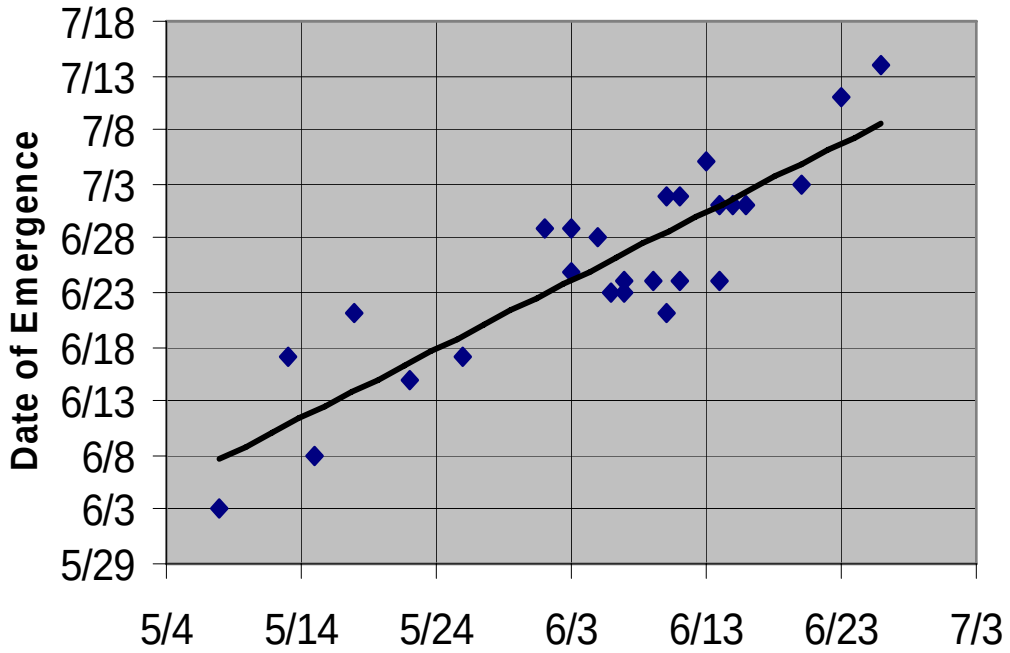
Series 1 Males and Females denning on north and south slopes
Series 2 Females with cubs denning on south slopes
Series 3 Females with cubs denning on north slopes

PIPPIT NESTING DATES



DATA FROM PAUL HENDRICKS, NRIS

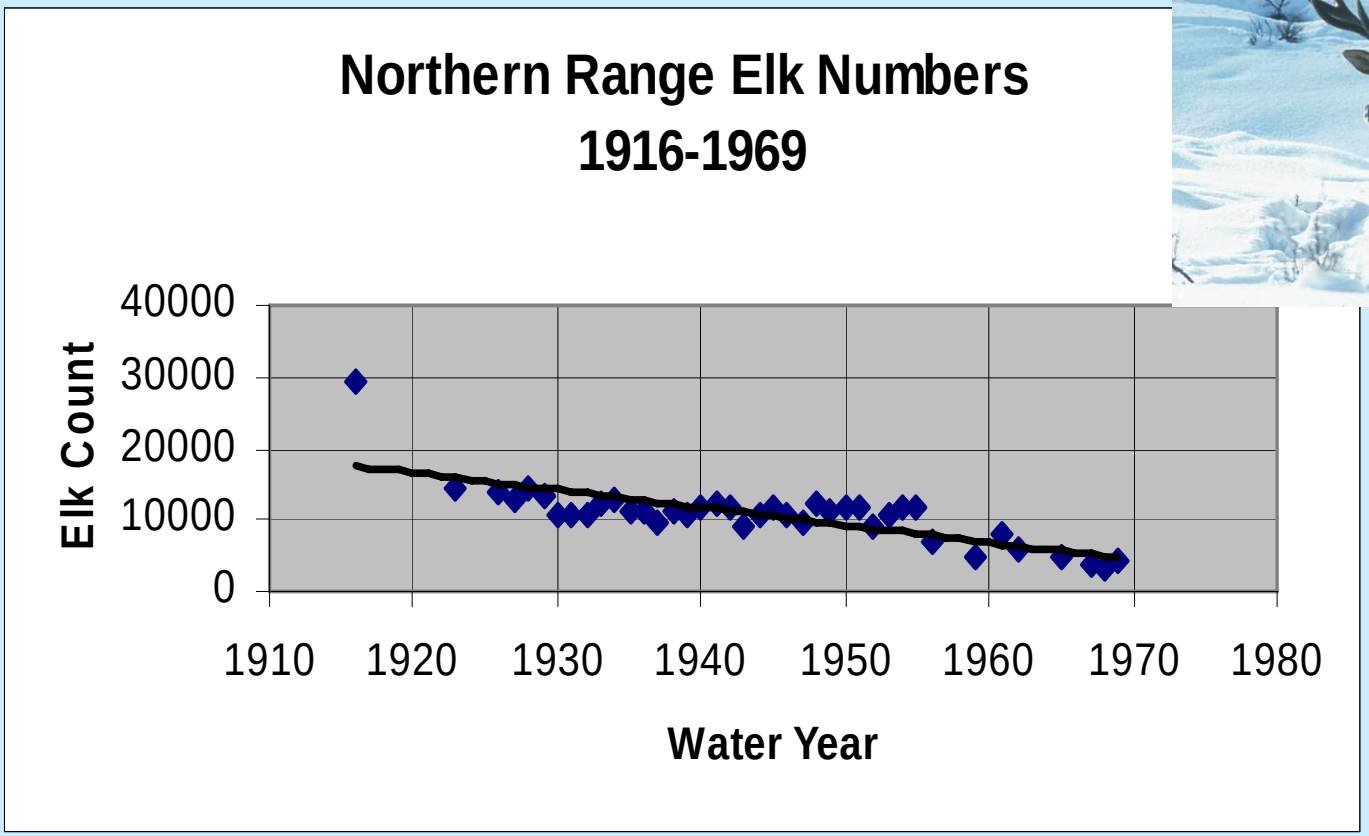
EMERGENCE OF SALMON FLIES



CAUTION

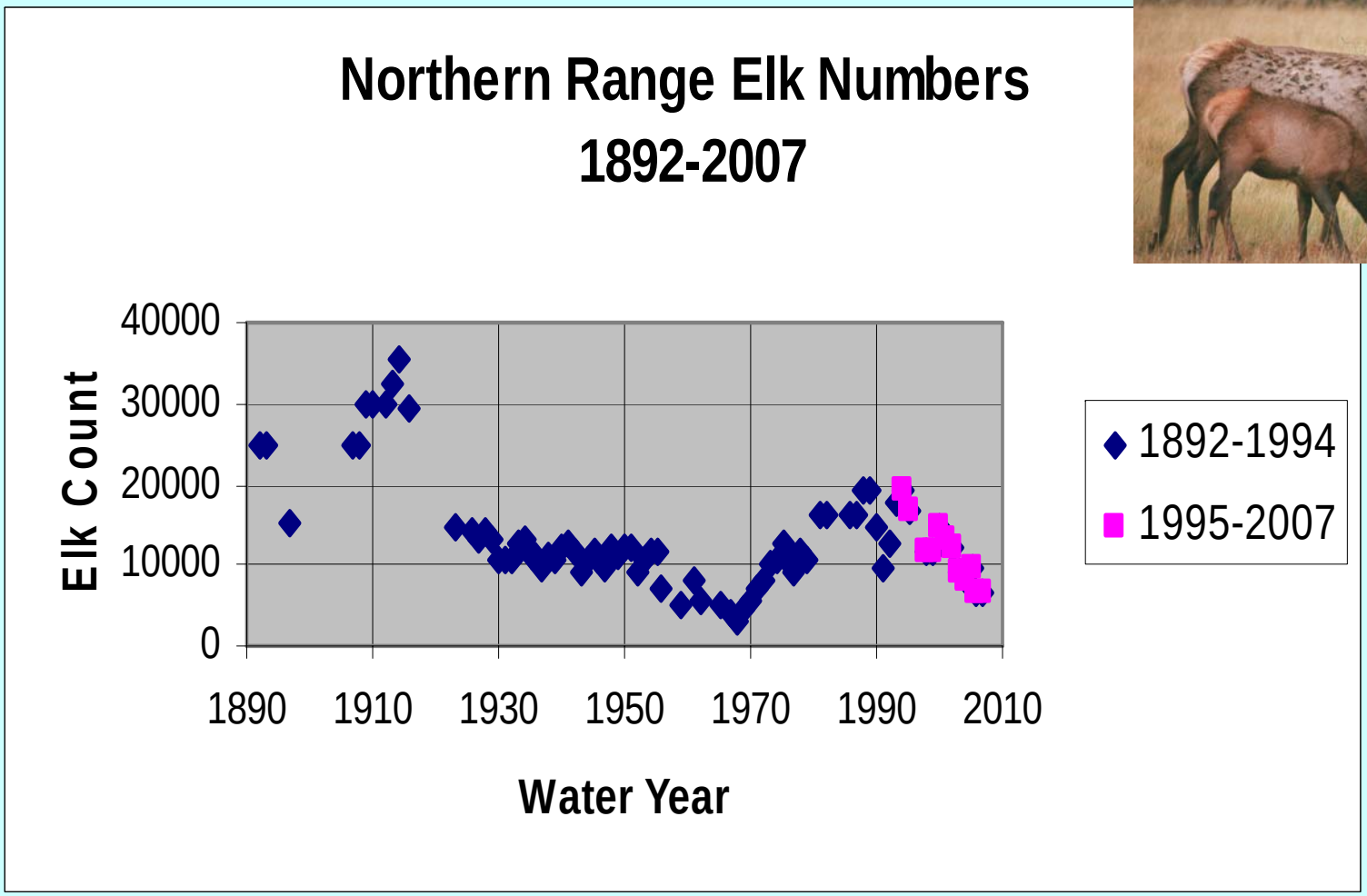
- **BE CAREFUL WHEN PREDICTING THE FUTURE USING SHORT TERM TRENDS**

ELK

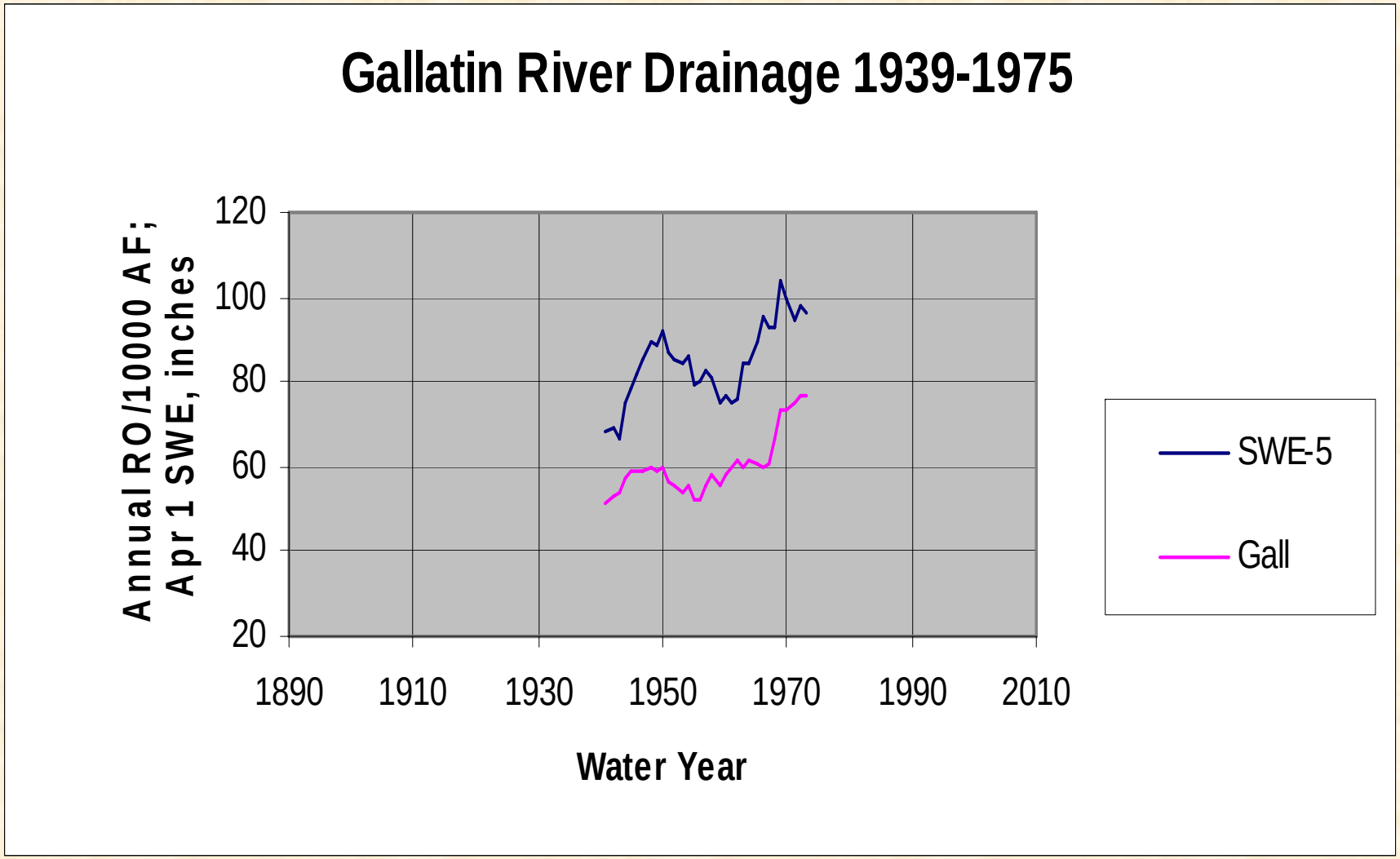


NO ELK ON NORTHERN RANGE BY 1988?

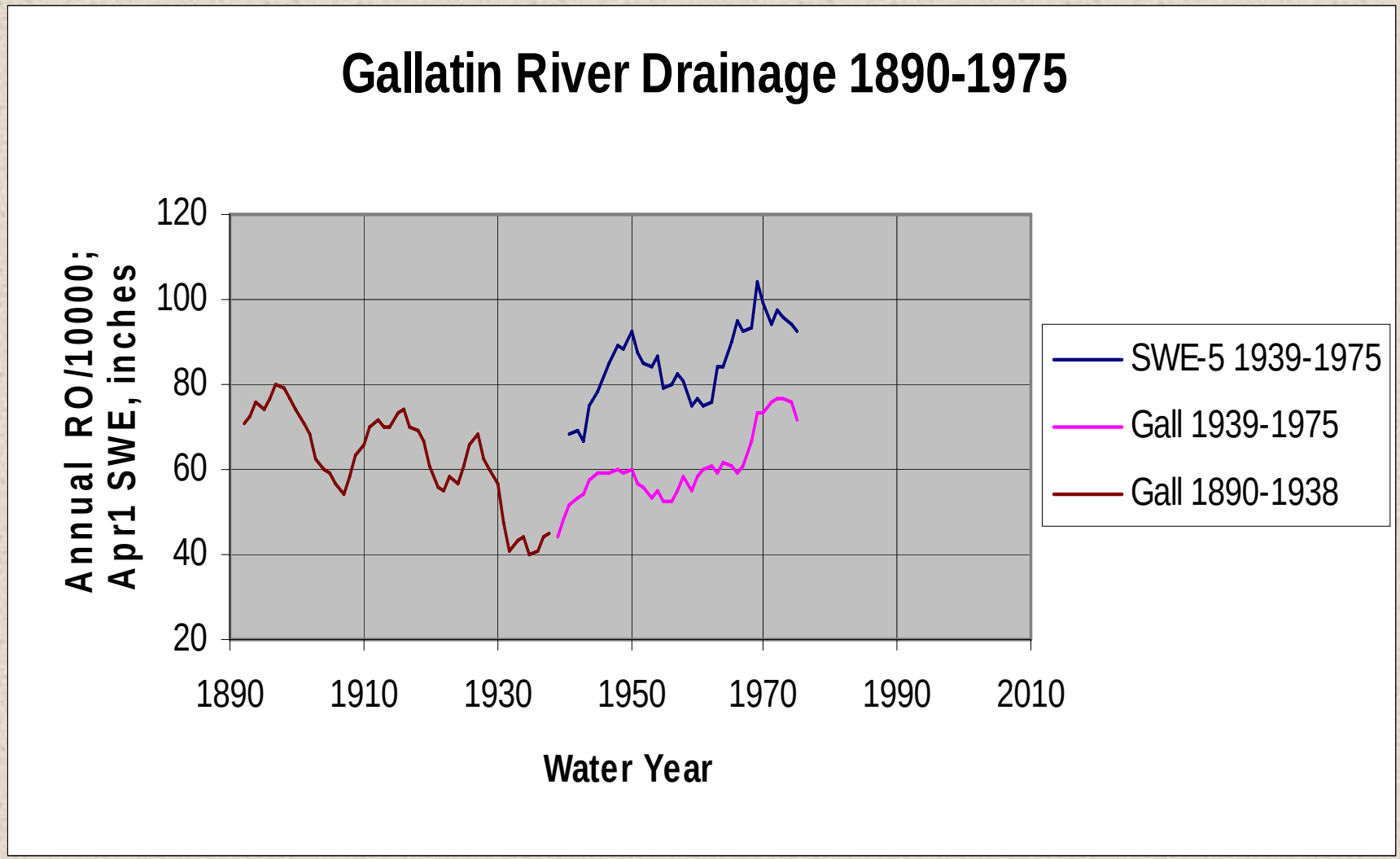
ELK


Northern Range Elk Numbers
1892-2007
Elk Count
40000
30000
20000
10000
0
1890
1910
1930
1950
1970
1990
2010
Water Year
1892-1994
1995-2007

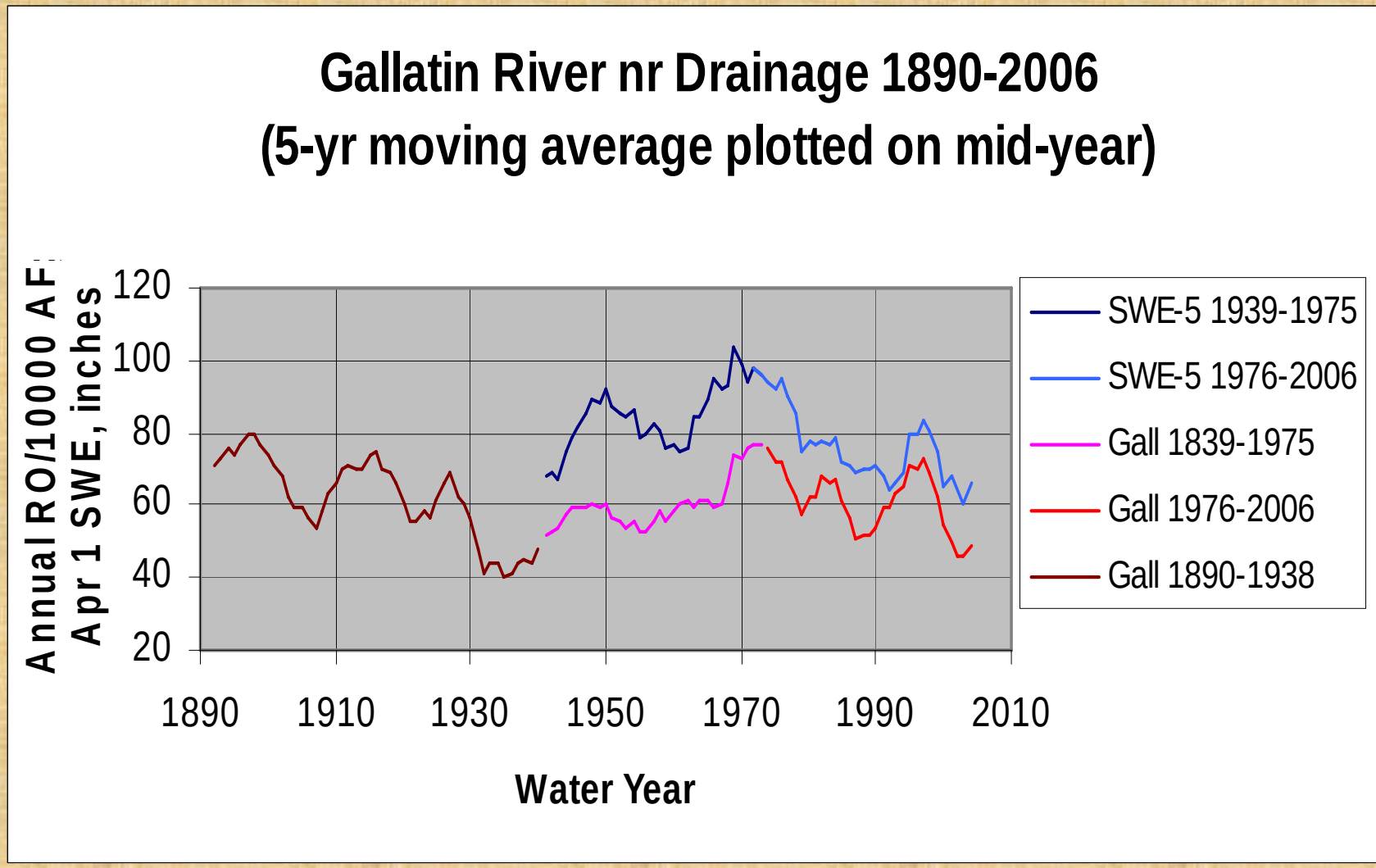
SHORT VS LONG TERM



SHORT VS LONG TERM

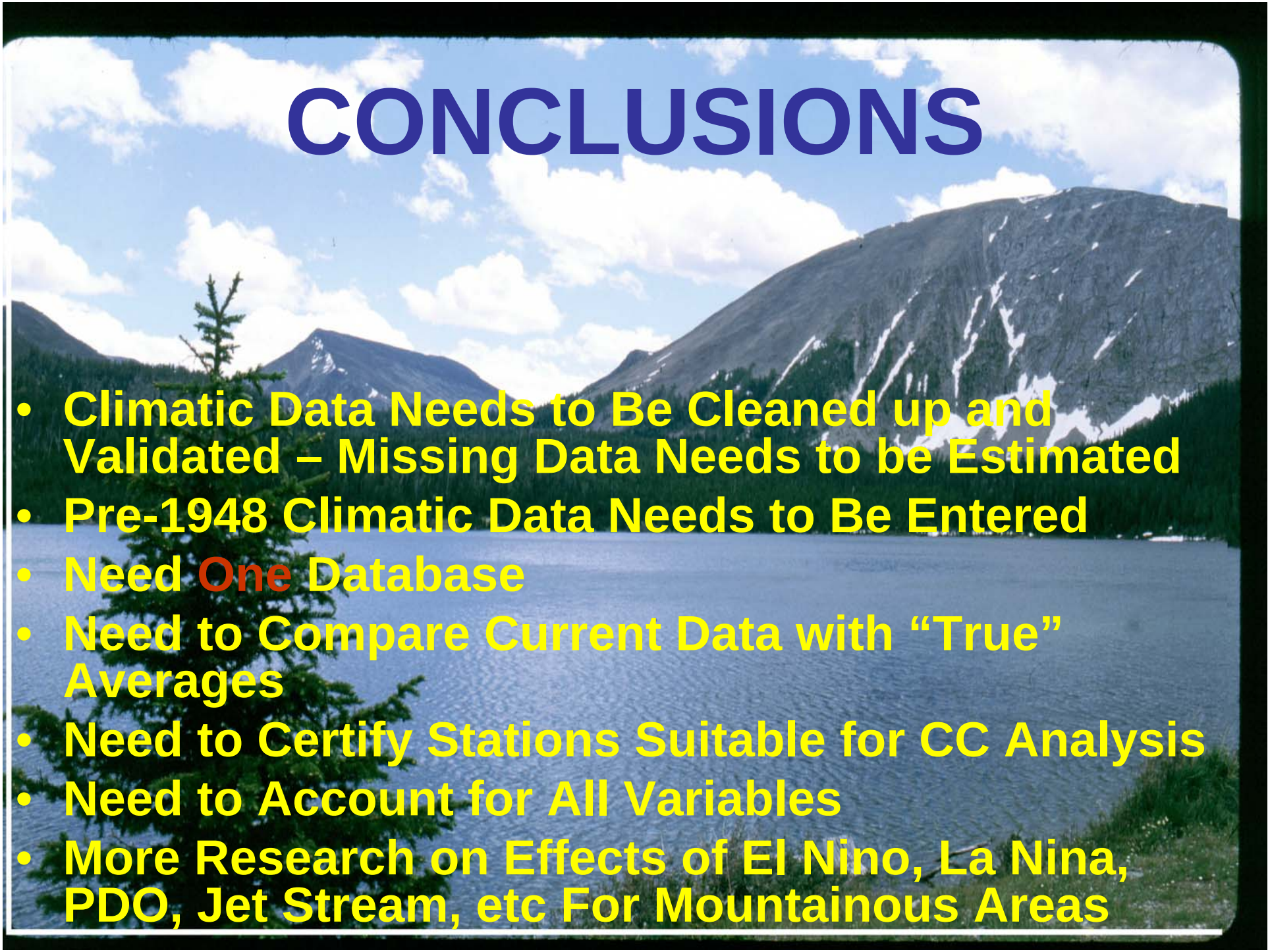


SHORT VS LONG TERM



WHITEBARK PINE

- 20 TO 30 % YEARS GROWING SEASON TOO SHORT TO START CONES (830 GDD F)
- 5-10% YEARS GROWING SEASON TO SHORT TO MATURE CONES (700 GDD F)
- INCREASE OF 2^0 F AVERAGE DAILY TEMPERATURE WOULD INCREASE PROBABILITY OF PRODUCING CONES
- COULD ALSO INCREASE OCCURRENCE OF BLISTER RUST
- COULD IMPROVE GRIZZZLY BEAR SURVIVAL



CONCLUSIONS

- Climatic Data Needs to Be Cleaned up and Validated – Missing Data Needs to be Estimated
- Pre-1948 Climatic Data Needs to Be Entered
- Need One Database
- Need to Compare Current Data with "True" Averages
- Need to Certify Stations Suitable for CC Analysis
- Need to Account for All Variables
- More Research on Effects of El Nino, La Nina, PDO, Jet Stream, etc For Mountainous Areas

MORE CONCLUSIONS

- Need to Evaluate Orographic Responses
- Valley Response Does Not Translate Into the Same Response in Mountains
- Need to Look at Whole System Responses
- Need to Understand Difference Between Phenological Dates and Calendar Dates
- Models Developed Using Short Term Data May Not be Capable of Predicting Long Term Responses
- R^2 Indicates How Well the Data Fits, Not How Well It Will Predict

EVEN MORE CONCLUSIONS

- Response Needs to be Determine for Specific Areas
- Expect Variability – 50 to 150 % is Common - New Records Will be Set
- All Disciplines and Research Needs to be Considered
- Temperatures Are Increasing
- Need to Separate Human Caused from Natural
- Everyone Needs to Do Some Research To Separate Real Facts From Implied Facts –


THE
END