PALMER DROUGHT INDICES AS INDICATORS OF LONG TERM STABILITY AND PERMANENCE OF SURFACE COAL MINE RECLAMATION[1]

by

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Abstract. The ten-year minimum liability period for coal mine reclamation bonds in arid and semi-arid western USA is a cornerstone of the Surface Mining Control and Reclamation Act of 1977 (SMCRA). Its inclusion in the law was motivated by contemporary research that emphasized a need to test the stability and permanence of apparently successful reclamation with exposure to climatic variability. The law and regulations associate no measurement of reclamation permanence with minimum liability periods. Reclamation success under SMCRA is measured by a body of performance requirements in regulations and guidelines that are functionally independent of minimum liability periods. This investigation used long run climatic data to infer the likelihood of reclamation permanence in West-central North Dakota. Comparison of mine-related biotic and hydrologic variables with precipitation, temperature and Palmer Indices showed that Palmer Indices provided equal or better correlations than precipitation or temperature alone. A 308-year long proxy and instrument-based Palmer Drought Severity Index (PDSI) was used to compare moisture patterns during the first 20 years of successful SMCRA reclamation with the duration, intensity and periodicity of climatic events over 3 centuries. Wet and drought events of above normal duration and intensity occurred during the past 20 years in West-central North Dakota, and high-frequency cycles identified in the 308-year PDSI record have periods of about 23 years or less. Palmer Indices, including those reconstructed from tree ring chronologies, seem to integrate precipitation, temperature and soil moisture into a variable that functions well for explaining responses in groundwater heads, surface water bodies and vegetation. Reclamation results, and the moisture events that they have persisted through, can be compared to historic records as a measure of probable long-term stability.

Additional Key Words: climate, spectral analysis, northern great plains, dendrochronology

Introduction

North Dakota enacted its first surface coal mining reclamation law in 1969, which became more stringent with each biannual legislative session until interim federal regulation based on the Surface Mining Control and Reclamation Act of 1977 (SMCRA) came in force in 1978. North Dakota rules based on SMCRA and U.S. Office of Surface Mining Reclamation and Enforcement (OSM) permanent program regulations became effective on August 1, 1980. In the formative years of surface mine regulation in the 1970's, successful reclamation of mined land to fully productive agricultural use was largely unproven, and the permanence of stability and productivity on reclaimed lands over long periods of time was often questioned. Mined lands successfully reclaimed under SMCRA are now common, and concerns are seldom raised about their long term sustainability over a scale of hundreds or even thousands of years.

The long-term sustainability of reclaimed environments can be evaluated somewhat by

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comparing the brief time interval in which successful reclamation has been achieved under SMCRA with historic climatic patterns on the Northern Great Plains. This approach assumes that similar patterns will recur in the future albeit modulated by natural changes or human interventions. Along with showing the climatic extremes that may face reclaimed lands in the future, comparison of the SMCRA time frame with longer climatic records lets us consider the adequacy of our regulatory requirements and expectations for accommodating the potential range of long-term climatic variation.

The North Dakota surface mining rules (NDAC 69-05.2) and statutes (NDCC 38-14.1), like all SMCRA based regulation, make little mention of climate or weather except in definitions such as those for hydrologic regime and steep slopes or as data to be recorded in blasting records. In spite of this, mining permits contain at least minimal information on climate because of its importance in surface water management, interpretating water resources data and demonstrating revegetation success. Climate, especially the precipitation regime, is the determining factor in vegetation and water resources reclamation for attaining bond release in the western US, and it is probably the easiest factor on which to acquire information. Abundant data are available over the Internet at various National Oceanographic and Atmospheric Administration (NOAA) web sites, and mines generally collect rainfall and other meterologic data.

This presentation proposes the Palmer Drought Indices as tools for comparing climatic variability with climate conditions during periods of reclamation success. It considers the 10-year minimum liability period as an attempt by the authors of SMCRA to cope with the influence of climatic variation on the permanence and stability of otherwise successful reclamation results in the semi-arid and arid west.

Bickel (2000) showed the suitability of the Palmer Drought Severity Index (PDSI) for evaluating mine-related environmental data and compared the last 20 years of climate during SMCRA-based mining regulation in West-central North Dakota with climatic conditions over the past 308 years. Response records of groundwater aquifers, surface water bodies and vegetation production at or near surface mines have been compared with long term climatic records. Environmental records from mines or mining areas spanning all or most of the last 20 years include NDPDES water discharges from mines, stream flows, vegetation production on mines, average annual county crop production records, and monitoring well head levels. Climatic data specific to west central North Dakota includes about 50 years of daily records from US Weather Service stations. Among the longest records are monthly Palmer Drought Indices calculated for the region from weather station records extending back to 1895 and annual proxy values reconstructed to 1691 from tree ring chronologies as described by Cook, et al. (1996).

The climate of western North Dakota is cool, semiarid and continental with hot periods in summer months having maximum temperatures above 95°F and more frequent cold waves in winter with minimum temperatures below -20°F. The average annual precipitation at Beulah, ND is about 16 inches with most falling as thundershowers in spring and summer. Winter snow cover is generally light but variable and provided by periodic snowstorms. Late winter and early spring warm periods typically produce rapid melting of accumulated snow. Since evapotranspiration and plant use typically exceed late spring and summer rainfall contributions, snowmelt water is a significant source of recharge for the hydrologic regime.

SMCRA and the resulting OSM and North Dakota rules do not address the rationale for a minimum liability period on reclamation bonds, and no measurement or specific requirement is associated with the time period. Information and recollections from the formative period of SMCRA suggest that the technical rationale for a 10-year minimum liability period came from reclamation research and state regulation, primarily of Montana, and was summarized in National Academy of Sciences (1974). National Academy of Sciences (1974, p.3) notes the absence of a climatic "safety factor" in the evaluation and regulation of reclamation practice, and that even supplying all the requirements for a reclamation practice to be successful over a short term will not guarentee stable and permanent results in all instances. It emphasizes that stability and permanence of successful reclamation must be determined by the proper application of proven techniques yielding acceptable results at all the "critical times" in regional climate.

The 20 to 23-year lengths of high-frequency climatic cycles identified in West-central North Dakota and elsewhere in the west (Cook, et al., 1997; Bickel, 2000) could suggest that a 10-year minimum liability period may be too short for western mining. The minimum liability period is a sub-optimal approach to meeting the original intent of SMCRA not because of period length but that it provides no specific requirement to estimate probable long-term stability and permanence.

Materials and Methods

Data in this analysis came from monitoring reports and bond release applications submitted by mining companies to fulfill regulatory requirements of mine permitting and from NOAA, USGS and USDA Internet sites that distribute environmental data. All environmental data submitted to meet regulatory requirements are publicly available, but commonly not in digital format at present.

Direct meteorologic and hydrologic measurements can be manipulated and combined to characterize climatic events more accurately than the records of individual environmental variables. Climatic indices of varying complexity are used worldwide (Hayes, 1999) but all have strengths and limitations suited to certain uses and regional climates. The Palmer Drought Severity Index (PDSI) and its modifications are widely used in the USA and Canada and seem best suited to regions with relatively uniform topography. Extensive background information for the Palmer and other climatic indices are available from several sources on the Internet.

The PDSI is an index to departure of measured precipitation from an expected "near normal" moisture balance based on evaporation, soil moisture gain and loss, runoff, and precipitation. The calculation weights each value for its location in or between an established wet or dry period. The Index scale varies roughly from +6 to –6; negative values are dry conditions. In general terms, the index is calculated from current precipitation by subtracting evapotranspiration, soil moisture gain, and runoff and adding soil moisture loss. The resulting moisture anomaly index is used along with the previous period's PDSI value and a moisture balance term to calculate a value for the current period. The moisture balance term depends on a month falling within or transitioning from a wet or dry period. Values are calculated for each period for each of these three possible states, and the value ultimately used is determined by conditions in subsequent months defining a wet or dry spell. Palmer (1965) and Guttman (1991) give details on computation of the PDSI.

The multi-month delays in getting a final PDSI value led to use of a modification, termed the Palmer Hydrologic Drought Index (PHDI), that avoids the PDSI's backtracking to define transitions between wet and dry spells and provides immediate availability of a final value. The two indices are identical during an established wet or dry period and differ only during transitions between wet and dry spells. The PHDI is more conservative than the PDSI in showing changes in the moisture regime and has been considered more representative of hydrologic systems. Correlation of both indices with mining-related data sets from quarterly and annual sampling periods showed that the PDSI generally provided correlations equal to the PHDI.

The drought indices data sets used here were obtained from three Internet sites. Monthly PDSI, PHDI, temperature and precipitation from U.S. Weather Service records were obtained from the NOAA National Climatic Data Center Web site at www.ncdc.noaa.gov/onlineprod/drought/ftppage.html. These data were for North Dakota regional climatic Division 4 that includes the west-central region where mines and counties considered in this report are located. Weekly PDSI values for North Dakota's Division 4 were obtained from a NOAA FTP site, ftp.ncep.noaa.gov/pub/cpc/sabol/palmer. Annual PDSI values from U.S. Weather Service data and reconstructed from tree ring data for Grid Point 65 in west-central North Dakota by Cook, et al. (1996) were obtained from the NOAA Paleoclimatology Program Web site at www.ngdc.noaa.gov/paleo/usclient2.html. The instrument based PDSI data in this set were updated from 1995 through 1998 using the average of June through August PDSI values for North Dakota Division 4 to approximate the methods of Cook, et al. (1996). Quarterly values were calculated by averaging monthly data.

Proxy climate data are measurements of a natural process that has made a permanent record of climatic effects that covers periods of time for which direct measurements are not available. Tree rings provide reconstructed proxy records of climatic variability on an annual scale. Temperature, precipitation and climatic indices can be reconstructed by correlating tree ring properties with instrument data from growing seasons of overlapping time intervals, and the derived regression relationships are used to reconstruct climatic records from tree ring data spanning earlier time intervals. The PDSI reconstructions of Cook, et al. (1996) selected tree ring chronologies that showed strong responses to drought to develop a nation-wide 155-point grid of proxy data. The reconstruction at Grid Point 65 included tree ring records from Minnesota, South Dakota and Montana. A few tree ring chronologies from bur oak are available in the International Tree Ring Data Bank (http://tree.ltrr.arizona.edu/~grissino/ itrdb.htm) for sites closer to Grid Point 65 and the coal mining areas of North Dakota; but Sieg, et al. (1996) note limitations to deriving reliable long climatic records from bur oak chronologies.

Table 1. Examples of correlation of mine-related vegetation production and hydrologic variables with temperature, precipitation and the PDSI.

Dependent Variable	Independent Climate Variable	Years of Run	Sample Periods	n	Correlation Coefficient	R^2	F ratio (MSR/MSE)	p - Value	Relationship (p<.05=signif.at 0.95 confidence level)
NDPDES discharges from all mines	Region 4 Precipitation	1986-98	annual	12	0.4087	0.187	2.21	0.1655	not significant
NDPDES discharges Glenharold Mine	Region 4 Precipitation	1986-98	annual	12	0.5061	0.2561	3.79	0.0766	not significant
NDPDES discharges from all mines	PDSI	1986-98	annual	12	0.8066	0.6507	20.49	0.0009	significant
NDPDES discharges Glenharold Mine	PDSI	1986-98	annual	12	0.6375	0.4064	7.53	0.0191	significant
Falkirk Mine Monitoring Well 3-2	PDSI	1984-97	quarterly	75	0.4698	0.2207	20.96	0.0000	significant
Falkirk Mine Monitoring Well 3-2	Underwood, ND quarterly precip.	1984-97	quarterly	55	0.1873	0.0351	1.96	0.1670	not significant
Falkirk Mine Monitoring Well 9-3	PDSI	1984-97	quarterly	72	0.4535	0.2056	18.38	0.0001	significant
Falkirk Mine Monitoring Well 9-3	Underwood, ND quarterly precip.	1984-97	quarterly	55	0.2967	0.088	5.21	0.0264	significant
Falkirk Mine Monitoring Well 19-2	PDSI	1984-97	quarterly	57	0.3151	0.0993	6.17	0.0160	significant
Falkirk Mine Monitoring Well 19-2	Underwood, ND quarterly precip.	1984-97	quarterly	55	0.2833	0.0802	4.71	0.0344	significant
Falkirk Mine Monitoring Well 92-1	PDSI	1984-97	quarterly	75	0.0713	0.0051	0.38	0.5407	not significant
Falkirk Mine Monitoring Well 92-1	Underwood, ND quarterly precip.	1984-97	quarterly	55	0.3004	0.0923	5.36	0.0245	significant
Mercer Co. Spring Wheat yield bu/ac	PDSI	1929-1998	annual	69	0.4764	0.227	19.97	0.0000	significant
Mercer Co. Spring Wheat yield bu/ac	Region 4 Precipitation Apr-Spt.	1929-1998	annual	69	0.3323	0.1104	8.44	0.0050	significant
Mercer Co. Spring Wheat yield bu/ac	Region 4 Average PDSI Apr-Spt	1929-1998	annual	69	0.2901	0.0841	6.25	0.0149	significant
Mercer Co. Spring Wheat yield bu/ac	Region 4 Average Temp. Apr-Spt	1929-1998	annual	69	0.1659	0.0275	1.93	0.1698	not significant
Oliver Co. All Wheat yield bu/ac	PDSI	1919-1998	annual	79	0.4211	0.1773	16.81	0.0001	significant
Oliver Co. All Wheat yield bu/ac	Region 4 Average PDSI Apr-Spt	1919-1998	annual	79	0.2376	0.0565	4.67	0.0338	significant
Oliver Co. All Wheat yield bu/ac	Region 4 Precipitation Apr-Spt.	1919-1998	annual	79	0.2178	0.0474	3.89	0.0523	significant
Oliver Co. All Wheat yield bu/ac	Region 4 Average Temp. Apr-Spt	1919-1998	annual	79	0.1716	0.0294	2.37	0.1280	significant
Glenharold Mine Reference Area lb/ac Thin Claypan	Region 4 Average Temp. Apr-Spt	1979-1998	annual	19	0.4577	0.2095	4.77	0.0424	significant
Glenharold Mine Reference Area lb/ac Thin Claypan	Region 4 Precipitation Apr-Spt.	1979-1998	annual	19	0.5354	0.2866	7.23	0.0150	significant
Glenharold Mine Reference Area lb/ac Thin Claypan	Region 4 Average PDSI Apr-Spt	1979-1998	annual	19	0.5208	0.2712	6.7	0.0186	significant
Glenharold Mine Reference Area lb/ac Thin Claypan	PDSI	1979-1998	annual	19	0.4995	0.2496	5.99	0.0249	significant
Glenharold Mine Reference Area lb/ac Silty Range Site	Region 4 Average Temp. Apr-Spt	1979-1998	annual	19	0.1353	0.0183	0.34	0.5696	not significant
Glenharold Mine Reference Area lb/ac Silty Range Site	Region 4 Precipitation Apr-Spt.	1979-1998	annual	19	0.4259	0.1814	3.99	0.0612	not significant
Glenharold Mine Reference Area lb/ac Silty Range Site	Region 4 Average PDSI Apr-Spt	1979-1998	annual	19	0.311	0.0967	1.93	0.1819	not significant
Glenharold Mine Reference Area lb/ac Silty Range Site	PDSI	1979-1998	annual	19	0.1961	0.0384	0.72	0.4074	not significant
North Dakota Coal Production (tpy)	PDSI	1920-1998	annual	78	0.0297	0.0008	0.07	0.7951	not significant
North Dakota Coal Production (tpy)	Hemisphere Temp. Deviation (Mann et al. 1998)	1920-1998	annual	78	0.66612	0.4437	61.42	0.0000	significant

The relationship of climate variables to mine related phenomena over the time interval of SMCRA-based mine reclamation. A hybrid set of PDSI data was assembled for Grid Point 65 using instrument records extending back through 1895 and reconstructed values covering the period from 1691 to 1894.

The 20 years from 1979 through 1998 were considered the span fully influenced by modern mine regulation, and this subset was then correlated year by year with each 20-year interval from 1691 to 1978 to identify occurrences of similar patterns in the long record. The lengths of runs of positive or negative PDSI values were evaluated as a measure of wet and dry spells. Patterns of intensity were examined through the occurrence of severe wet or dry years that are generally defined as having PDSI values at or more extreme than +3 or –3. Spectral analyses were made of the PDSI and results of the year-wise correlation to identify major cycles for comparison with the 20 years of modern reclamation. Microsoft Excel 97 and Statgraphics Plus Version 3.1 were used for data analysis.

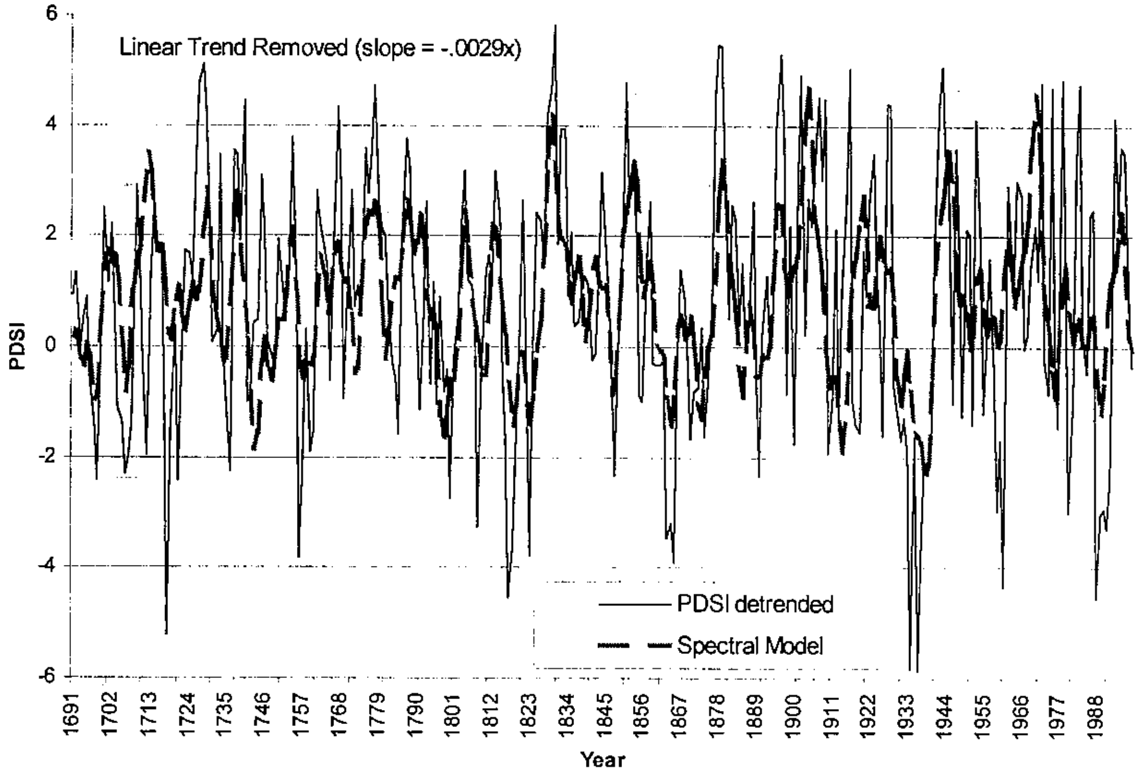

Figure 1. West-central North Dakota PDSI reconstructed from tree ring data (1691-1894) and instrument records (1895-1998) overlain with a spectral model based on periods discussed in the text.

Results

The PDSI correlated as well as or better than regional temperature and precipitation with various mine-related water resources and vegetation production data (Table 1). It was assumed that local weather data would generally correlate better with local mine variables than would regional averages or indices. However, the PDSI provided better correlations with static water levels in shallow monitoring wells at Falkirk Mine than precipitation totals at nearby Underwood, ND. It correlated poorly with the hydrograph from a deeper monitoring well, Well 92-1, which is completed in the lower of two lignites mined at Falkirk Mine. It correlated better than regional precipitation with NDPDES discharges and estimated county production of wheat and hay. Regional precipitation had slightly stronger but comparable correlation with reference area production at Glenharold Mine. The PDSI appeared to be the best variable representatiing regional climate insofar as it influences water and vegetation resources related to mine reclamation in west-central North Dakota.

Bickel (2000) also made year-wise correlations of the PDSI record for 1979 through 1998 with the years from 1691 through 1978 and found 14 closely matching intervals with correlation coefficients of 0.40-0.78 among the total number of positively correlated intervals (Table 2). All correlation values showed about 22 cycles over the 288-year record that could be modeled with a 12.8-year cycle. The climatic pattern in the west-central North Dakota PDSI from 1979 to 1998 has occurred multiple times in the reconstructed regional PDSI.

Table 2. Years of events in the West-central North Dakota climatic record

Correlation (.40-.78) of 1979-98 with 20-year intervals beginning:	Visual Curve Matching: 1979-98 with 20-yr. intervals beginning:	Periods of 5 or more Wet Years	Periods of 5 or more Dry Years	Severe Wet Years	Severe Dry Years
		1691-95			
			1704-08		
1709	1711				1718
1723		1723-30		1726-29, 33, 37-38, 40	
1746	1750	1750-55		1754	
1763					
1772		1770-82		1767, 1775, 77-78	
1789	1775	1786-90		1787	
		1802-07	1815-20		
1807	1808	1810-14			1817, 23
		1825-35		1828-30, 32-33	
1836		1849-54	1859-66	1851	
1854		1876-80	1869-75		
1862	1865			1877-79	1865
1880	1883			1895-97	
		1904-09		1902, 07, 09, 16	
1924			1929-40	1927-28	1934, 36-37
	1935	1920-24			
		1941-45		1942-43	
1948	1952			1953	
1961		1962-66		1972, 75, 78	1961
				1983	
			1988-92		1988, 91
				1993	

Events related to wet conditions rather than drought have characterized climatic history in the region for the past 300 years. When severe drought or wet conditions are defined as PDSI values at or more extreme than 3.0 or –3.0, the period from 1691 to 1998 had 40 wet years and 10 dry years that represented severe to extreme conditions (Table 2). The 1979-98 period had two severe wet years, 1983 and 1993, and two severe dry years, 1988 and 1991. Throughout the record, severe wet and dry years occurred during multiyear periods of corresponding wet or drought with the exception of 1975 that was a single-year severe wet period. Over the preceding 308 years in west-central North Dakota, there have been more wet than dry spells spanning 5 or more years, and there have been 4 times as many severe wet years as dry years.

The pattern in the lengths of wet and dry intervals is the distinguishing characteristic of the years 1979-98 in west-central North Dakota (Figure 2). The first 9 years of the period were alternating 2-year wet and dry spells through 1987. These are followed by 5 dry years, 4 wet years and by 2 dry years in 1997-98. The PDSI record from 1691 to 1998 has 177 wet and 131 dry years distributed in 104 alternating wet and dry spells of 1 to 13 years in length (Figure 3). The 5-year dry spell from 1988-92 ranked as 5th longest in the record and above the 75th percentile with the longest dry period being the 12 years from 1929 to 1940. The 4-year wet period from 1993 through 1996 ranked 15th longest and at the 75th percentile with the longest wet spell running 13 years from 1770 to 1782. The lengths of periods had a slight linear trend of decreasing period duration (slope of –0.01x) and seemed to show a transition to shorter climatic periods occurring near the beginning of the last quarter of the 19th Century. Wet and dry spells 5 years or longer are listed in Table 2. With exception of the 1929-40 drought, the latter part of the 19th and most of the 20th Century appeared characterized by more frequent changes between wet and dry conditions than occurred prior to the 1880's.

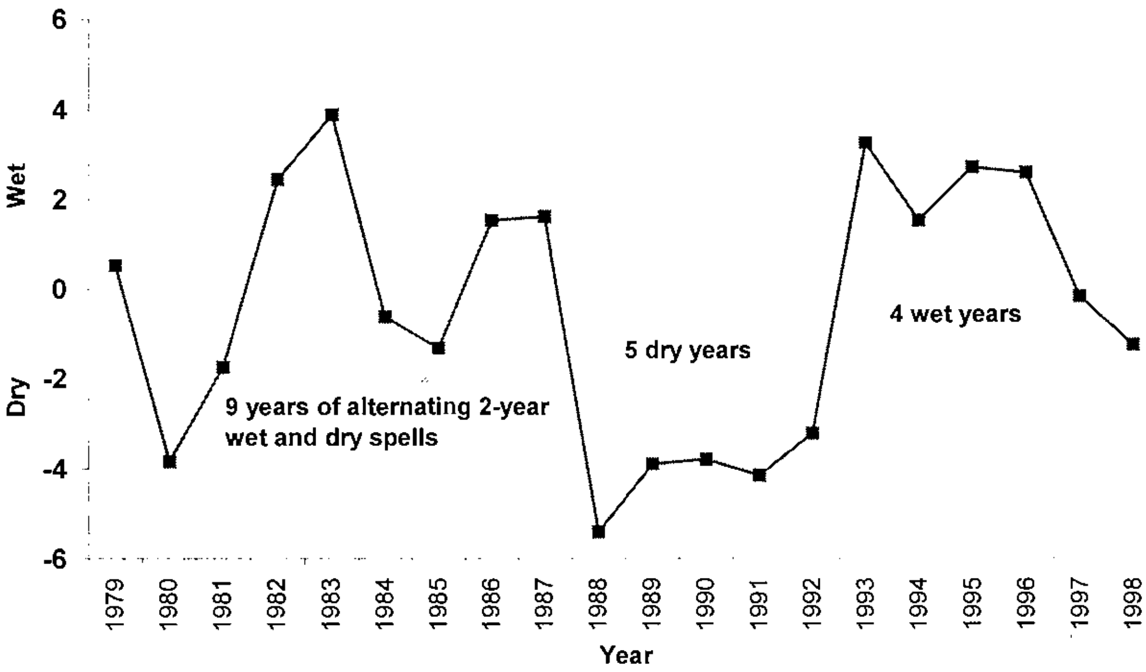

Figure 2. West-central North Dakota annual PDSI from 1979 through 1998

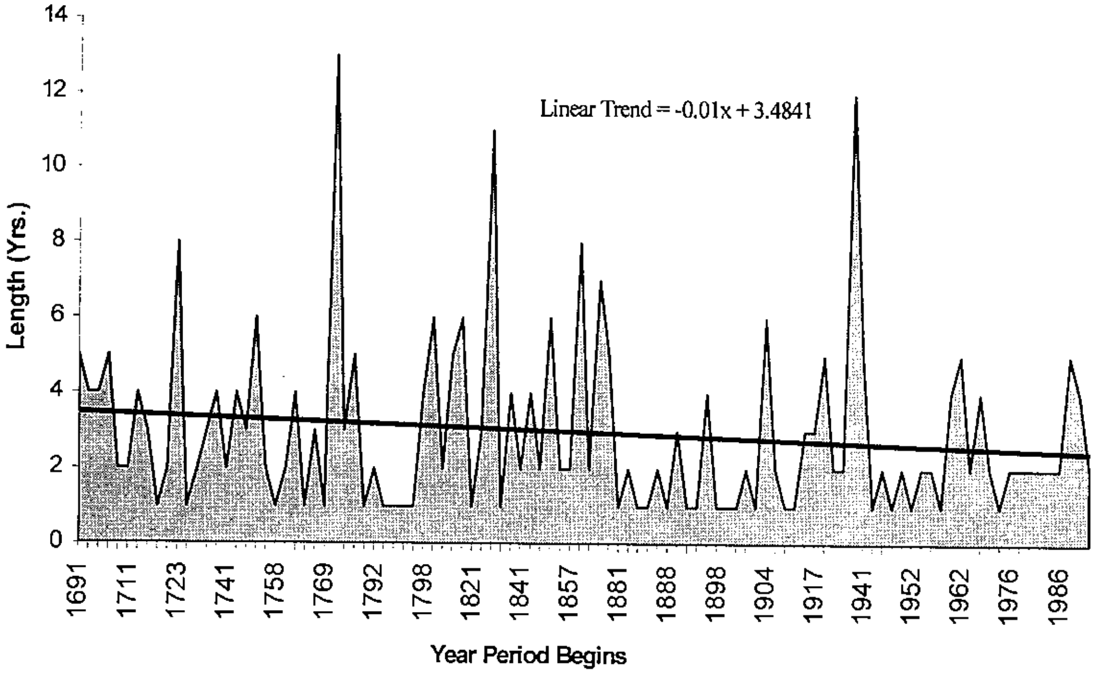

Figure 3. Lengths of consecutive west and dry periods in West-central North Dakota 1691-1998.

Cook et al. (1997) investigated drought rhythms in the western United States using the grid network of 115 regional PDSI reconstructions and found significant spectral peaks in the data at 20-23, 7.8, 4.1 and 2.5 years. A spectral analysis of the West-central North Dakota proxy PDSI data (Bickel, 2000) found proximate fits for the 20-23, 7.8 and 4.1-year periods observed by Cook, et al. (1997) in the larger western US data set. Periodogram evaluation and fitting of a spectral model (Figure 1) after removal of a slight linear trend (R^2=0.31) found significant periods of 4.1, 7.5, 8.3, 9.3, 12.8, 19, 22, 23 and 61.6 years in the data set. A 20-year moving average over the data showed 5 cycles that were modeled adequately with 58 and 72-year periods (R^2=0.58). Correlation coefficients from year-wise correlation of the 1979-98 interval with the data set were fitted with 12.8 and 9.3-year periods (R^2 = 0.30). The 9.3 to 12.8 year periods suggest the 11-year sunspot cycle, which Cook, et al. (1997) did not find in their investigation. A low frequency period at 58 to 62 years may be comparable to similar periods Michaelsen (1989) found in ENSO data. Cook et al. (1997) were primarily investigating drought rhythms in the western United States using the grid network of proxy PDSI records. They counted the number of years at each point with a PDSI less than –0.1 as a measure of drought conditions, and most of North Dakota was outside the more drought-prone areas.

Discussion

The PDSI is a valuable tool in baseline and bond release evaluations for several reasons. Monthly PDSI, PHDI, temperature and precipitation for the NOAA climatic divisions of the U.S. are readily available from NOAA Internet sites. The reconstructed annual PDSI allows long-term assessment of climatic patterns that can extend back to the 17th Century while weather data regularly measured with instruments extends into the late 19th or early 20th Century for most of the western U.S. The structure of the index makes analysis of intensity, duration and frequency of wet and dry periods easy over this multi-century range. An analysis of runs of signs is an easy measure of duration using the Palmer Index.

Given the long life of western mines and the role of climatic variability in their operation and reclamation, analysis of climate is an essential aspect of evaluating reclamation success. Results suggest that an analysis of PDSI can provide more useful baseline and final bond release information than an evaluation of temperature and precipitation data alone, because:

1. The regional, seasonal and annual moisture regime can be succinctly characterized.
2. Palmer Indices can provide substantive data for PHC assessment of stream flows, spring flows, well responses, recharge fluxes, drought and water use patterns.
3. The long-run data sets available provide a sound historical basis for defining abnormal dry or wet conditions and making climatic comparisons over time that can provide insights for mine and reclamation planning relative to water management, surface stability, revegetation and public perception of mining effects on water resources.
4. Palmer Indices are useful for differentiating between climatic effects and the effects of mining on environmental variables.
5. Successful reclamation results, and the moisture events that they have persisted through, can be compared to historic records as an indicator of long-term reclamation stability and permanence.

The concern during the formation of SMCRA was reclamation practices that may produce successful results for a few initial years but not persist through variations in the arid and semi-arid climate of the western U.S. Thus each instance of reclamation would be exposed to at least 10 years of climate in the absence of 1) a body of regulation to prescribe and measure reclamation and 2) a means of inferring stability and permanence. A system of massive regulation is now well established through federal and state SMCRA-based programs, and successful reclamation for final bond release is actually controlled by a large and detailed set of performance standards specific to vegetation, hydrology, soils, land stability and wildlife. These requirements in the North Dakota regulations are summarized as 75 to 80 major items on checklists for bond release applications.

The mining and regulatory communities in each distinct coal-producing region quickly develop a set of successful reclamation practices in response to environmental conditions and the performance requirements of regulations. With only slight variation, these techniques are common knowledge and used throughout the regional industry. This common usage of successful practices in a particular mining district is as old as mining itself. In terms of assessing stability and permanence, the object to be measured is the success of these practices over a full range of temporal variability. Climatic analysis, particularly of moisture regime, provides a means of assessing the stability and permanence of reclamation practices and of inferring their persistence through future variations in regional climate.

The data to carry out sound temporal analysis are generated by mines as extensive baseline and life-of-mine environmental data to meet permit requirements. Long run data sets exist in established mining districts to evaluate stability and permanence of reclamation during variations in wet and dry conditions in the regional climate. Once the products of a set of reclamation practices have proven successful and persisted through the high frequency cycles and typical severe periods of regional climate, there is no need to attach a time period to each land tract in addition to performance standards and guidelines requirements.

A logical alternative to the present liability period requirement on each reclaimed tract would be for each distinct climatic and coal producing region to have a 10-year minimum liability period in force until successful reclamation results from the set of common SMCRA-based practices have survived variations in drought and wetness on the scale of high frequency cycles in the regional climate. Once a set of successful reclamation practices and the persistence of their results can be demonstrated, the 10-year minimum liability period can be eliminated and bond release controlled solely by the performance based requirements in regulations. West-central North Dakota is an example of a western coal-producing region with established surface mining and regulation prior to SMCRA. However, the 20-year period from 1980 to the present can be considered the period of SMCRA-based reclamation. The high frequency cycles in the regional PDSI record range up to about 23 years. Drought and wet periods of notable duration and intensity have occurred from the late 1980s through the present and are well documented in the regional PDSI. Successful reclamation to post-mining land uses and of water resources have been proven during this interval. Extensive and detailed documentation is feasible to show application of these reclamation practices and survival of their successful results under the stresses posed by regional climate variation. Once this evaluation was successfully completed, removal of the 10-year minimum liability period in the next 5 years would be reasonable.

Removal of the 10-year minimum liability period in such instances would speed bond release by allowing more orderly formation of logical land use units out of the patchwork of reclamation dates, land use and ownership characteristic of large-scale western mines. The blanket 10-year delay in bond release can hamper the formation of logical ownership and agricultural management units needed for efficient bond release. The approach provides a direct measurement of reclamation stability and permanence closer to the intent of SMCRA. A climatic analysis of reclamation results is more grounded in science and reclamation technology than an arbitrary 10-year period - that, by itself, is not linked to any measured performance requirement. Most important, the approach doesn't alter the performance standards that actually control regulatory compliance and bond release.

The alternative has some disadvantages not the least of which is the 10-year minimum liability period's stature as a cornerstone of SMCRA. A 10-year period is unambiguous while a climate-based alternative requires detailed analysis and interpretation. The minimum liability period has always been a part of the SMCRA landscape, and time requirements in several performance standards assume a minimum liability period is in place. These requirements would have to be revised to periods dictated by technology of the respective fields. The need for change is not great at present because of the low volume of final bond release activity in western states. As mining regions mature under SMCRA, the amount of acreage to be bond released will increase as will the documentation of reclamation stability and permanence. At that time, stakeholders will be less tolerant of ineffective delays from a minimum liability period applied to proven reclamation.

The two essential questions concerning climatic periodicity are, have the last 20 years included enough variety in climatic events to assure that modern mine reclamation has successfully coped with conditions likely to occur on the scale of centuries, and how does the 20-year span of SMCRA compare with the periods of cycles in the regional climate? The duration and intensity of events over a period is more important than pattern. Strong but complex periodicity exists in all climatic data, so any 20-year segment would correlate with multiple intervals over a 300 year span in such a system.

Comparisons of paleoclimate with annual scale mine-related events become less meaningful further back in time, because there are few high-resolution proxy climatic data for the western U.S. before the 17th Century. High quality tree ring chronologies from long-lived tree species are uncommon and records from even less common banded fluvial, eolian, and lake sediments rarely have the distinct and continuous annual record of tree rings. Woodhouse and Overpeck (1998) reviewed reconstructed drought information for the Great Plains region and noted that two drought events in the 13th and 16th Centuries evidently exceeded the severity, length and geographic extent of 20th Century droughts, and similar or longer drought periods occurred prior to the 13th Century.

The duration and intensity of events in the PDSI data agree well with climatic events that were notable for their impact on human affairs. Although, the duration of spells defines extreme wet or drought periods in the PDSI record better than their intensity, the severe drought years, 1934, 1936, 1937, 1988 and 1991 mark the 1930's and the 1988-92 droughts. Wet events are more prominent in the climatic record for west-central North Dakota than drought; however, the region is commonly perceived as being drought prone largely because dry spells of moderate intensity or length have far greater impact on human affairs than wet spells of comparable severity and duration.

The 20 years of modern reclamation have probably encompassed the high frequency patterns in the regional climate. All of the currently operating large-scale surface mines in North Dakota will continue for several more decades in operation or final reclamation. At least 50 years of reclamation practice and environmental monitoring can be anticipated for these operations that will span all but the low frequency climatic cycles. Although economically and emotionally hard to bear, stress of the above normal lengths and intensities of wet and dry events during the SMCRA years in western North Dakota have contributed to the quality and resilience of modern surface mine reclamation and the regulatory framework that guides it.

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