Assessing Drought Regions and Vulnerability Through Soil Climate Regimes

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Abstract

The agricultural landscapes of the Great Plains reflect a complex pattern of soil climate regimes (*Soil Taxonomy*, Soil Survey Staff, 1999) and inherent variability that influence the cropping systems and behavior of farmers. The historical crop yields and acreage harvested of crops were compared with climatic events through time to describe the trends and adaptations of farmers and changes in agroecology. The USDA National Agricultural Statistics Service and Risk Management Agency's county-level databases were coupled with soil climate regimes derived from the Enhanced Newhall Simulation Model to explain spatial relationships of crop yields and identifying growing environments favorable to corn, soybeans, sorghum, and wheat. In addition, these geospatial databases can be used to characterize shifts in growing environments through time and space. Comparisons were generated at the county level between irrigated and nonirrigated yields, yield ratios (corn:soybean) to identify favored environments, shifts in crop acreages reflecting past climatic events and changes in genetics, and dominant "cause-of-loss" processes for specific crops. The Enhanced Newhall Simulation Model was used to derive probabilities of soil climate regimes and differentiate agroecological zones. This study also addresses the changes in the agroecology and behavior of soil climate regimes in the Great Plains and connections to El Nino/La Nina events.

Introduction

Drought is the dominant process of crop loss nationally and within Nebraska. As Table 1 illustrates, on a statewide basis for Nebraska, nearly two-thirds of the 18.6 million harvested acres are covered by crop insurance. For the most part, Nebraska's crop losses range from $50 to 75 million in non-drought years, but the losses approach nearly $200 million in drought years, such as 2000. The current growing season (2002) losses are projected to greatly exceed $200 million in Nebraska. The analysis and understanding of drought processes in the Great Plains is an important component to developing drought mitigation strategies and reducing agricultural risks on the landscape. In building a drought decision support system for Nebraska, we have proposed a suite of drought indices linked to geospatial databases describing the agricultural statistics or infrastructure to identify drought regions and potential impacts. Most approaches to visualizing drought indices, such as the traditional Palmer Drought Severity Index (PDSI), Standardized Precipitation Index (SPI), and the Drought Monitor, are small-scale maps that provide a regional (climate divisions) or national perspective, emphasizing current conditions. Most mapping approaches do not integrate thematic overlays of the agricultural infrastructure or provide the historical context, relative to agroecosystems, farms with policies, or the potential economic liabilities. In our research, we are describing the underlying agricultural framework, its vulnerabilities, and the drought characteristics at multiple temporal and spatial scales to enhance the understanding of agricultural drought.

In this paper, we will introduce new applications of soil moisture regimes as a drought risk indicator within an agricultural drought decision support system. The Enhanced Newhall Simulation Model represents a longer-term time window (growing season; 6 to 9 months) and historical context that can compliment SPI, PDSI, and the Drought Monitor in describing different parameters of drought events.

Table 1. The economics of crop insurance and droughts in Nebraska.

Year	Policies (total)	Acres Covered	Liabilities ($)	Premiums ($)	Indemnities Paid ($)
2002	150,156	12,172,924	2,136,981,414	168,489,920	?
2001	153,767	13,237,297	2,337,479,726	185,809,580	75,135,250
2000	148,514	12,960,865	2,173,397,770	144,290,644	190,954,577
1999	137,289	12,250,254	1,885,823,030	119,557,862	50,960,674
1998	142,226	11,811,018	1,982,140,724	110,105,947	37,545,806
1997	146,046	12,020,306	1,855,313,778	103,888,183	41,606,984
1996	172,731	13,098,947	2,030,408,701	110,155,278	53,356,825
1995	169,019	13,448,171	1,508,894,644	72,992,228	76,529,965

The Enhanced Newhall Simulation Model is a modified version of Van Wambeke et al. (1992), originally intended for classification of soil climate regimes. Soil climate regimes (Van Wambeke et al., 1992; Soil Survey Staff, 1999) describe the pattern of days when soils are above 5^{o}C and moist, moist to dry, and provide a classification of growing season environments. Although the Newhall Simulation Model has been run on individual weather stations with 30 year normals for classifying soil moisture and temperature regimes, it has not been extended to describing drought events and their historical context.

Objectives

Our research is designed to build a suite of geospatial risk assessment tools within a drought decision support system that assists USDA programs and the National Drought Mitigation Center's ability to: 1) compute and map drought metrics (Enhanced Newhall Simulation Model) across multiple time windows and spatial scales, 2) develop new drought interpretations and vulnerability maps through integration of national USDA databases with those from the automated weather network of the High Plains Regional Climate Center and the NWS cooperative station network, and 3) develop new thematic maps and interpretations to better visualize the potential exposure of the agricultural infrastructure to drought events.

Materials and Methods

Soil Climate Regimes

Soil climate regimes were modeled for long-term weather stations and Research and Extension Centers (see Figure 1) in Nebraska to detect and characterize climatic shifts through time. Weather stations were modeled on an annual time-step using the Enhanced Newhall Simulation Model (ENSM) and summarized to develop frequencies and probabilities of soil moisture regimes, as well as identify major drought and wet cycles. The root zone water-holding capacity for each weather station was spatially derived through the State Soil Geographic Database (STATSGO; Soil Survey Staff, 1994; 1999) and Soil Ratings for Plant Growth (SRPG; Soil Survey Staff, 2000) and used as the primary soils input for the soil water balance calculations within ENSM.

The Newhall Simulation Model (NSM) has long been used by the USDA Natural Resources Conservation Service to estimate soil moisture regimes as defined in *Soil Taxonomy* (Soil Survey

Staff, 1975, 1999; Newhall and Berdanier, 1996). Van Wambeke et al. (1992) modified the original model and introduced new subdivisions of soil moisture regimes (Figure 2) and variable soil moisture storage. Van Wambeke (1981, 1982, and 1985) applied the model to map soil moisture regimes across Africa, South America, and Asia.

The NSM was developed to run on monthly normals for precipitation and temperature; generally 30 year normals were most reasonable and appropriate. However, the ENSM can also be run on monthly records of individual years to develop frequency distributions of soil moisture regimes. Both the NSM and ENSM rely upon a modified Thornthwaite (1948) approach for the calculation of potential evapotranspiration (PET). Although the ENSM still shares inherited routines and concepts from the Palmer Drought Severity Index (Palmer, 1965), even with these constraints, the ENSM provides reasonable estimations of soil moisture and temperature regimes, which can yield the historical perspective of shifts in soil climate regimes.

A GIS interpolation approach was used in conjunction with the ENSM results to spatially extend soil climate regimes at multiple scales--subcounty, county, watershed, and major land resource area. Similarly, subcalculations behind the soil climate regime classification can be mapped to produce themes of growing season precipitation, potential evapotranspiration, monthly/annual water balances, mean summer soil water balance $(\text{Precipitation-PET})_{\text{June-July-August}}$, and soil biological windows (cumulative days that the soil is above 5^{o}C and moist).

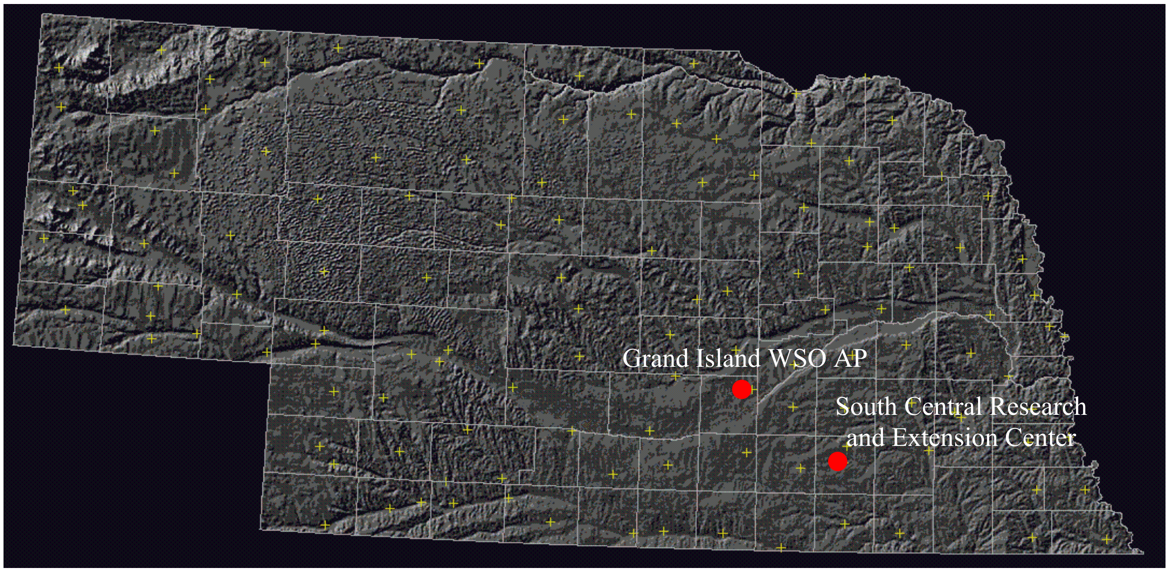
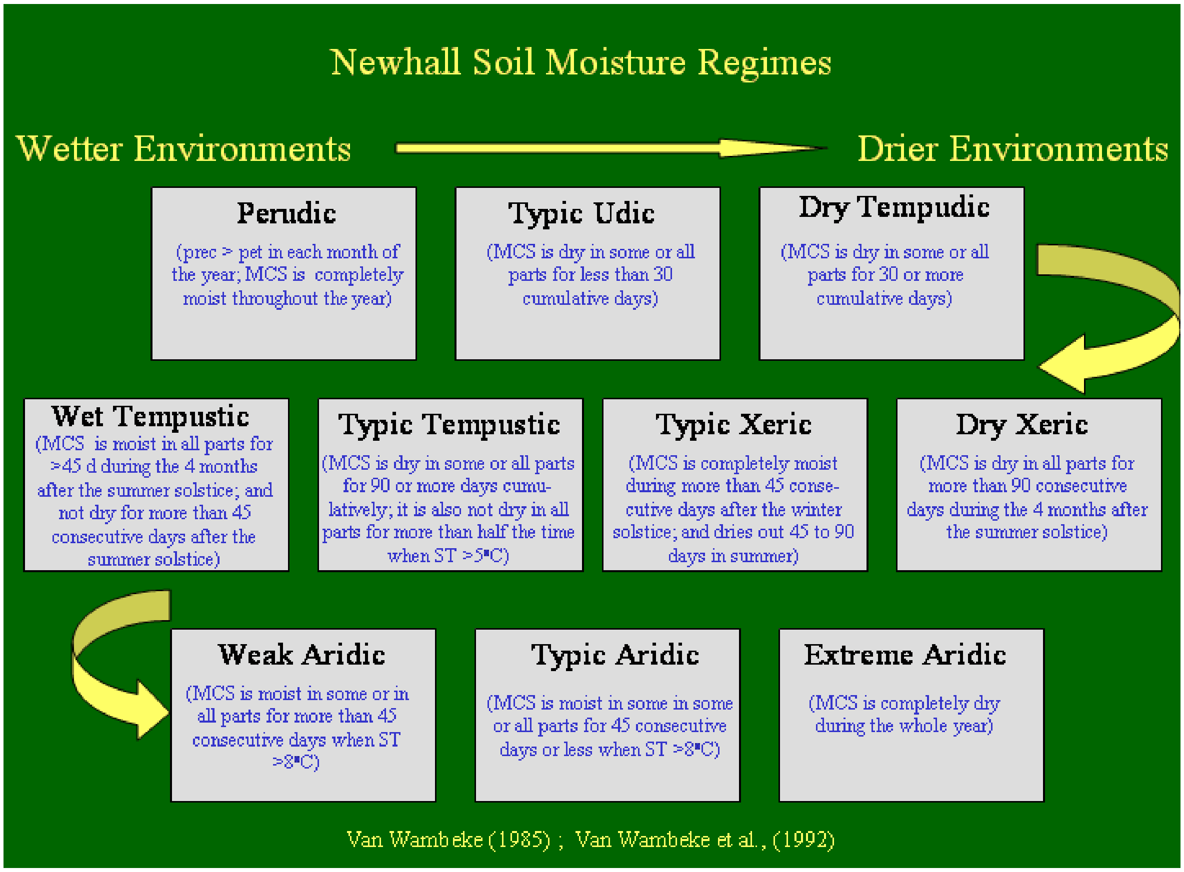


Figure 1. Distribution of NWS cooperative stations, the Grand Island WSO, and the South Central Research and Extension Center (Clay Center) in Nebraska. The Grand Island WSO has a climatic record extending from 1900 to the present.

Exposure and Vulnerability Analysis

The USDA National Agricultural Statistics Service and Risk Management Agency's county-level databases were coupled with climatic characteristics to derive new relationships for estimating crop yields and identifying growing environments favorable to corn, soybeans, sorghum, and wheat. In addition, these geospatial databases can be used to characterize shifts in growing environments through time. Comparisons were generated at the county level between irrigated and nonirrigated yields, yield ratios (corn:soybeans) to identify favored environments, shifts in crop acreage reflecting past climatic events, and dominant “cause-of-loss” processes for crops.


Newhall Soil Moisture Regimes

Perudic
(prec > pet in each month of the year; MCS is completely moist throughout the year)

Typic Udic
(MCS is dry in some or all parts for less than 30 cumulative days)

Dry Tempudic
(MCS is dry in some or all parts for 30 or more cumulative days)

Wet Tempustic
(MCS is moist in all parts for >45 d during the 4 months after the summer solstice; and not dry for more than 45 consecutive days after the summer solstice)

Typic Tempustic
(MCS is dry in some or all parts for 90 or more days cumulatively; it is also not dry in all parts for more than half the time when ST >5°C)

Typic Xeric
(MCS is completely moist during more than 45 consecutive days after the winter solstice; and dries out 45 to 90 days in summer)

Dry Xeric
(MCS is dry in all parts for more than 90 consecutive days during the 4 months after the summer solstice)

Weak Aridic
(MCS is moist in some or in all parts for more than 45 consecutive days when ST >8°C)

Typic Aridic
(MCS is moist in some in some or all parts for 45 consecutive days or less when ST >8°C)

Extreme Aridic
(MCS is completely dry during the whole year)

Van Wambeke (1985) ; Van Wambeke et al., (1992)

Figure 2. Classification scheme of soil moisture regimes as defined in the Enhanced Newhall Simulation Model.

Results and Discussion

The Enhanced Newhall Simulation Model

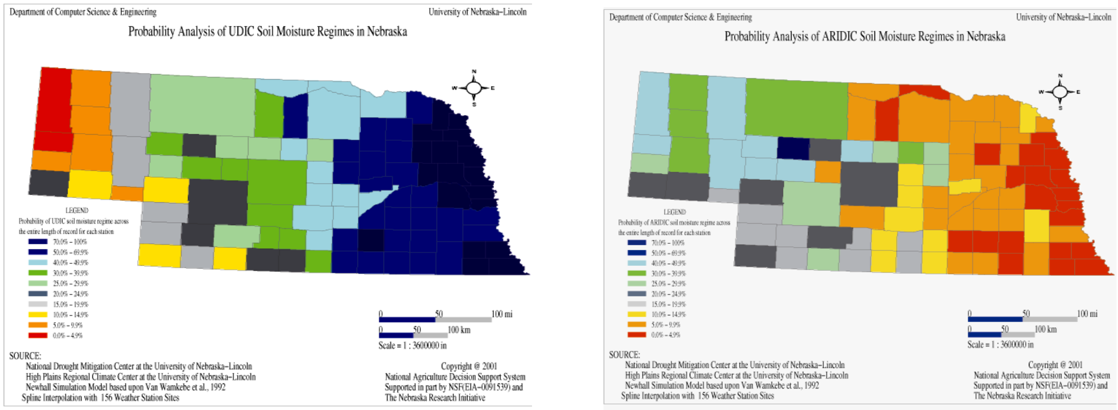
The South Central Research and Extension Center (Clay Center) was modeled for each climate year from 1949 to 2000, illustrating the shifts in soil moisture regime through time. The distribution of soil moisture regimes over the period of record (51 years) was characterized as: Typic Udic (52%), Dry Tempudic (17%), Wet Tempustic (4%), Typic Tempustic (19%), Typic Xeric (2%), Weak Aridic (4%), and Typic Aridic (2%). The dominant soil moisture regime through time was Typic Udic, which is defined as having less than 30 days during the growing season where the soil profile is partly dry or dry. The occurrences of Typic Tempustic, Typic Xeric, Weak Aridic, and Typic Aridic regimes indicate the major drought events at this location. The droughts of 1956, 1974, and 1966 were the most significant events as the soil moisture regime shifted to Weak Aridic and Typic Aridic, respectively. The ENSM results suggest that these severe shifts are limited to single year events and generally rebound to an Udic (Typic Udic or Dry Tempudic) moisture regime.

Table 2. Summary of soil climate characteristics through time at the South Central Research and Extension Center (Clay Center, NE). The soil moisture regimes were derived from the ENSM, using a root zone available water-holding capacity of 283 mm.

YEAR	**PREC (mm)**	**PET (mm)**	**AWB (mm)**	**SWB (mm)**	**Dry**	**M/D**	**BIO5**	**BIO8**	
					--------------days------------------				
1949	821	735	86	-96	0	0	233	225	**Typic Udic**
1950	675	675	0	-59	0	0	211	200	**Typic Udic**
1951	842	663	-179	45	0	0	209	195	**Typic Udic**
1952	681	738	-57	-150	0	47	164	201	**Dry Tempudic**
1953	491	754	-263	-319	59	25	118	108	**Typic Xeric**
1954	580	775	-195	-254	83	111	54	106	**Typic Tempustic**
1955	438	778	-339	-280	78	138	0	58	**Typic Tempustic**
1956	473	772	-299	-200	124	97	0	46	**Weak Aridic**
1957	853	759	94	49	0	0	216	200	**Typic Udic**
1958	758	711	47	-28	0	0	214	206	**Typic Udic**
1959	757	742	15	-283	0	34	186	206	**Dry Tempudic**
1960	683	718	-35	-149	0	11	202	209	**Dry Tempudic**
1961	498	746	-248	-171	106	119	0	78	**Typic Tempustic**
1962	598	735	-137	-74	66	154	0	151	**Typic Tempustic**
1963	672	808	-136	-112	13	232	0	72	**Typic Tempustic**
1964	498	746	-248	-171	106	119	0	78	**Typic Tempustic**
1965	839	728	-111	-123	0	0	227	215	**Typic Udic**
1966	391	736	-345	-238	140	92	0	41	**Typic Aridic**
1967	639	708	-69	-103	0	16	222	226	**Typic Udic**
1968	742	725	-17	-139	0	0	232	226	**Typic Udic**
1969	859	683	176	6	0	0	210	194	**Typic Udic**
1970	695	703	-8	-223	0	3	201	193	**Dry Tempudic**
1971	651	691	-40	-214	0	74	145	210	**Typic Udic**
1972	837	679	-158	-49	0	0	221	197	**Typic Udic**
1973	1046	679	367	-233	0	0	226	199	**Typic Udic**
1974	382	691	-309	-289	134	92	0	82	**Weak Aridic**
1975	679	663	16	-100	0	33	169	194	**Dry Tempudic**
1976	551	675	-124	-246	16	77	112	134	**Typic Tempustic**
1977	1065	711	-354	46	0	0	227	210	**Typic Udic**
1978	580	694	-114	-238	0	80	130	201	**Wet Tempustic**
1979	686	662	24	-218	0	43	164	191	**Dry Tempudic**
1980	569	703	-134	-137	59	25	132	154	**Typic Tempustic**
1981	775	690	65	-125	0	0	229	208	**Typic Udic**
1982	793	660	133	-153	0	0	204	192	**Typic Udic**
1983	828	673	155	-239	0	34	169	183	**Dry Tempudic**
1984	780	660	120	-140	0	31	174	191	**Dry Tempudic**
1985	668	651	17	-119	0	0	213	203	**Typic Udic**
1986	676	707	-31	-157	0	0	221	207	**Typic Udic**
1987	715	716	-1	-234	0	80	147	201	**Dry Tempudic**
1988	437	723	-286	-253	85	134	0	52	**Typic Tempustic**
1989	641	683	-42	4	0	0	215	206	**Typic Udic**
1990	651	707	-56	-84	0	0	233	211	**Typic Udic**
1991	583	734	-151	-263	0	82	137	204	**Wet Tempustic**
1992	712	668	44	74	0	0	227	206	**Typic Udic**
1993	1135	646	489	217	0	0	203	191	**Typic Udic**
1994	686	705	-19	-140	0	0	228	208	**Typic Udic**
1995	538	670	-132	-286	0	97	116	190	**Typic Tempustic**
1996	765	639	126	-93	0	0	197	192	**Typic Udic**

1997	743	678	65	-147	0	0	221	188	**Typic Udic**
1998	1049	726	323	182	0	0	217	205	**Typic Udic**
1999	710	699	11	-48	0	0	236	219	**Typic Udic**
2000	781	722	59	-120	0	19	202	203	**Typic Udic**
1949-2000	**696**	**707**	**-11**	**-132**	**21**	**40**	**158**	**174**	**Typic Udic**

For comparison, the Grand Island WSO Airport has a period of record extending back to 1900 and captures the full impact of the "Dust Bowl" years. The Grand Island WSO Airport is northwest of the South Central Research and Extension Center (SCREC) and occurs in the Central Platte Valley, which is also dominated by irrigated cropping systems. The distribution of soil moisture regimes at Grand Island also shows that it is dominantly Typic Udic (24%), followed by Dry Tempudic (20%), Typic Tempustic (19%), Wet Tempustic (17%), Typic Xeric (14%), Weak Aridic (6%), Dry Xeric (<1%), and Typic Aridic (<1%). Like the SCREC, the Typic Aridic event occurred in 1966 and the last Aridic (Typic or Weak) soil moisture regime in the record was 1974. The shorter period of record at the SCREC also creates a bias in the probabilities of Udic soil moisture regimes, since it lacks the Dust Bowl years. The occurrence of Typic Aridic soil moisture regimes is important in the rain fed portions of eastern Nebraska and generally do not occur east of the Missouri River, as the very high water-holding capacities (greater than 250 mm) of the loess-derived soils in eastern Nebraska limit or control the occurrence. Figures 3a and 3b summarize the probabilities of Udic and Aridic soil moisture regimes across Nebraska. The Grand Island WSO Airport station occurs on the western edge of the Udic zone, with relatively even proportions of Udic and Ustic (44% versus 36%, respectively) regimes.



(a) (b)

Figure 3. Probabilities of Udic and Aridic soil moisture regimes in Nebraska summarized from the weather stations located in each county, using total the length of record. These maps illustrate the pattern of soil moisture regimes, with some anomalies attributable to limited soil water-holding capacity or the period of record available.

The USDA Risk Management Agency's Policy Database includes the total producers, policies, and acres under insurance coverage, which can also translate into total premiums paid, liabilities, indemnities paid from claims, and cause-of-loss. Figure 4 presents the dominant cause-of-loss based upon total indemnities paid, across all crops grown, over a ten year period. Perhaps, the cause-of-loss information provides the important clues about targeting drought mitigation strategies to vulnerable regions at the state and county levels. The cause-of-loss can also be used to identify multiple hazards on the landscape. Drought (red) is a more dominant process of loss in the eastern rain fed portion (where Typic Udic moisture regimes are still dominant) of Nebraska and hail (green) events more strongly impact the western counties, where Aridic moisture regimes become more dominant.

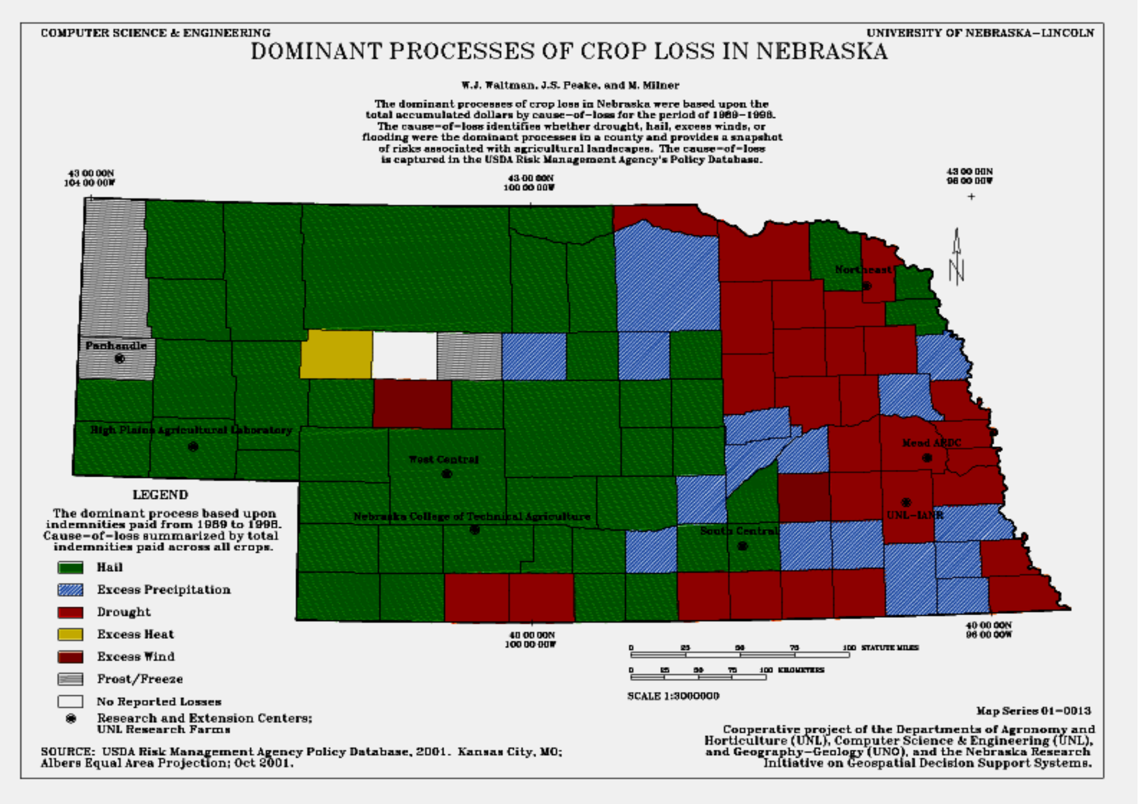


Figure 4. Dominant cause of crop loss by total indemnities paid ($) for the ten year period of 1989-1998. With the droughts of 2000 and 2002 included, the red regions of indemnities paid attributable to drought will expand westward.

Since the USDA Risk Management Agency's database only captures a limited period of record, we believe that the ENSM and soil moisture regimes can be used in the actuarial process to better represent drought vulnerabilities at local scales.

Summary and Conclusions

The Enhanced Newhall Simulation Model can provide historical context of drought events during growing seasons through soil moisture regimes. Soil moisture regimes can be mapped at multiple scales to identify counties and regions with higher probabilities of drought events. The distribution of soil moisture regimes can also help us visualize those geographic regions of higher climatic variability or where soil moisture regimes may be co-dominant. The Enhanced Newhall Simulation Model results can be coupled with USDA NASS and RMA databases to derive new drought interpretations for vulnerability mapping and mitigation.

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