RANGE CONDITION AS INPUT TO WATER QUALITY MONITORING IN THE NORTHERN PLAINS

Eric C. Wood
Bruce K. Wylie
Jesslyn F. Brown
David J. Meyer
Susan Maxwell
Science Staff
SAIC, USGS/EROS; Sioux Falls, SD 57198
woodec@usgs.gov

Bradley C. Reed
USGS Flagstaff Science Center, Flagstaff, AZ 86001

ABSTRACT

Federal Clean Water Act requires that states develop Total Maximum Daily Loads (TMDLs) for water bodies. Once the state has developed an inventory of TMDLs, it is required to provide public notice of the report and have it approved by the Environmental Protection Agency. The South Dakota Department of Environment and Natural Resources (DENR) is using the USDA's annualized Agricultural Non-Point Source Pollution Model to determine what land use changes are required to meet TMDL goals (South Dakota DENR, 2006). Of the approximately 450 parameters required for running the model, several are related to the condition of range and pasture sites and their respective management practices. Range condition is highly correlated with the nature of runoff occurring in a site. In addition to assisting the DENR, USGS is interested in improving its overall ability to monitor Northern Plains range condition with particular emphasis on the seven state study area (Colorado, Kansas, Montana, Nebraska, North Dakota, South Dakota, and Wyoming) being addressed by the Drought Monitoring, Carbon Cycle Research, Phenological Trends and other projects. It is understood than no one project can develop tools that adequately characterize the dynamics of the region's rangelands, but by developing a suite of tools brought together from a number of projects there exists the opportunity to provide state, regional, and tribal land managers with the ability to address their particular needs.

INTRODUCTION

Section 303(d) of the federal Clean Water Act requires that states develop Total Maximum Daily Loads (TMDLs) for water bodies. TMDLs are calculations to determine the sum allowable load of a pollutant from all contributing point and nonpoint sources that a water body can receive and still meet the applicable water quality standards. Once the state has developed an inventory of TMDLs, it is required to provide public notice of the report and have it approved by the Environmental Protection Agency.

The South Dakota Department of Environment and Natural Resources (DENR) is using the USDA's annualized Agricultural Non-Point Source Pollution Model (AnnAGNPS, an annualized multi event modification of the AGNPS model; http://wmc.ar.nrcs.usda.gov/technical/WQ/modeldesc.html) to determine what land use changes are required to meet TMDL goals (South Dakota DENR, 2006). Of the approximately 450 parameters required for running the model, several are related to the condition of range and pasture sites and their respective management practices. Range condition is highly correlated with the nature of runoff occurring in a site.

Overgrazing and degradation of range condition decreases water infiltration, increases erosion, reduces site productivity, alters dominant species, and promotes the expansion of invasive species. Because the resources available to the DENR are not sufficient to support field testing of all range sites in South Dakota, DENR is cooperating with USGS EROS to explore the use of remotely sensed data and additional modeling approaches for assessing range condition on a state-wide basis. In essence, the DENR is researching methodologies for rapid characterization of range condition to meet the following objectives:

- Parameterize the Annualized Agricultural Non-Point Source Pollution (AnnAGNPS) model with emphasis on range condition
- Determine the trends in range condition for any given range site
- Determine how a site is performing compared to sites with similar characteristics, i.e. against a site's "potential"

In addition, USGS is interested in improving its overall ability to monitor Northern Plains range condition with particular emphasis on the seven state study area being addressed by the Drought Monitoring and other projects (Colorado, Kansas, Montana, Nebraska, North Dakota, South Dakota, and Wyoming).

BACKGROUND

Five research projects at USGS's EROS facility in Sioux Falls, South Dakota and Science Center in Flagstaff, Arizona are related to monitoring various aspects of range health and productivity, both historical and real time. A team approach combining datasets and methodologies from these projects could assist the South Dakota DENR in addressing its modeling problems and still meet their own USGS project goals. Those projects include the following:

- Drought Monitoring (EROS)
- Phenological Trends (Flagstaff)
- NASA REASoN CAN - Rangeland Management (EROS)
- Agricultural Classification for the South Dakota DENR (EROS)
- Carbon Cycle Research (EROS)

Drought Monitoring

Drought is one of the major impacts on vegetation growth and productivity, especially in the rangelands and rainfed croplands found on the Northern Plains (Brown and Tadesse, 2003). A joint effort by the U.S. Geological Survey's EROS Data Center, the National Drought Mitigation Center, and the High Plains Regional Climate Center is underway to develop and deliver timely geographic information on drought at a 1-km resolution (Brown et al., 2006). Researchers have developed methods for regional and sub-county scale mapping and monitoring drought effects on vegetation. An experimental drought indicator, the Vegetation Drought Response Index (VegDRI), is calculated using data mining techniques that integrate complex information from satellite measures, climate-based drought indices, land cover type, soils characteristics, and additional environmental factors (see Figure 1). Future development will expand these techniques over the lower 48 states and assess the utility and validity of the VegDRI data. Further information and maps can be found at http://gisdata.usgs.net/website/Drought_Monitoring

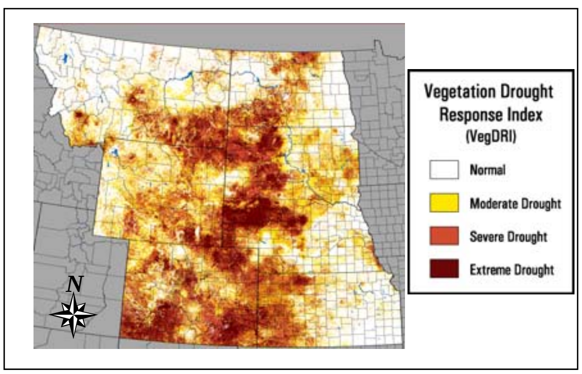

Figure 1. Vegetation Drought Response Index for July 25, 2002. (Brown et al., 2006).

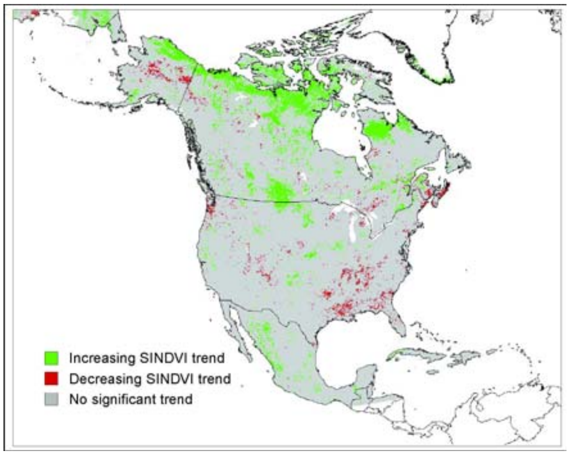

Figure 2. Trends in seasonally integrated NDVI (SINDVI) for the years 1989 to 2003. (Reed, 2006).

Phenological Trends

This project focuses on a trend analysis of satellite-measured changes in seasonal greenness characteristics for North America (Reed, 2006). Information provided by satellite-derived phenological metrics related to vegetation condition are being analyzed based on climate data, agricultural statistics, land use change and other ancillary information to explain increasing and decreasing trends in productivity (see Figure 2). The research hypothesis is: Climate and land use change during the time of the AVHRR satellite sensor record have caused an alteration in seasonal dynamics of vegetation in the conterminous United States.

NASA REASoN CAN - Rangeland Management (CAN-02-OES-01)

Sinte Gleska University on the Rosebud Sioux Reservation was awarded NASA funding through the Research, Education and Applications Solutions Network (REASoN) Cooperative Applications Notice (CAN) for its proposal "Using Geospatial Information to Enhance Tribal Rangeland Management Through Education and Understanding" to utilize NASA space data and related technologies for natural, economic and cultural resource management on tribal lands, with emphasis on rangelands. Over the last 150 years, the northern short grass prairies have been reduced to 40 percent of their original size, profoundly disrupting Lakota Sioux lifeways. It is believed that current and historical rangeland management practices have adversely affected the abundance and distribution of native plant species having economic, medicinal and cultural value to the Lakota. These practices include the alteration of natural land cover, the fragmentation of prairie ecosystems, and the introduction of exotic plant species.

The project is developing decision support tools for tribal rangeland management and providing education to tribal communities seeking to use these tools. A synoptic scale effort leverages the DENR work described below. The range site effort uses higher resolution Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper plus (ETM+) data to monitor and predict rangeland productivity at a finer scale. Ultimately, this effort will use meteorological and soils data to isolate these effects from management practices to assess both within-season and longer term management practices on rangeland systems.

Agricultural Classification for the South Dakota DENR

This project was collaboration between USGS EROS, the South Dakota DENR, and the East Dakota Water Development District. Crop maps for the years 200and 2001 for South Dakota were created to study the relationship between land use and water quality. An object-oriented knowledge-based approach was used to classify the crops in South Dakota using a combination of Landsat imagery, agricultural statistics and the USGS National Land Cover Dataset (NLCD) digital map (Maxwell et al., 2004).

Carbon Cycle Research

The Carbon Cycle Research team has two general areas of study, the first focusing on mapping range conditions, and the second on comparing maps of carbon fluxes produced by independent methods (Wylie et al., 2003; Gilmanov et al., 2005). In 2005 the project developed innovative approaches to integrate reflectance data with point fluxes of carbon to model an understanding of this "land cover performance" and to predict ecosystem performance regionally. This team continues to exploit and integrate various sources of remotely sensed imagery with geospatial and management information to monitor, develop, and implement quantitative assessments of both the status and the function of the land cover, particularly rangeland.

The first efforts at modeling range condition were developed based on the conclusion that Time Integrated Normalized Difference Vegetation Index (TIN) values have been demonstrated to be a surrogate for photosynthetic potential, gross primary productivity, and green biomass (see Figure 3). Long-term trends in SPOT VEGETATION

TIN can identify areas associated with climate change, climate variation, and management. In addition, seasonal NDVI metrics, like maximum NDVI, can be predicted from climate and other data (Schwabacher and Langley, 2001; Wessels et al., 2004). They investigated the difference between year-specific TIN predicted from climate and soil data sets and observed TIN as a means for identifying degraded or heavily grazed rangelands (Wylie et al., 2005). Degraded or consistently heavily grazed rangelands represent areas with increased vulnerability to erosion or areas with low vegetation cover relative to climatic and soil potential. This approach compensates for variations associated with drought and wet years and reveals areas having TIN greater or less than their climatic potential for a given year. This method was applied to rangelands in the Northern Great Plains from 1998-2001 at 1-km resolution.

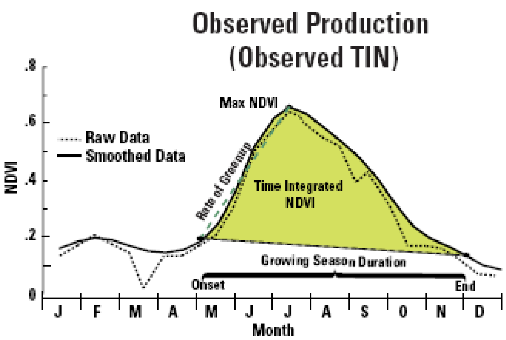

Figure 3. Time integrated NDVI (TIN). Reed et al., (2003).

METHODOLOGY

This study is addressing two problems: 1.) How to develop better inputs of range quality for the AnnAGNPS model. 2.) How the present state of any rangesite compares to its historical state. The results of this latter analysis are beneficial in assessing the appropriateness of present range management and alternatives in the context of the rangeland potential. The methods being used in the five USGS projects described above are being applied to these problems. The work is ongoing and only intermediate results have been obtained.

All datasets were clipped to one or both of the studies areas of interest, the seven state Drought Monitoring footprint, and specifically South Dakota. The South Dakota work has been be restricted to all lands in South Dakota that have been designated “rangeland” or similar grassland landcover types by the USGS MRLC 1990 land use / land cover product and the 2000 product that are presently being used as a baseline by the DENR. Although not required by the South Dakota’s TMDL assessment effort, for the sake of completeness, this study includes all relevant Tribal lands located in South Dakota.

South Dakota 2000 Crop Maps

Annual crop maps were needed to study the relationship between land use and water quality in South Dakota. A rule-based classification methodology was developed so that a consistent, rapid classification methodology was applied to each Landsat image to be interpreted (Maxwell et al., 2004). An object-based approach using eCognition software (eCognition User Guide, 2003) was used to reduce the complexity of the classification process, enable shape and contextual attributes to be used, and reduce the salt-and-pepper effects common in output products based on per-pixel approaches. Object-based systems allow for spectral information as well as many other characteristics such as texture, shape, and spatial context to be used. Object-oriented image classification allows the image to be interpreted closer to the way people see the landscape - as individual objects and their relationship to each other – not just as individual pixels (Blashke and Strobel, 2001).

Landsat images were purchased to cover the entire state of South Dakota for 2000. Early spring and late summer images were required to distinguish individual crop species based on their phonological characteristics. A decision was made to not perform classification on the Landsat images for 2002 due to the poor spectral separation of crop types resulting from the severe drought that year.

The primary ancillary data sets used in the classification included general land cover map (Source: USGS National Land Cover Dataset map), and a roads layer (Source: USGS derivative product from Geographic Data Technology, Inc. A combination of crop calendars, crop area estimates and knowledge of unique crop spectral characteristics were used to refine NLCD general land use classes (e.g., grassland, row crops) to crop specific classes (e.g., corn, soybeans, alfalfa, spring grains, and winter wheat). The NLCD map identifies 21 land use / land cover classes – including 4 general agricultural groups (row crops, small grains, hay/pasture, and fallow). These four general agricultural groups and the NLCD grassland class were grouped into one unit for further refinement to specific crop type. All other classes were assumed to have not changed since 1992. Obviously, some changes would have occurred during the time from 1992 to 2000 (e.g., near urban areas); however, these changes would be minor in terms of total landscape change.

Range condition modeling (original)

1998-2001 The original range condition model was developed using a robust regression model to predict vegetation production from soil and climate data (Wylie et al., 2005). Maps of growing season time integrated NDVI (TIN) from SPOT Vegetation were used to represent the observed vegetative production for each study year. Next, a large number of random pixels were sampled over several years to develop a regression model between the vegetation production (the dependent variable) and climate and soil factors, including precipitation, temperature, STATSGO range production estimates, percent clay, available water holding capacity, or long-term average TIN (the independent variables). The monthly temperature and precipitation estimates were from the CMAP interpolated climate data sets.

The model was applied over the Northern Great Plains rangelands to make annual maps of expected vegetative production. The yearly differences were computed (expected minus observed production) to identify areas of anomalously low or high vegetative performance. These are then assessed across multiple years to identify areas where the estimated production is consistently lower or higher than the observed production. This approach compensates for production variation associated with climate and reveals production variation associated with stress from a wide range of factors, including most import to this study, poor management.

Range condition modeling (revised)

This model is being developed as a revision of the one described above and presently focusing on the DENR requirements. The work is ongoing with the following describing its development to date (Wylie et al., 2005).

Several key revisions are being explored in the new model. The NOAA AVHRR NDVI 1989-present data sets created in the Drought Monitoring project were used to develop the TIN because they provide a longer record than SPOT Vegetation data (only available since 1998). The PRISM 8 km-climate data sets of monthly minimum and maximum temperature and precipitation (http://www.ocs.orst.edu/prism/products/) were used rather than the CMAP dataset. Monthly climate variables were replaced with data summarized over seasonal periods (see Table 1). Smart et al. (2004) and Heitschmidt et al. (2005) noted the importance of early summer precipitation in the NGP. The average TIN (avg_TIN) was added as a potential independent variable to help account for variations in site productivity at a finer resolution than the STATSGO soils data, which was eventually removed. The analysis for South Dakota was confined to “rangeland” that was present in both the 1990 NLCD landcover and 2000 South Dakota crop maps (Maxwell et al., 2004).

The multiple regression was derived from 34128 random observations drawn from the datasets covering the years 1998-2004 (approximately 5,000 random observations per year) and accounted for 67% of the variation in TIN and soils information was replaced by avg_TIN. The final regression model was as follows:

$$TIN = -13.4 + 0.81\ avg\_TIN + 0.077\ p456 + 0.53\ mx3 - 0.24\ mnwin - 0.34\ mn78$$

Variable	Period	Abbreviation
Early Summer	April to June	p, mn, or mx456[1]
Mid Summer	July to Aug.	p, mn, or mx78
Fall	Sept. to Oct.	p, mn, or mx 910
Winter	Nov. to Feb.	p, mn, or mxwin
Spring	March	p, mn, or mx3
average TIN	1989 to 2004	avg_TIN

[1]p = precipitation, mn = min. temperature
mx = max. temperature

Table 1. Inputs to revised range condition model.

DISCUSSION / RESULTS

Range condition modeling (original)

This approach strives to remove or account for climatic effects and shows the effects of management and other stresses. The range condition maps are a tool for monitoring changes in the ecosystems, as climate change is expressed and as invasive species expand. We anticipate detecting ecological changes, such as conversion of a sage brush system to one dominated by an invasive annual grass (for example, cheat grass).

Areas with observed TIN similar to the TIN estimated from climate (plus or minus the mean absolute error) were considered to be rangelands in fair condition (see Figure 4a). Annual maps showing low and high TIN relative to their climatic potential TIN were produced (see Figure 4b) and areas that were consistently above or below their climatic potential from 1998 to 2001 were identified. Range condition maps compared with higher resolution imagery were found to be consistent interpretations of degraded or good condition rangelands.

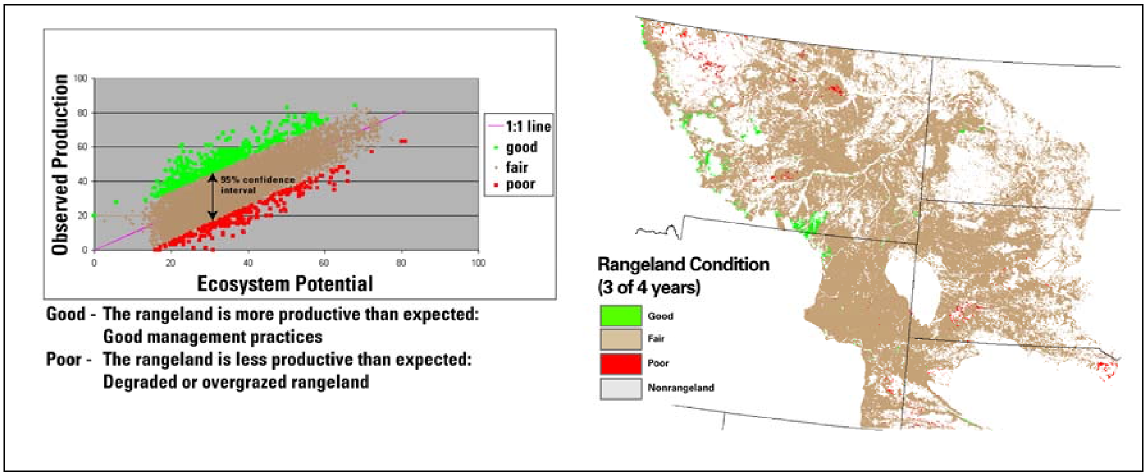

Figure 4a.

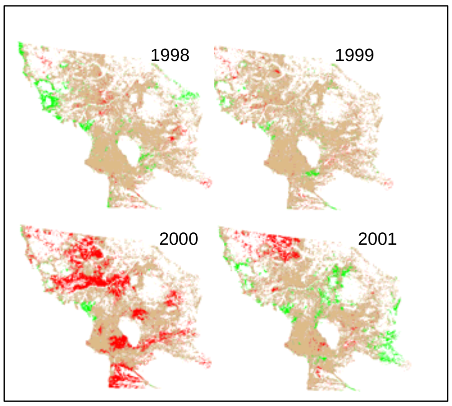

Figure 4.b

Figure 4. Ecosystem potential compared to observed production. The scatter plot shows the estimated potential production (climatic potential) on the horizontal axis and the TIN (observed production) on the vertical axis. Pixels are classified into three groups: good, fair and poor rangeland production. Interpreting the index as the “climatic potential” for range productivity, areas mapped in green are considered more productive than expected and those in red less productive, possibly degraded. (Wylie et al., 2005).

Range condition modeling (revised)

When consistency across multiple years was taken into account, mapped range condition agreed with indicators of range condition interpreted from higher resolution imagery. This approach can assist modeling efforts of carbon sequestration and erosion. This approach may also identify stressed or altered ecosystems.

The improvements of this model over the original are:

- Higher resolution PRISM climate data than climate CMAP data (0.25^{o})
- Longer NDVI data record than SPOT VEGETATION
- Seasonal not monthly climate data
- Simpler model with comparable accuracies
- Coarse resolution soils data were replaced by long term average TIN
- Use of confidence limits to identify anomalous pixels
- A future revision will be look at the variation in production against potential as a continuous result rather than a three tiered class. This will allow us to better statistically analyze the trends over time and to build a tool to graph an individual pixel’s performance.

NASA REASoN CAN – Rangeland Management

Figure 5. illustrates early results from this effort – using multi-date Landsat data to discriminate between different functional types of grasslands at different broad levels of productivity. Using images collected on May 19 (TM), June 12 (ETM+), July 30 (ETM+) and October 10 (TM) in the year 2000, a temporal NDVI feature vector was used to classify warm versus cool season grasses. Two other classes were included which require special attention due specific relationships between NDVI and actual productivity – Sand Hills systems where bright underlying soils lower the apparent productivity, and dense mesic-hydric systems where NDVI saturates. A second step, using the soils data to stratify range sites having similar field-observed productivity, is currently being used to address these special classes.

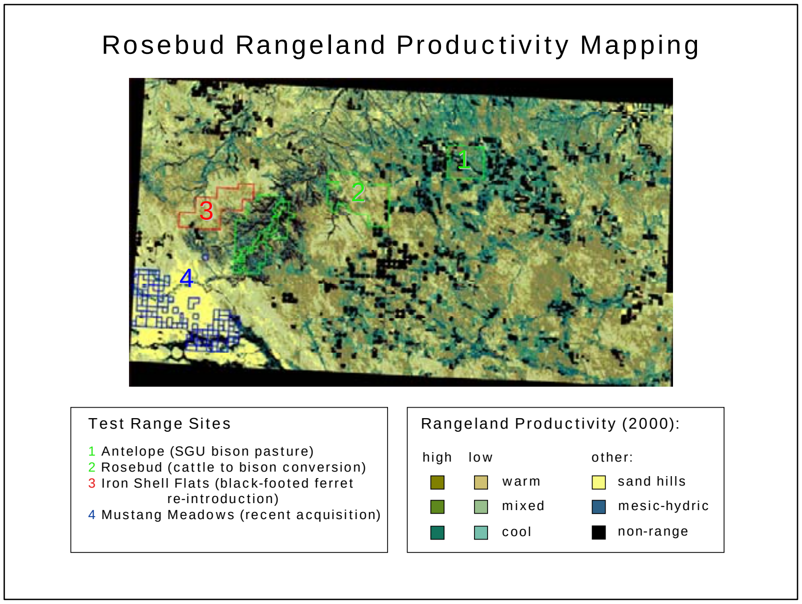

Figure 5. Rosebud Sioux Tribe rangeland productivity mapping.

CONCLUSION

A number of methods have been developed at the USGS and elsewhere to monitor rangeland on the Northern Plains. Datasets developed by the Drought Monitoring project such as the AVHRR Time Integrated NDVI are key for looking at long-term production trends. The Drought Monitoring project, using a variety of datasets from a wide range of agencies has also develop the Vegetation Drought Response Index (VegDrI) which allows for the monitoring of range condition on a regular basis throughout the year. The work of the Phenological Trends and Carbon Cycle Research projects has given us the ability to look at the trends in rangeland performance over time (1989 – present). Projects such as NASA REASonCan or the South Dakota DENR TMDL inputs are addressing specific problems at tribal and state levels.

The range condition mapping approach described above provides a unique opportunity to monitor and assess regional range land performance while compensating for climatic variation, potentially revealing management effects. This approach could be used to assess how rangeland systems respond to climate change and multiple years of droughts, just to mention a few applications.

While certain problems still have not been sufficiently well addressed, including the determination of the existence of long term degradation, misclassification of rangeland, effects from land use /landcover change on the analysis, scale of regional soils mapping, etc., these approaches are all moving us closer to a systematic look at range condition. It is understood than no one project can develop tools that adequately characterize the dynamics of the region's rangelands, but by developing a suite of tools brought together from a number of projects there exists the opportunity to provide state, regional, and tribal land managers with the ability to address their particular needs.

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