FINAL REPORT

Identification of Source Areas Affecting Dust Concentrations at Salt Creek and White Mountain Wilderness Areas in New Mexico

Prepared for:
New Mexico Environment Department and;
Western Regional Air Partnership

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Definitions

20% worst-case visibility day	A day with estimated aerosol extinction coefficient higher than the 80th percentile of aerosol extinction coefficient measurements for a given year
Worst dust day	A 20% worst-case visibility day where soil dust accounted for more than 20% of estimated aerosol extinction coefficient
WEG	Wind Erodibility Group is an indicator of soil susceptibility to wind erosion, estimated by USGS using soil properties
LU/LC	AVHHR classification of Land use and Land cover data into 13 categories for North America
DEP	Dust Emission Potential is a metric of soil susceptibility to wind erosion estimated as follows:
LU/LC-derived DEP	Dust Emission Potential estimated through the relationships between land use and wind erodibility group. Only for Mexico
WEG-derived DEP	Dust Emission Potential calculated using only wind erodibility group. Only for U.S.A.
Backward trajectory	Trajectory of air mass is the backward-time integration of the position of a parcel of air as it is transported by the wind to the site
Trajectory speed	The speed of the air mass at a given time of the backward trajectory. Because trajectory resolution is 1-hour, the distance between two trajectory points is a measure of the speed of the air mass between these two points.
Trajectory density	Estimated for trajectory points using Kernel-type probability density functions.
WDI	Windblown Dust Index estimated as the product of DEP and the normalized density of trajectories. It highlights areas that most likely influenced airborne dust concentrations during the 2001-2003 worst dust days period
WDI/distance	The ratio of WDI to distance from-the-cell-to-the-site. It highlights areas located in the vicinity of the site that may affect airborne dust concentrations

1. Introduction

Soil dust is a major component of atmospheric aerosol affecting visibility at Class I areas in the Western United States. It is defined as the sum of Fine Soil mass (FS) and Coarse Mass (CM) as measured by monitors in the IMPROVE network, which operates 24-hr filter samples on a one in three day basis. CM is the difference between PM_{10} and $PM_{2.5}$ fractions. FS is calculated from a linear equation based on the measured concentrations of five metals associated with mineral dust (Al, Si, Ca, Fe, and Ti) (http://vista.cira.colostate.edu/improve/Tools/AerTypeEqs.htm). They are inherently subject to both positive and negative sampling and analysis biases including, dust-related CM overestimation due to inclusion of sea spray, non-soil organic debris, or emissions from wildfires. Dust concentrations have strong spatial and seasonal characteristics due to source variations in spatial scale, time, location, and causes of emission. For example, long-range transport dust events from Asian deserts influence almost the entire Western United States during spring while windblown dust occurs in a smaller scale throughout the year, either locally or in regional scale, due to high surface wind speed over soils that are susceptible to erosion.

Salt Creek and White Mountain Wilderness areas are part of the IMPROVE monitoring network. Figure 1-1 shows the location of sites, national forests and the road network near the sites. Table 1.1 includes information on the location and characteristics of each site. Analysis of 2001-2003 aerosol samples for both indicated that up to 35% of 20% worst-case visibility days ("worst days", hereafter) at the Salt Creek and White Mountain Wilderness areas are primarily due to high dust concentrations ("worst dust days", hereafter). Specifically, 22 and 10 worst days in Salt Creek and White Mountain, respectively, during 2001-2003 are associated with high dust concentrations. Recent analyses indicates that: (a) local/regional windblown dust and upwind transport from Mexico and Texas are the major events during the worst dust days and; (b) windblown dust accounts for up to 94% and 84% of total measured dust during worst dust days in Salt Creek and White Mountain, respectively (Kavouras et al., 2005).

Figure 1-1: Map of south New Mexico showing Salt Creek and White Mountain Wilderness. The background is a combination of elevation and relief images.

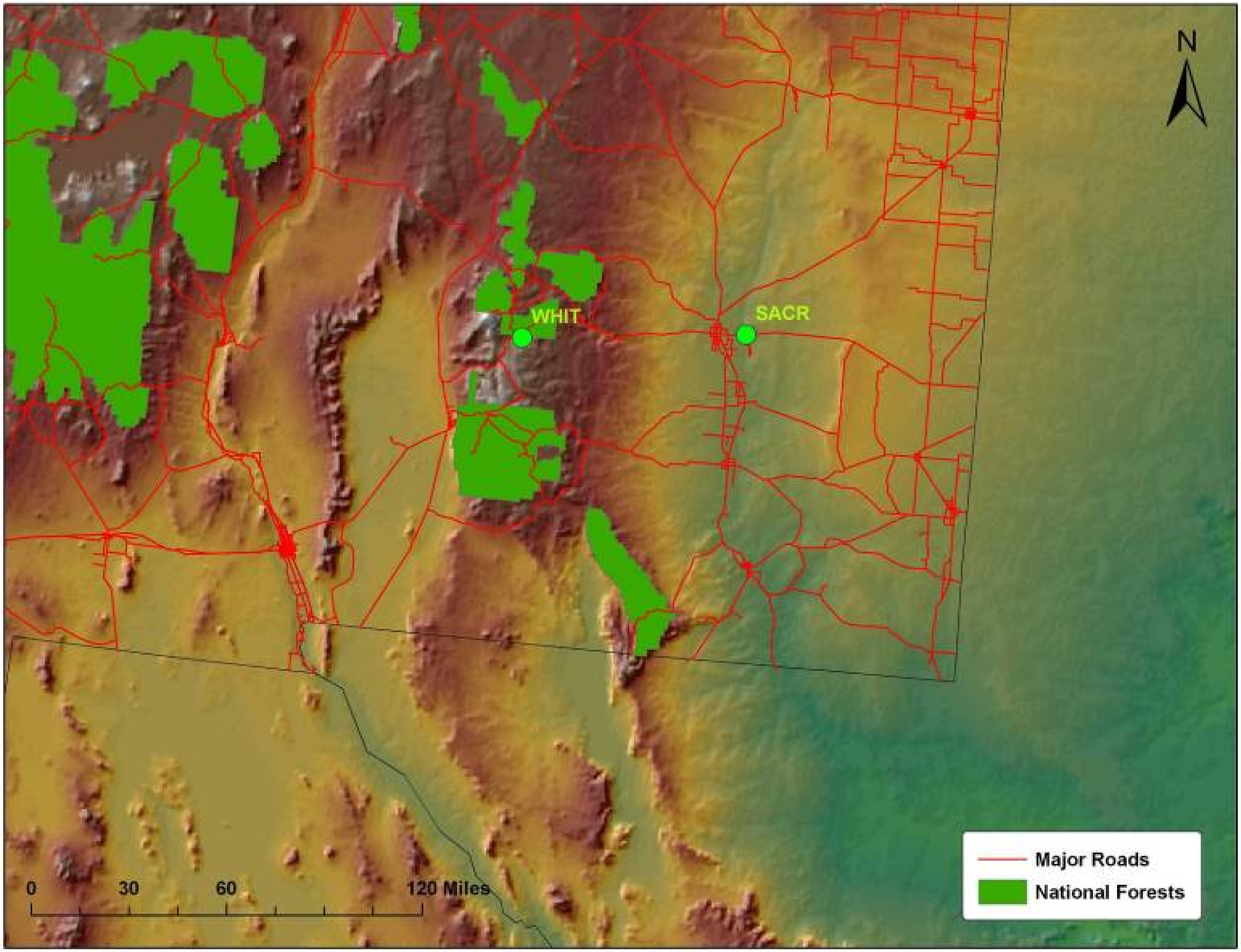


Table 1-1 Descriptions of Salt Creek and White Mountain Wilderness areas

SiteName:	Salt Creek	White Mountain
Site Code:	SACR1	WHIT1
State:	NM	NM
County FIPS:	017	027
County Name:	Grant County	Lincoln County
Latitude:	33.4598	33.4687
Longitude:	-104.4042	-105.5349
Elevation MSL:	1072.3333	2063.5
Improve Region:	WTEXA	MPLAT
Agency Name:	U.S. Fish and Wildlife Service	U.S. Forest Service
Start Date:	4/6/2000	1/15/2002

2. Objectives and methodology

The primary objective of this pilot study was to specifically identify the sources areas that most likely contributed to elevated dust concentrations at the Salt Creek and White Mountain Wilderness areas in New Mexico by:

A. developing a metric of soil susceptibility to wind erosion for the southern U.S. and northern Mexico using existing soil properties data;
B. identifying areas where the speed calculated from air-mass backtrajectory analysis, a surrogate for threshold surface wind speed, facilitated soil erosion;
C. calculating an index based on A and B that highlights geographical regions that were likely sources of windblown dust during the 2001-2003 worst dust days at both sites.

The approach utilized several existing tools in novel ways including soil erodibility maps, air mass backward trajectories and land use/land cover maps. These tools were combined to identify the potential sources of dust for all worst dust days at the two sites. While the identified area sources exert an influence at many locations in the US, the analysis here is restricted to the contribution of source areas to worst dust days at the Salt Creek and Whit Mountain sites over the 2001 – 2003 time period.

3. Dust Emission Potential (DEP) for US and northern Mexico

3.1 United States

Soil susceptibility to wind erosion controls the amount of suspended dust under specific surface wind conditions. It depends on a number of factors including soil texture, organic and mineral content, effervescence due to carbonate reaction with HCl, rock and para-rock fragment content, soil moisture, ambient temperature and precipitation (snow, ice) and soil disturbance from natural (e.g thunderstorms) and anthropogenic activities. Existing databases for soil erodibility are based on a limited number of measurements taken at specific areas.

Despite these limitations, the USGS has mapped the soil characteristics of the United States and based on textural properties has estimated the rates of wind erosion that certain areas are likely to experience. The Wind Erodibility Group (WEG) index provided by USGS was utilized to provide a screening level assessment of areas that were potentially large contributors to measured dust concentration through the wind erosion process. The WEG number ranges from 1 to 8, with 1 representing the most erodible soil types and 8 representing the least erodible soil types. WEG data for the 48 contiguous US states were downloaded from USGS Water Resources (Table 3-1).

Table 3-1 Description of soil properties for Wind Erosion Group values[a]

WEG	Description
1	Very fine sand, fine sand, sand or coarse sand
2	Loamy very fine sand, loamy fine sand, loamy sand, loamy coarse sand; very fine sandy loam and silt loam with 5% or less clay and 25% or less very fine sand; and sapric soil materials except folists.
3	Very fine sandy loam, fine sandy loam, sandy loam, coarse sandy loam, and noncalcareous silt loam that has 20% to 50% very fine sand and 5 to 12% clay
4	Clay, silty clay, noncalcareous clay loam that has more than 35% clay, and noncalcareous silty clay loam that has more than 35% clay. All of these do not

	have sesquic, parasesquic, ferritic, ferruginous, or kaolinitic mineralogy (high iron oxide content). Calcareous loam, calcareous silt loam, calcareous silt, calcareous sandy clay, calcareous sandy clay loam, calcareous clay loam and calcareous silty clay loam.
5	Noncalcareous loam that has less than 20% clay; noncalcareous silt loam with 12 to 20% clay; noncalcareous sandy clay loam; noncalcareous sandy clay; and hemic materials.
6	Noncalcareous loam and silt loam that have more than 20% clay; noncalcareous clay loam and noncalcareous silty clay loam that has less than 35% clay; silt loam that has parasesquic, ferritic, or kaolinitic mineralogy (high iron oxide content)
7	Noncalcareous silt; noncalcareous silty clay, noncalcareous silty clay loam, and noncalcareous clay that have sesquic, parasesquic, ferritic, ferruginous, or kaolinitic mineralogy (high content of iron oxide) and are Oxisols or Ultisols; and fibric material
8	Soils not susceptible to wind erosion due to rock and pararock fragments at the surface and/or wetness; and folists

[a] *WEG data were obtained from http://soils.usda.gov/technical/handbook/contents/part618p7.html#ex16*

The WEG index classification was used to identify geographic areas that were susceptible to wind erosion and may served as likely sources of windblown dust under appropriate meteorological conditions, i.e. high wind speeds. The WEG index was transformed to a Dust Emission Potential (DEP) with values that ranged between 0 and 1 as follows:

$$DEP = 1 - \frac{WEG - 1}{7} \qquad \text{Equation 3-1}$$

DEP values close to one indicated high emission potential; while DEP values close to zero indicated insignificant emission potential. Figure 3.1 shows the geographical variation of DEP values for the 48 contiguous U.S. states. Figure 4-1-2 shows the relationship between the WEG and DEP.

Figure 3-1 DEP values for contiguous US states

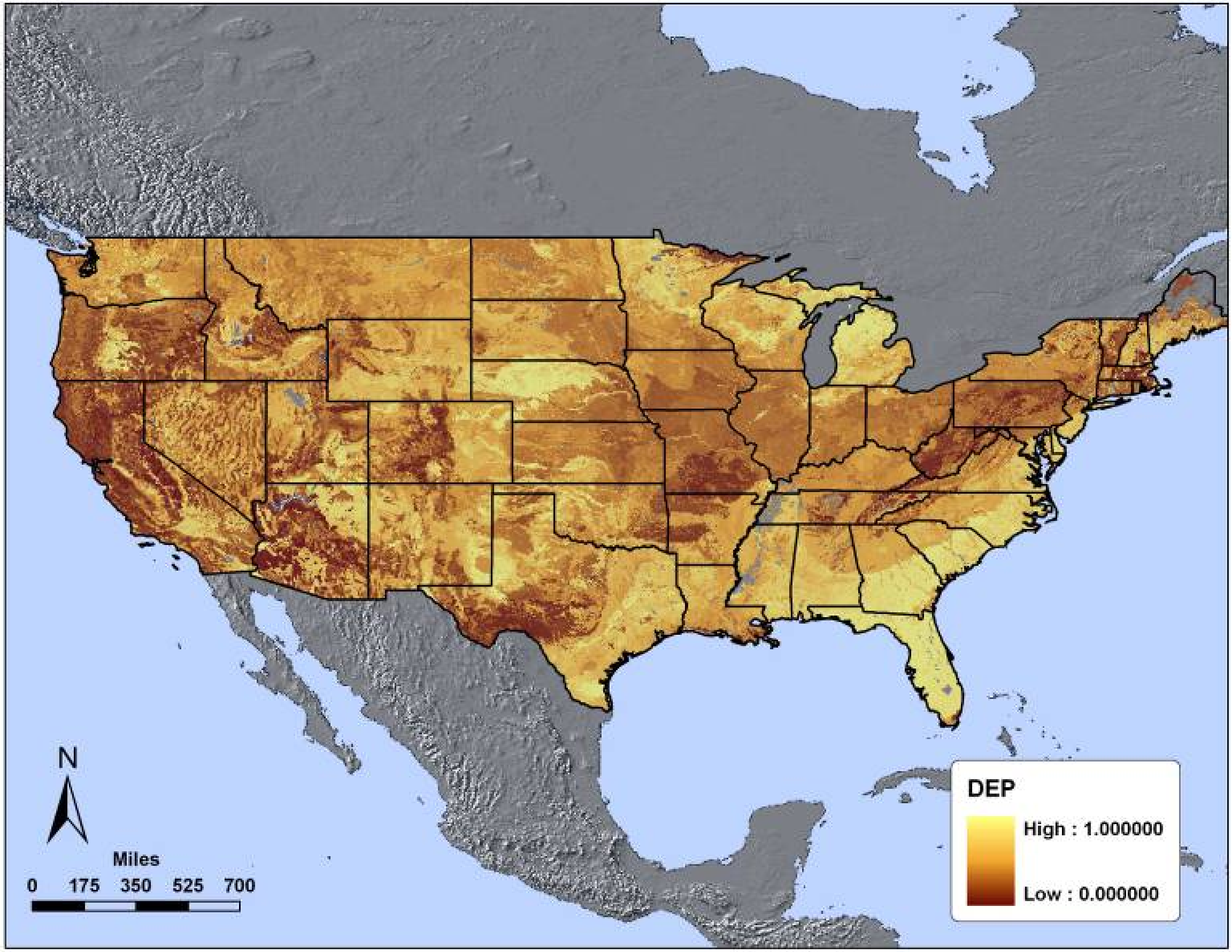
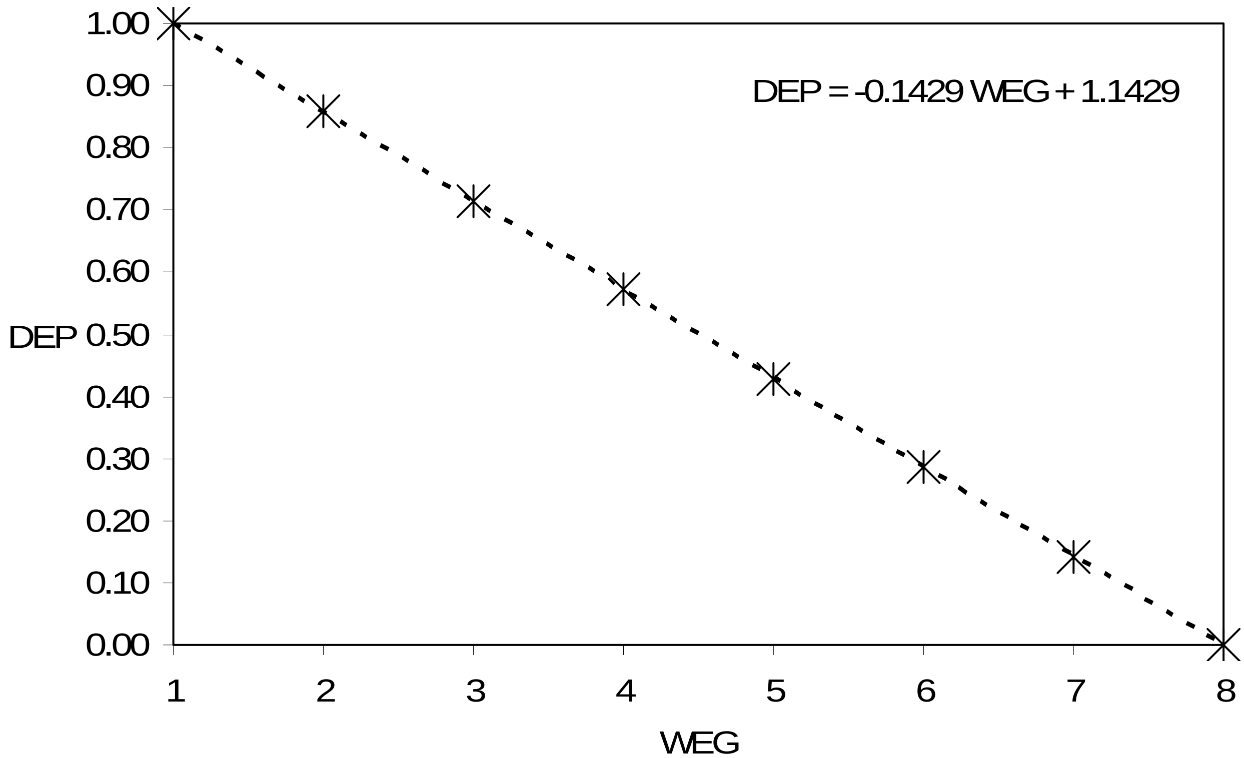


Figure 3-2 Transformation of Wind Erodibility Group (WEG) to Dust Emission Potential (DEP)



3.2 Mexico

Backwards air-mass trajectory analysis ("backtrajectory" hereafter) showed that the Salt Creek and White Mountain Wilderness areas were affected by air masses passing through northern Mexico and Baja California. This suggested a possible contribution of dust from those areas and that a metric for soil erodibility for Mexico was needed. To the best of our knowledge, geographic databases for soil properties in northern Mexico are not available at present. To overcome this limitation and in order to include Mexico in our analysis, several approaches were tried:

- use a "middle of the road" DEP value of 0.571429 (corresponding to a WEG index of 4) for all of northern Mexico;
- use a land use/land (LU/LC) cover geographic database as a standalone surrogate for wind erodibility;

- use a combination of USGS WEG and US and Mexico LU/LC data to infer Mexican soil erodibility values.

After detailed evaluation of the pros/cons for each alternative method (see Table 3.2), the combination of WEG and land use/land cover data was selected. The selected method involved the following steps:

- identify and obtain a LU/LC dataset for all of north America including Mexico;
- evaluate changes in DEP values for each LU/LC class at US regions near US-Mexico border (in California, Arizona, New Mexico and Texas states);
- divide southwest US states and northern Mexico into four regions with similar DEP values for LU/LC classes and estimate LU/LC- specific DEP values for each region;
- classify Mexican LU/LC data using estimated DEP values for each region.

Table 3-2 Analysis of pros/cons for each alternative method

Approach	Pros	Cons
DEP value of 0.571429 for Mexico	- Fast analysis by ArcMap - Compatibility with US DEP calculations*	- Misrepresentation of source areas near and far-away US-Mexico border
Only LU/LC	- Accurate representation of LU/LC - Fast analysis by ArcMap	- Not compatible with DEP estimation methods for US* - Differences in soil erodibility for the same land use
Combination WEG and LU/LC	- Compatibility with US DEP calculations* - More reliable representation of source areas near US-Mexico border - Validation using US DEP values	- Misrepresentation of source areas far away fro US-Mexico border - Work load to define areas and determine representative WEG values

** In terms of the range of DEP values from 0 to 1.*

The AVHRR Global Land Cover dataset covering all of North America was obtained from the NASA/NOAA Pathfinder Land (PAL) database. The database provided a 1 km by 1 km delineation of land use using 13 categories (See Table 3.3). Figure 3.3 shows the LU/LC for

Canada, US contiguous states, Alaska, and Mexico. Southwest US states (CA, AZ, NM and TX) were divided into four regions according to differences in DEP values for different LU/LC classes (Table 3.4 and Figure 3.4).

Figure 3-3 AVHRR Land Use and Land Cover for North America

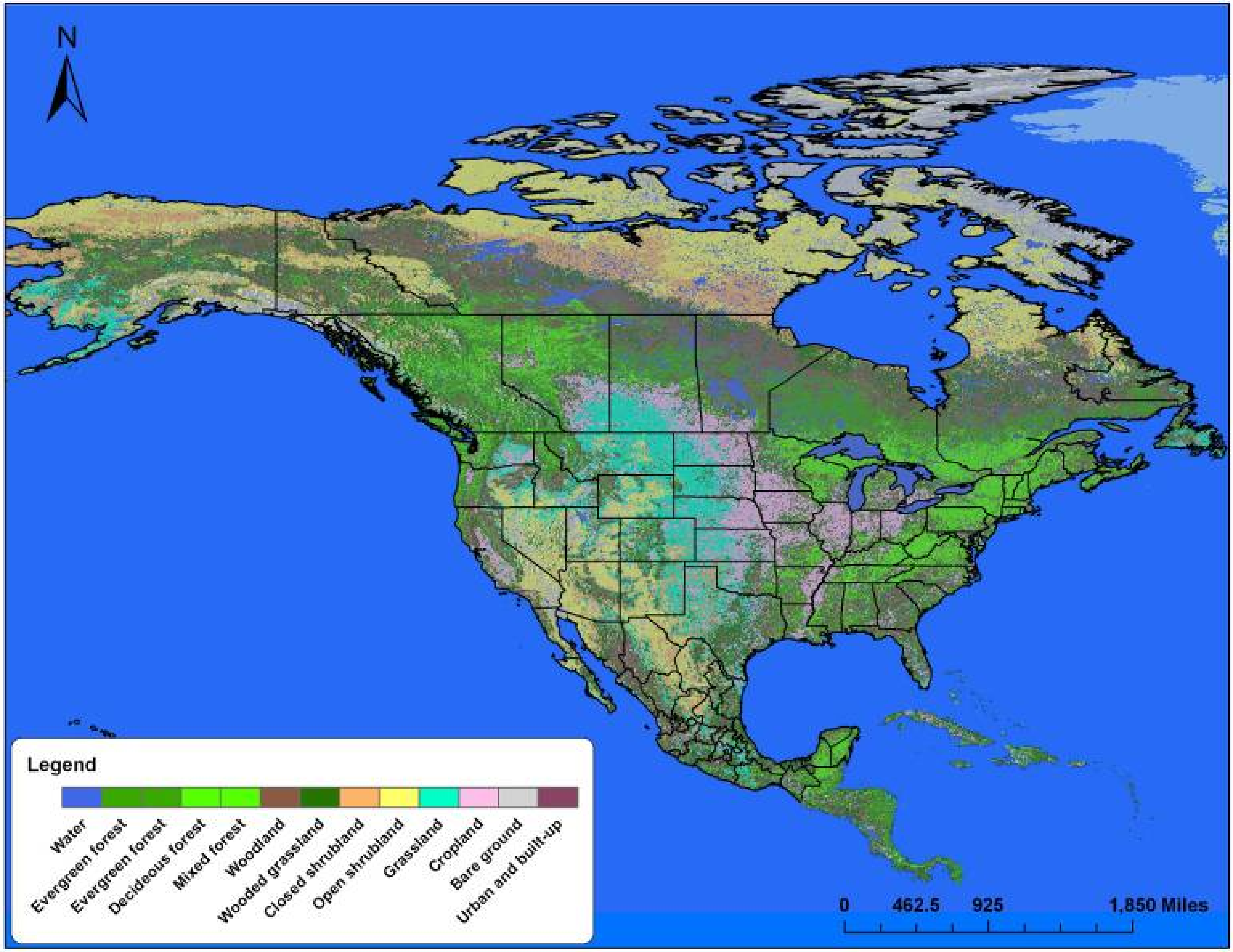


Figure 3-4 Classification of south US and north Mexico in four regions based on LULC and WEG data

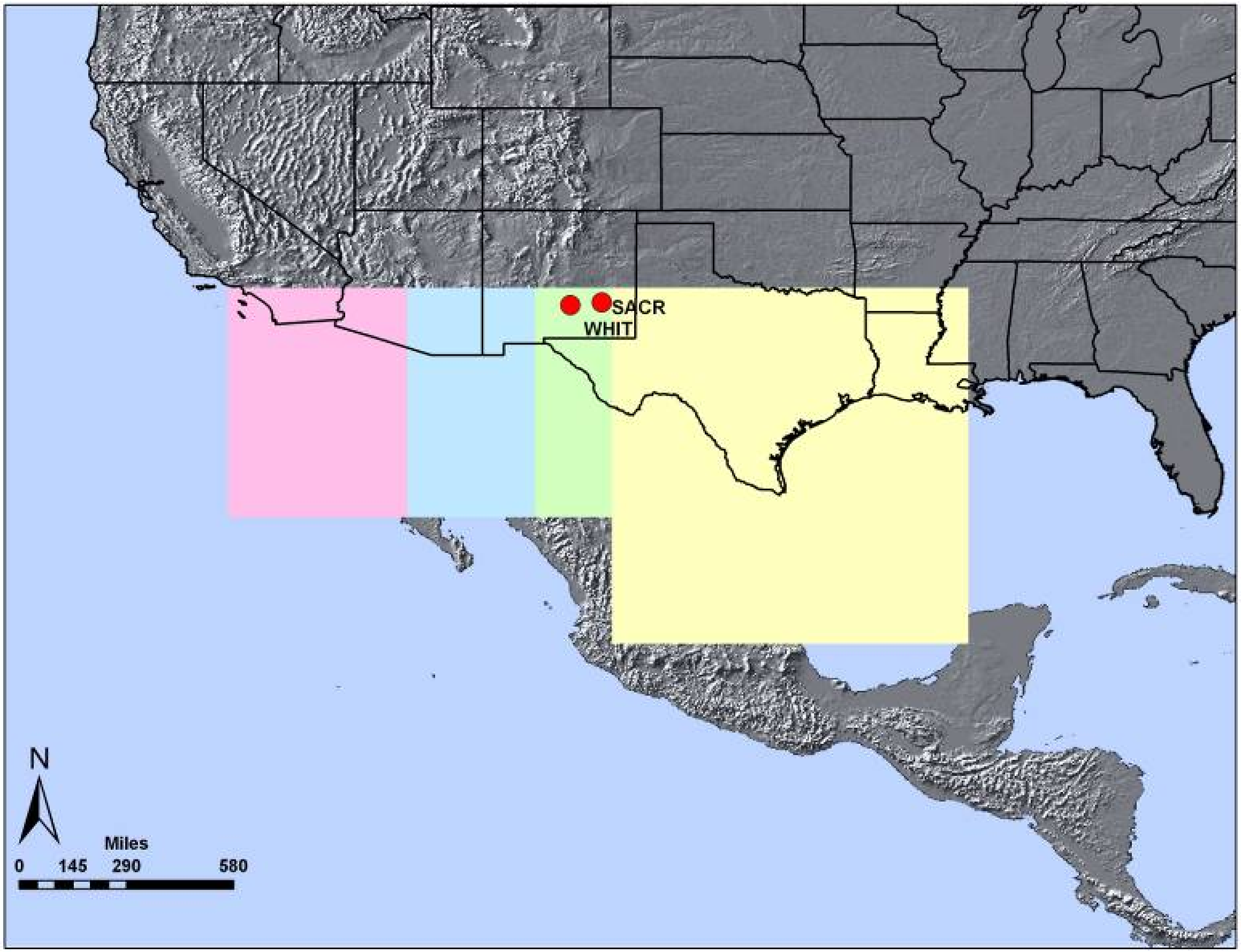


Table 3-3 Descriptions of AVHRR LU/LC Dataset (GLFC) classification[a]

Code	Description
1	Water
2	Evergreen forest
3	Evergreen forest
4	Deciduous forest
5	Mixed forest
6	Woodlands
7	Wooded grasslands
8	Closed shrublands
9	Open shrublands
10	Grasslands
11	Croplands
12	Bare lands
13	Urban and built-up

[a] *Data were obtained from http://glcf.umiacs.umd.edu/data/landcover/*

Table 3-4 Geographical border of four regions and estimated DEP values for each LU/LC class

Region	1	2	3	4
North border	N 34.000^o	N 34.000^o	N 34.000^o	N 34.000^o
East border	W 112.000^o	W 107.000^o	W 104.000^o	W 90.000^o
South border	N 25.000^o	N 25.000^o	N 25.000^o	N 20.000^o
West border	W 118.000^o	W 112.000^o	W 107.000^o	W 107.000^o
LU/LC				
1	0.00000	0.0000	0.00000	0.00000
2	*n.d.*	*n.d.*	0.285714	0.285714
3	*n.d.*	*n.d.*	*n.d.*	*n.d.*
4	*n.d.*	*n.d.*	0.285714	0.285714
5	*n.d.*	*n.d.*	0.167429	0.167429
6	0.442429	0.571429	0.411571	0.411571

7	0.442429	0.171429	0.157143	0.561429
8	0.442429	0.614286	0.200000	0.245714
9	0.607143	0.428571	0.534286	0.600571
10	0.142285	0.571429	0.476714	0.209143
11	0.632857	0.428571	0.544286	0.428571
12	0.607143	0.552857	0.674286	0.333280
13	0.198282	0.552857	0.195286	0.198260

n.d. not determined because this land-use class was not observed into this region

To estimate the error introduced by this approach, DEP values were calculated for CA, AZ, NM and TX states using the same methodology. Comparison of LU/LC-derived DEP with WEG-produced DEP values was done for each 1 km X 1 km cell and on a state-wide basis.. Differences are presented in Figures 3.5 and 3.6. Most of the cells in the four states exhibited absolute differences of less than 0.1429 (one WEG category) (white color in both Figs), indicating that the deviations between the two methods were generally small. Estimation of the mean difference for each state (Figure 3.5) showed that overall the soil erodibility index was not altered significantly (less than 0.1429) by the transformation in AZ, NM and TX. In CA, the difference was higher than 0.1429 in CA, mostly due to deviations in northern California.

We note that this analysis does not provide direct insight into whether or not the LU/LC provides a reasonable surrogate for the DEP measure of soil erodibility in Mexico. Rather, it shows that, at least for the four US states, the "smearing" introduced by lumping together land use categories to estimate DEP values is at an acceptable level.

Figure 3-5 Difference of LULC-derived and WEG-derived DEP per map cell

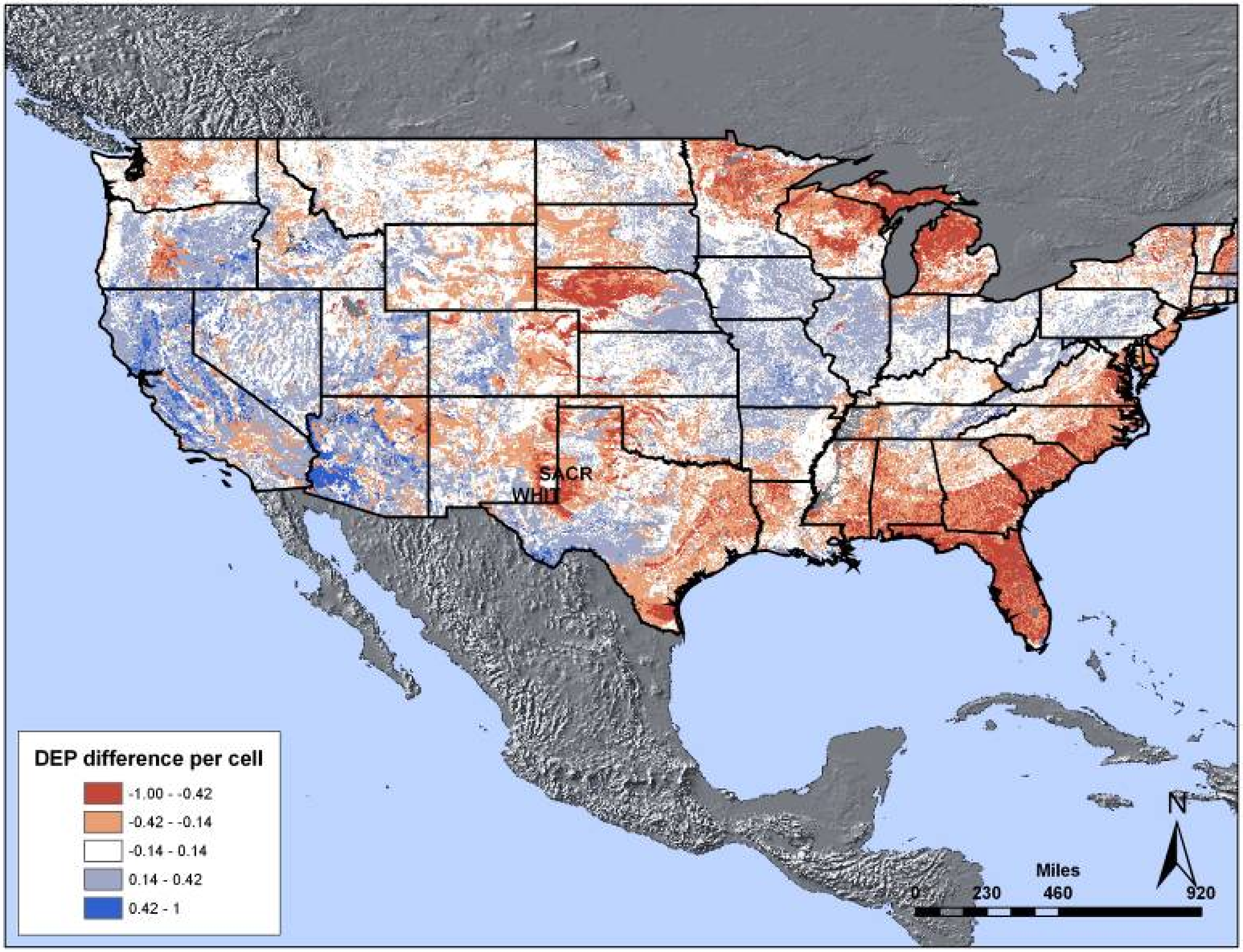
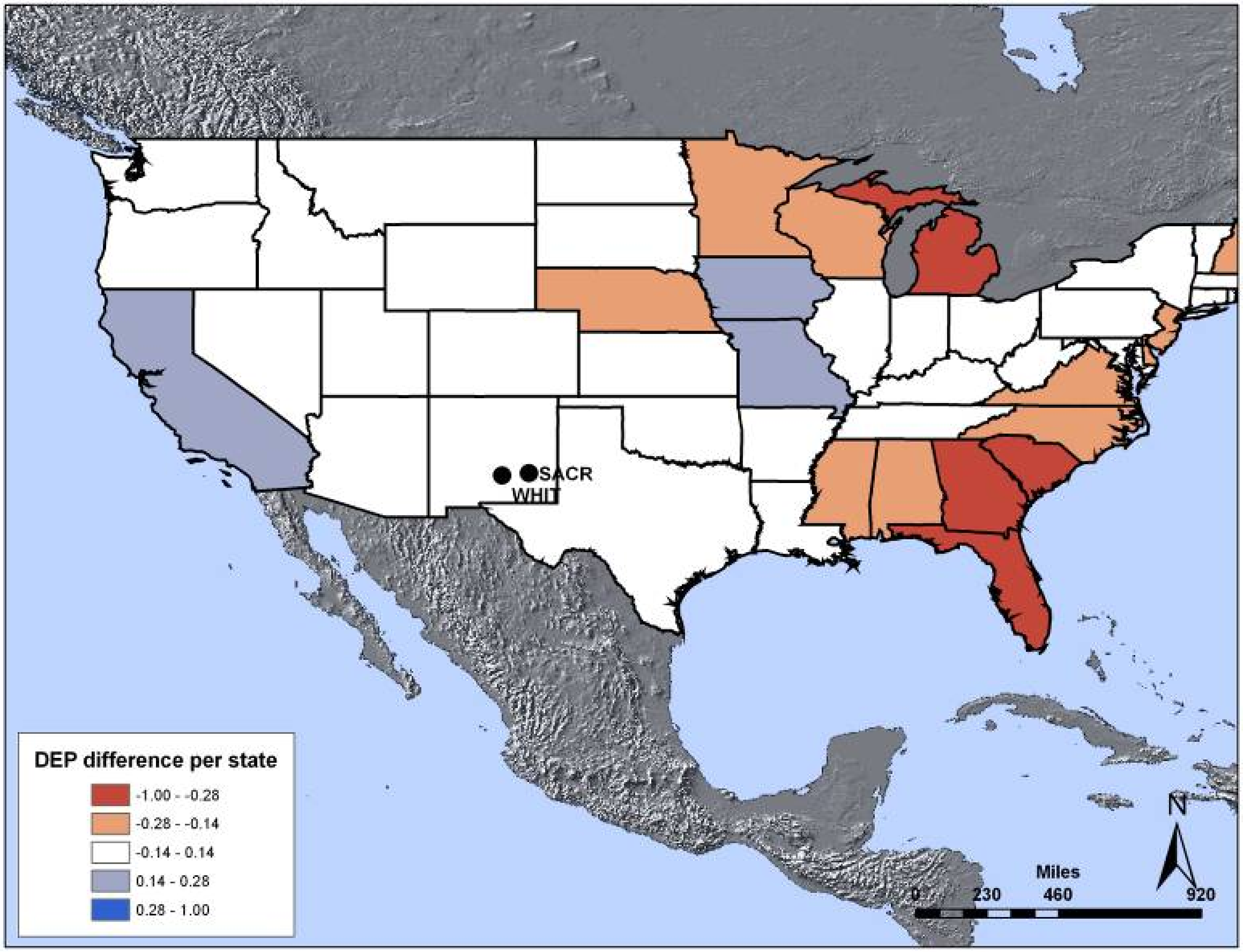


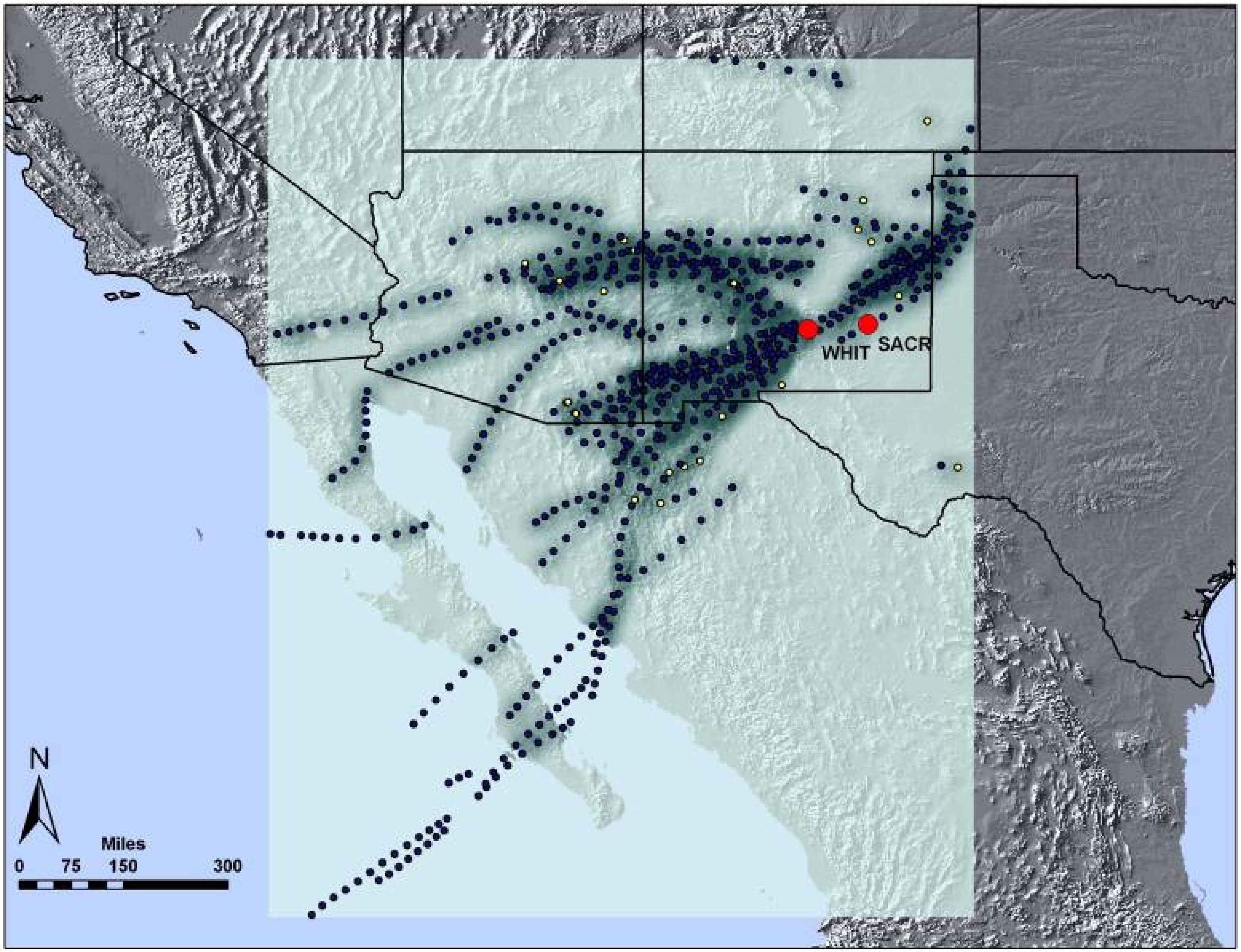
Figure 3-6 Mean difference of LULC-derived and WEG-derived DEP for each state



4. Trajectory analysis

Backward trajectories with a resolution of one hour and going back two days were generated for the Salt Creek and White Mountain Wilderness areas at 3 hour intervals using the NOAA HYSPLIT trajectory model (Draxler and Hess, 1997) and Eta Data Assimilation System (EDAS) meteorological fields as inputs. Starting heights for both sites were 500 m above ground level. Trajectory speeds (in miles/hour) were calculated as the distance between two consecutive trajectory points (divided by one hour). The density of the trajectory points associated with worst dust days that exhibited wind speeds higher than either 20 or 26 miles/hour (potential threshold values for dust emission) was calculated using the Kernel-type spatial probability density. The density was normalized by the total number of trajectory points for all worst dust days in order to estimate the frequency that an air mass passes over the grid cell at a speed above the threshold value. The normalized density values ranged from 0 (the air mass did not go over the area during the worst dust days) to 1 (mass went over the area during all the worst dust days). A typical example of trajectory points and the estimated density is depicted in Figure 4.1.

Figure 4-1 Trajectory points and estimated density for White Mountain site, 2001-2003 period and trajectory speed > 20 miles/hour



5. Windblown Dust Influence (WDI) Index

To identify areas located in New Mexico and surrounding regions that were potential sources of windblown dust during the 2001-2003 worst dust days, the product of the DEP index and back-trajectory threshold probability index was calculated for each 1 km X 1 km grid cell. Because both parameters were normalized (i.e. range from 0 to 1), the product provided an index of windblown dust influence (also from 0 to 1). By definition WDI was specific for the site, time period and threshold trajectory speed. WDI assumed that the impacts of vertical dilution and dry/wet deposition can be neglected. While the WDI did not provide a direct source attribution for windblown dust, it highlighted the source areas that were likely to exert the greatest influence on the Salt Creek and White Mountain Class I areas. The ratio of WDI/distance from the site was also calculated for each cell. By stressing potential source areas near the receptor site the WDI/distance ratio can provide qualitative information about the relative contribution of source areas.

6. Results

6.1 Salt Creek Wilderness

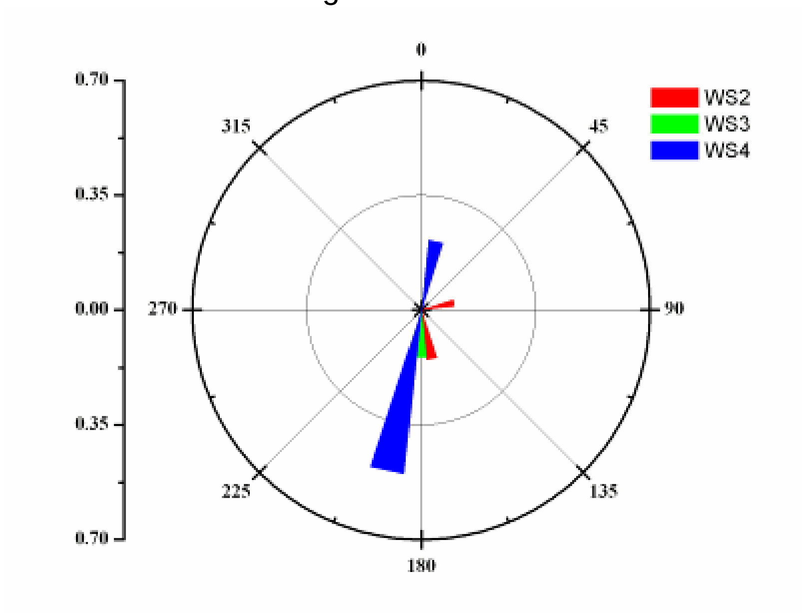
Twenty-two of the 2001 - 2003 20% worst-case visibility days were characterized as worst dust days (dust is the largest component contributing to reconstructed extinction). For worst dust days, dust concentrations varied from 22.5 to 98.3 $\mu g/m^3$ with a mean of 45.0 $\mu g/m^3$ (Table 6.1). Ten worst dust days were observed during 2002 and six worst dust days in each 2001 and 2003. The mean concentrations varied from 36.5 (for 2002) to 58.9 $\mu g/m^3$ (for 2003) (Table 6.1). More than half of worst dust days were observed during spring (12 days) followed by summer (6 days) (Table 6.1). Mean dust concentration for each season did not vary significantly, from 37.8 (during fall, one worst dust day) to 50.8 $\mu g/m^3$ (during summer, six worst dust days) (Table 6.1).

Table 6-1 Mean (and n, minimum and maximum) dust concentrations during the 2001-2003 worst dust days at Salt Creek Wilderness area

Period	n	Mean	Minimum	Maximum
2001-2003	22	45.0	22.5	98.3
2001	6	45.4	30.4	98.3
2002	10	36.5	22.5	48.5
2003	6	58.9	25.2	94.7
Winter	3	46.4	30.7	68.4
Spring	12	42.4	22.5	98.3
Summer	6	50.8	23.1	94.7
Fall	1	37.8	37.8	37.8

Recent analysis of dust concentration and prevailing wind conditions (Kavouras et al., 2005) indicated that the dust concentrations were associated with strong winds (WS4, surface wind speed > 26 miles/hour) from the S/SW and N/NE corridors (Figure 6.1), providing information about the orientation of possible windblown dust sources with respect to the SACR site.

Figure 6-1 Polar plots of standardized regression coefficients for Salt Creek Wilderness



6.1.1 WDI index

The WDI index during the 2001-2003 worst dust days period for Salt Creek Wilderness area and trajectory speeds higher than 20 and 26 miles/hour are presented in Figures 6.2 and 6.3, respectively. The WDI index contour plots for the same parameters using land use and land cover as background are presented in Figures 6.4 and 6.5, in order to obtain more information about the type of activities at highlighted areas.

Figure 6-2 Spatial distribution of WDI for Salt Creek Wilderness area (2001-2003 period, traj. speed > 20 miles/hour)

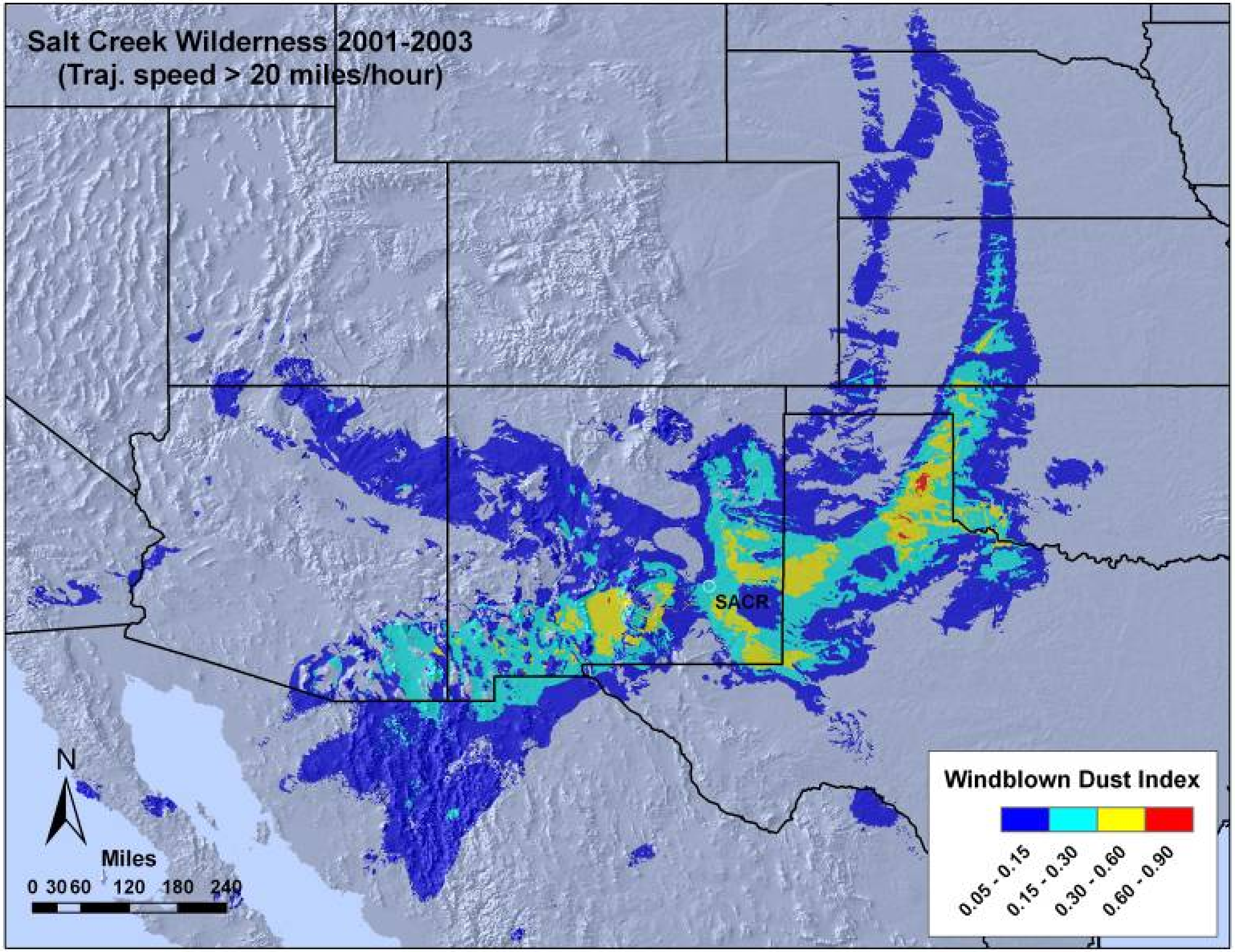


Figure 6-3 Spatial distribution of WDI for Salt Creek Wilderness area (2001-2003 period, traj. speed > 26 miles/hour)

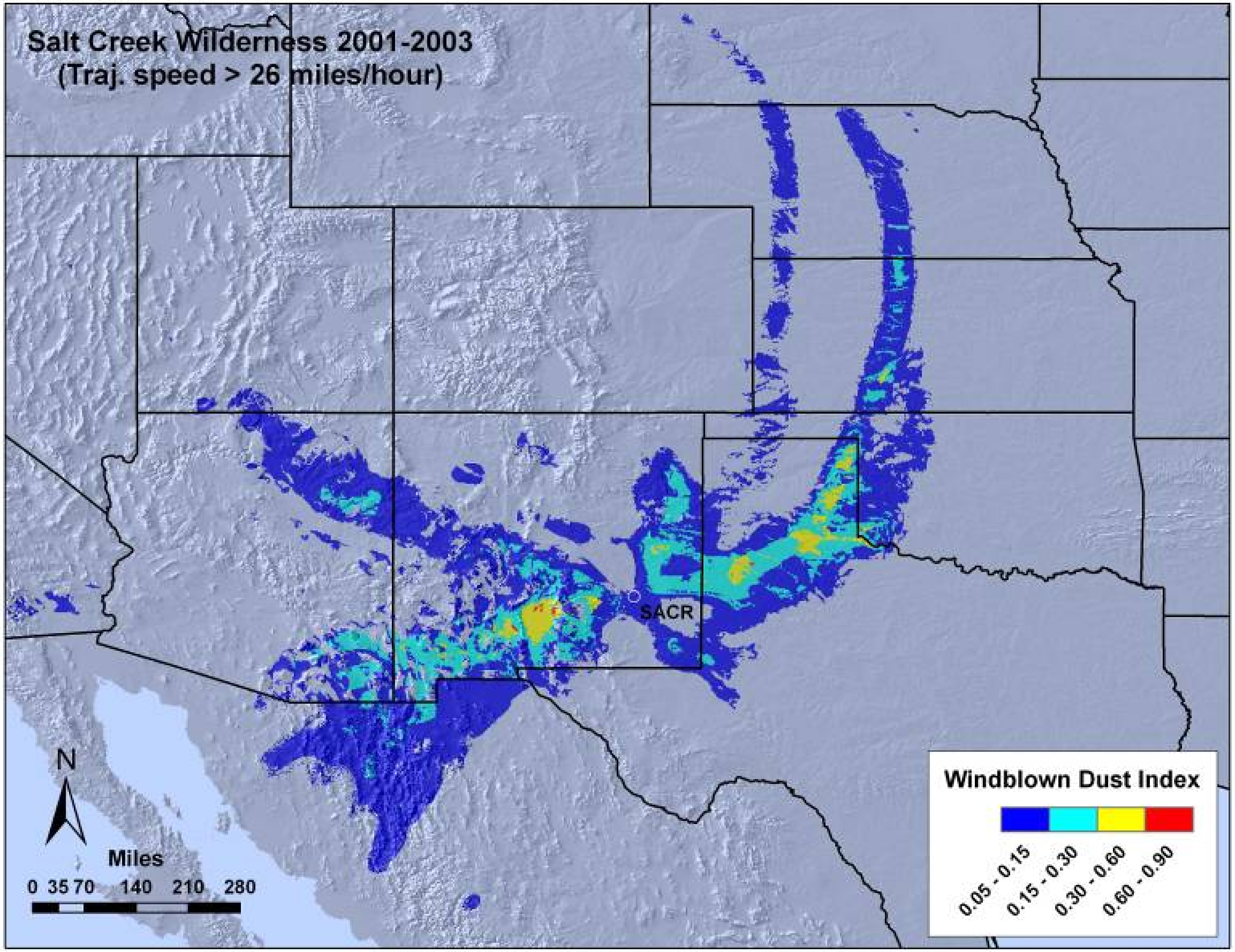


Figure 6-4 Contour plot of WDI for Salt Creek Wilderness area (2001-2003 period, traj. speed > 20 miles/hour)

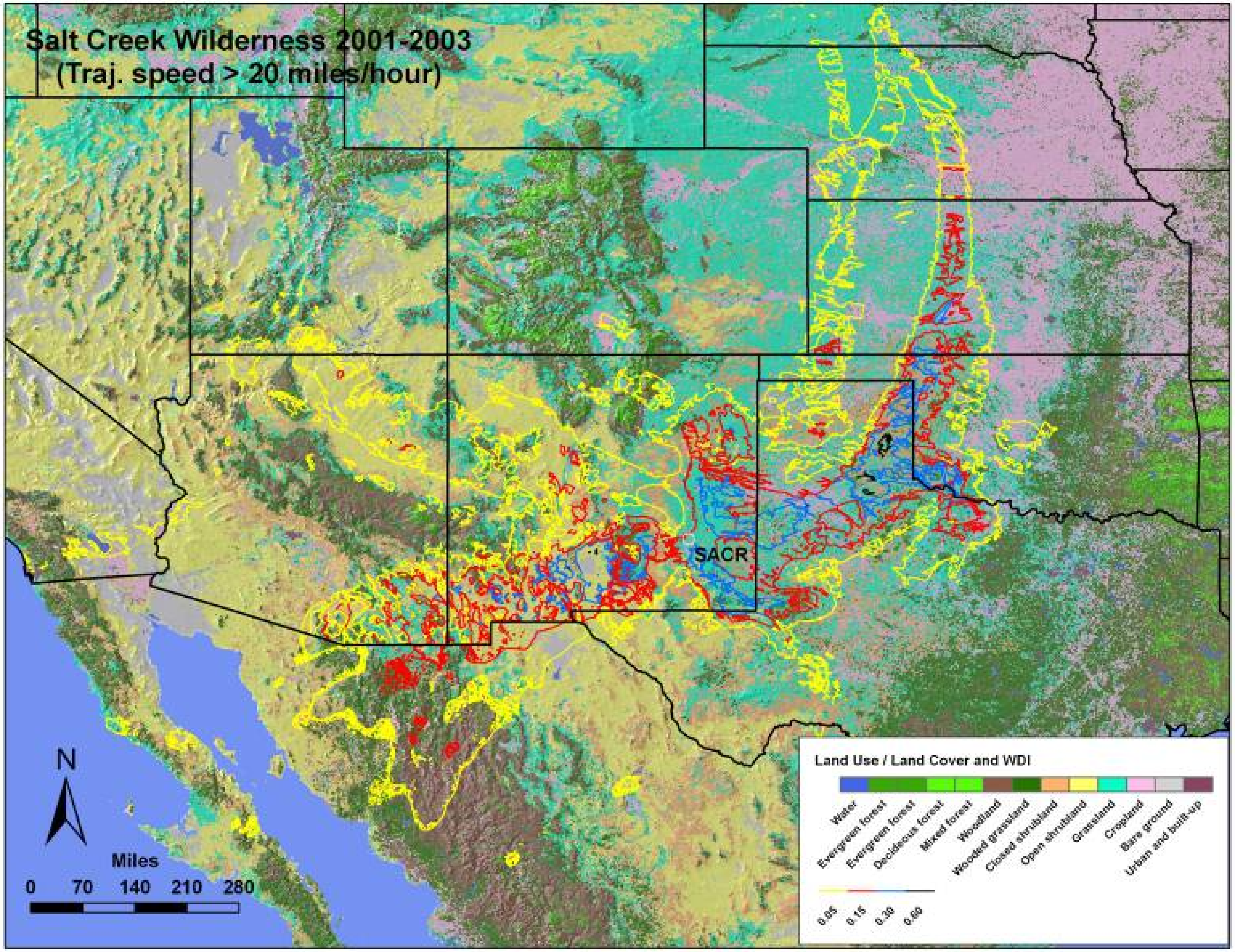
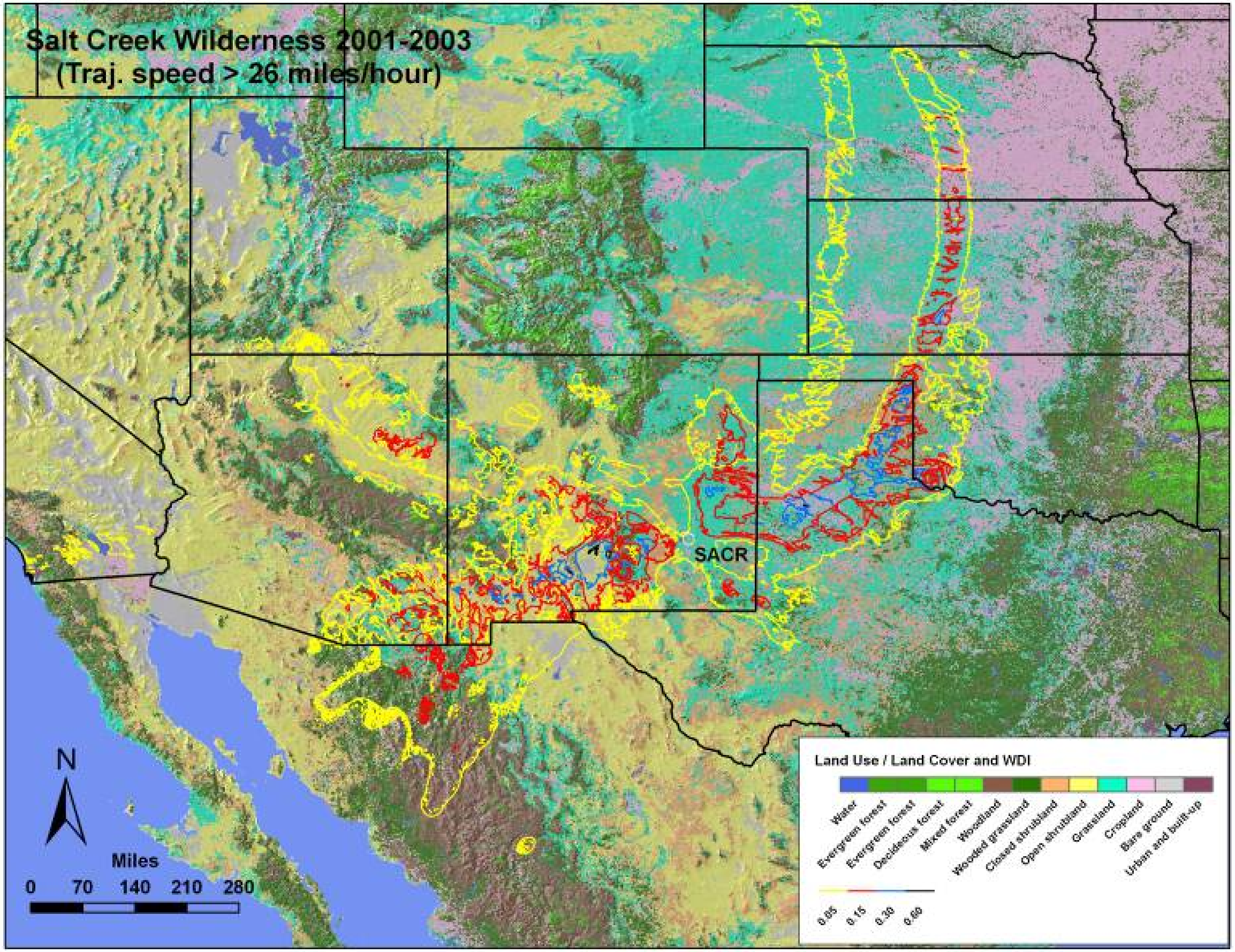


Figure 6-5 Contour plot of WDI for Salt Creek Wilderness area (2001-2003 period, traj. speed > 26 miles/hour)



6.1.2 WDI/distance ratio

The WDI/distance (from the site) ratios of each cell during the 2001-2003 worst dust days period for Salt Creek Wilderness area and trajectory speeds higher than 20 and 26 miles/hour are presented in Figures 6.6 and 6.7, respectively. The WDI/distance contour plots for the same parameters using land use and land cover background are presented in Figures 6.8 and 6.9, in order to obtain more information about the type of activities at highlighted areas.

Figure 6-6 Spatial distribution of WDI/distance ratio for Salt Creek Wilderness (2001-2003 period, traj. speed > 20 miles/hour)

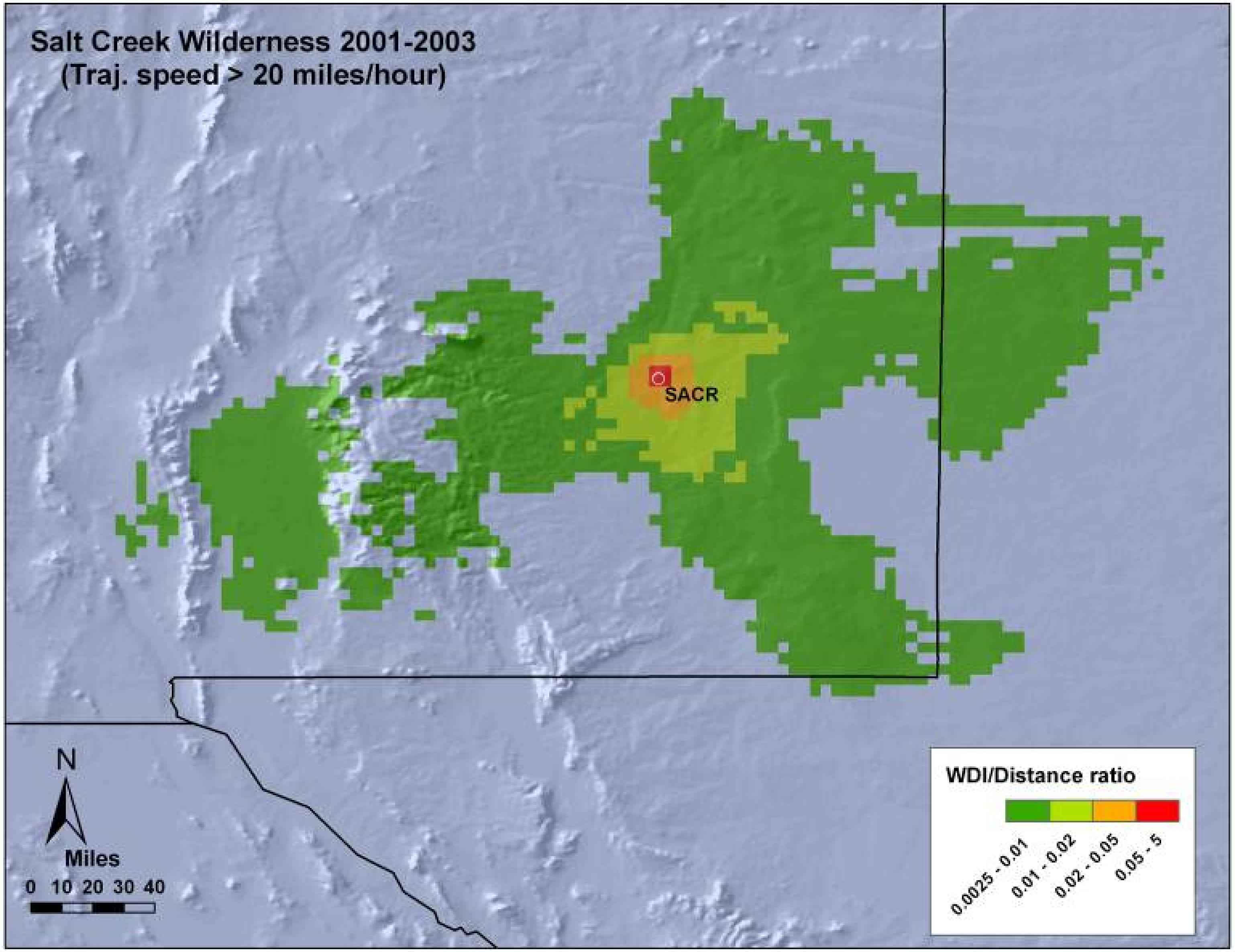


Figure 6-7 Spatial distribution of WD/distance ratio for Salt Creek Wilderness area (2001-2003 period, traj. speed > 26 miles/hour)

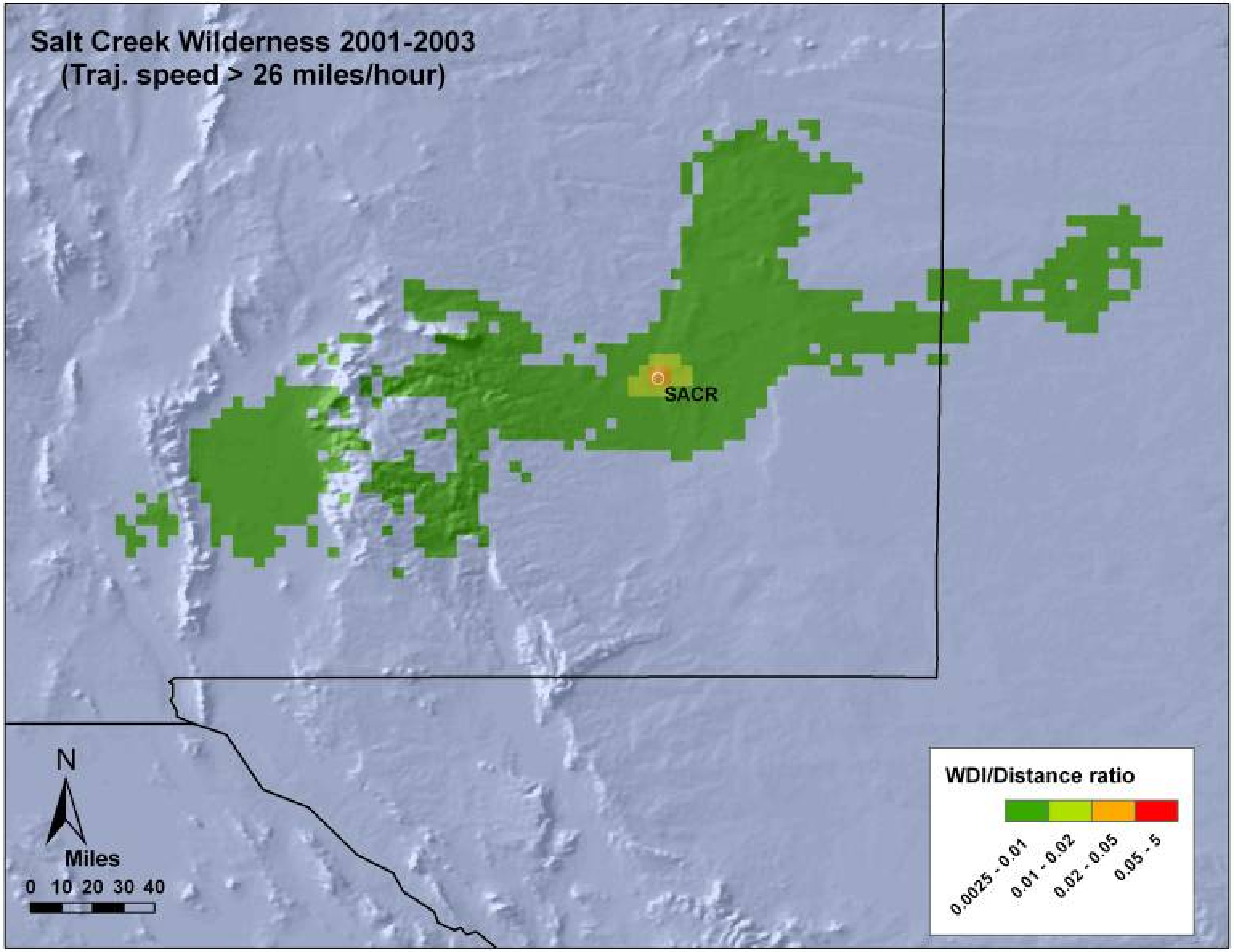


Figure 6-8 Contour plot of WDI/distance for Salt Creek Wilderness area (2001-2003 period, traj. speed > 20 miles/hour)

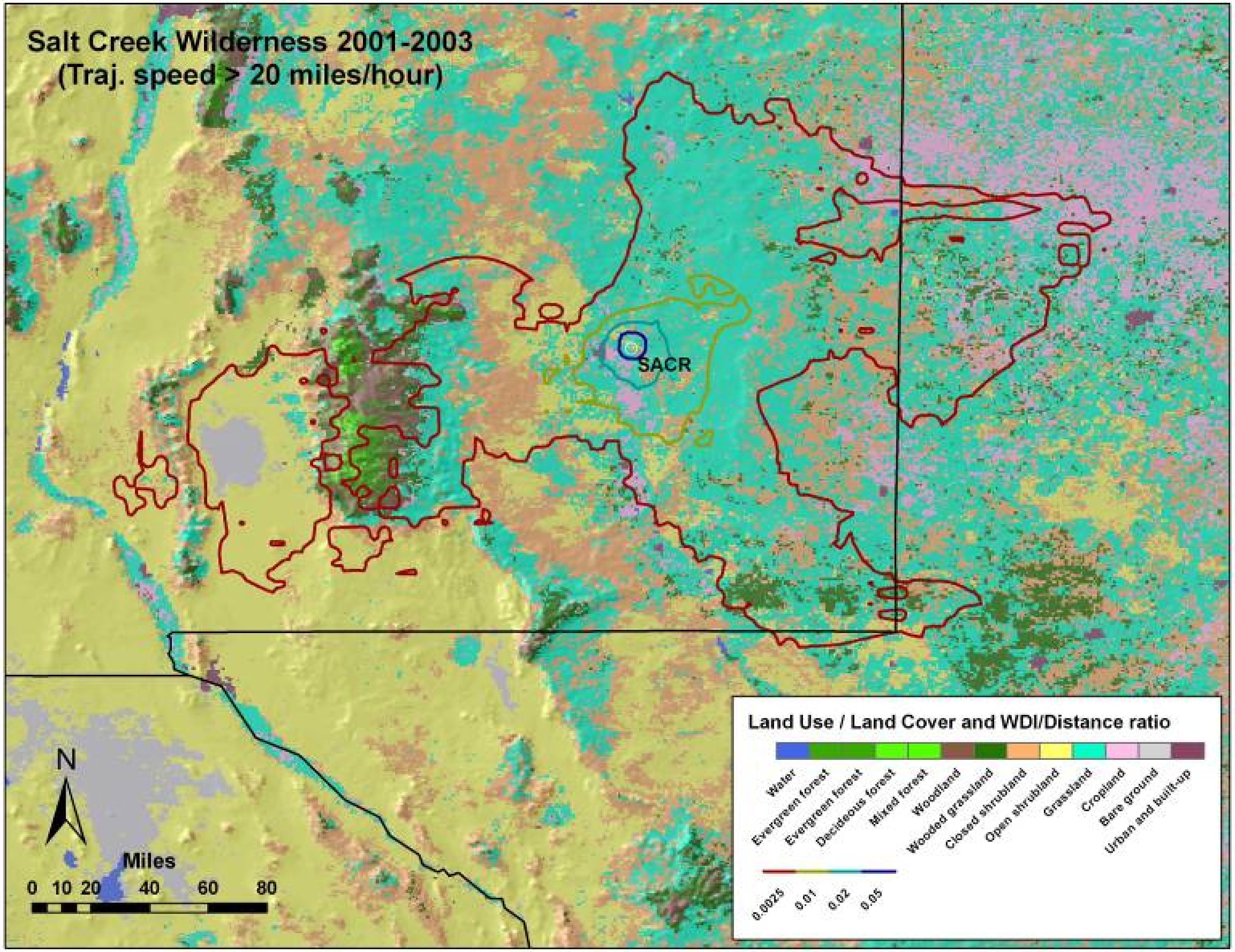
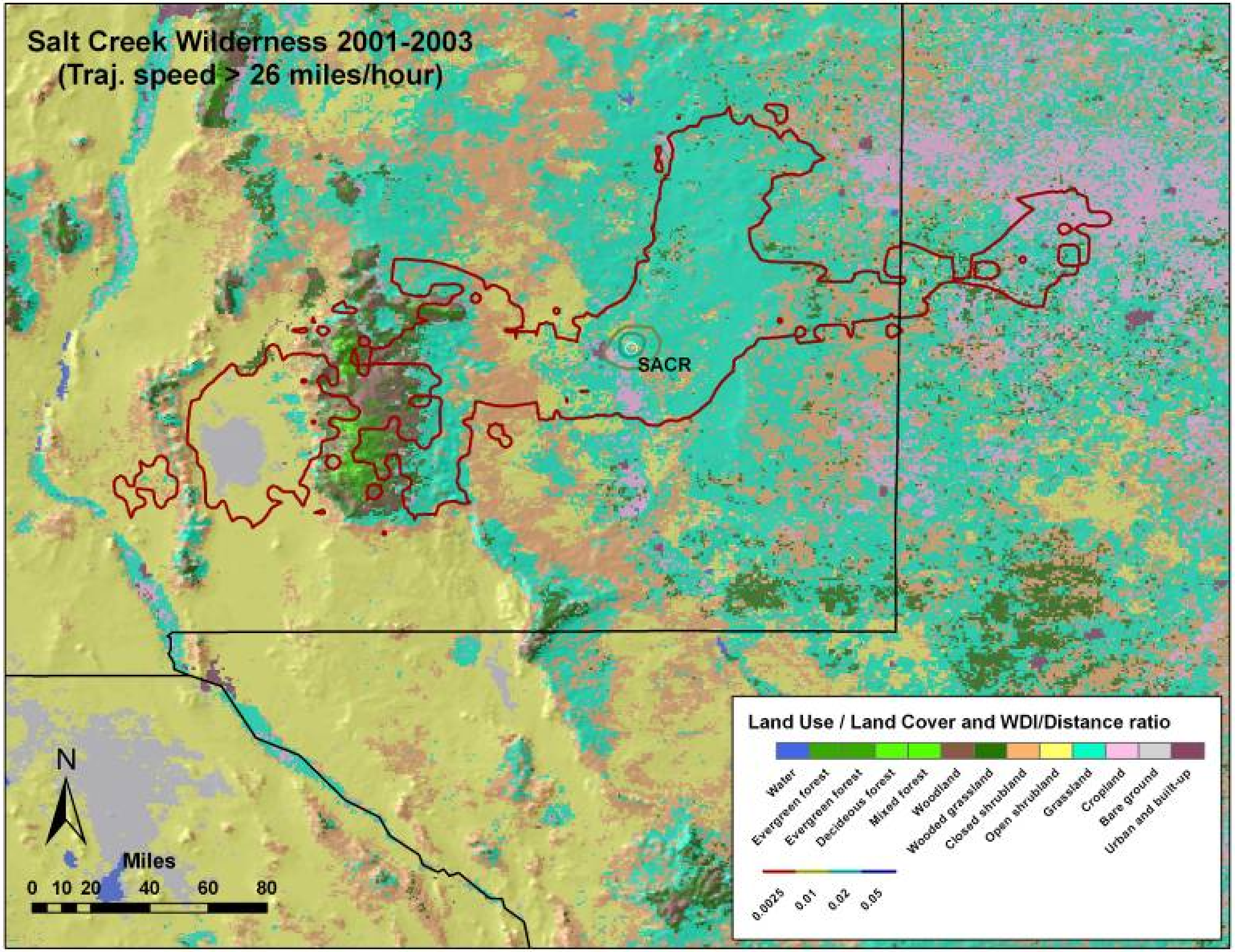


Figure 6-9 Contour plot of WDI/distance for Salt Creek Wilderness area (2001-2003 period, traj. speed > 26 miles/hour)



6.2 White Mountain Wilderness

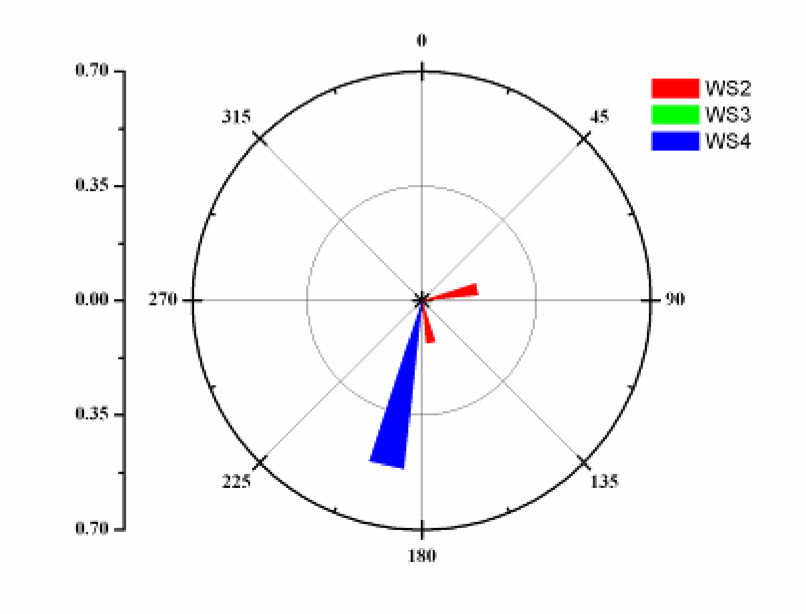
Ten of the 2001-2003 20% worst-case visibility days were characterized as worst dust days (dust is the largest component contributing to reconstructed extinction). For worst dust days, dust concentration varied from 16.7 to 81.4 µg/m^3 with mean of 42.7 µg/m^3 (Table 6.2). Worst dust days were evenly distributed in each 2002 and 2003. The mean concentrations varied from 36.2 (for 2002) to 49.3 µg/m^3 (for 2003) (Table 6.2). More than half of worst dust days were observed during spring (6 days) followed by winter (3 days) (Table 6.2). Mean dust concentration for each season did not vary significantly (with the exception of summer due to only one worst dust day), from 44.5 (during winter, three worst dust day) to 44.6 µg/m^3 (during spring, six worst dust days) (Table 6.2).

Table 6-2 Mean (and n, minimum and maximum) dust concentrations during the 2001-2003 worst dust days at White Mountain Wilderness area

Period	n	Mean	Minimum	Maximum
2001-2003	10	42.7	16.7	81.4
2001	-	-	-	-
2002	5	36.2	24.0	73.4
2003	5	49.3	16.7	81.4
Winter	3	44.5	16.7	81.4
Spring	6	44.6	24	73.4
Summer	1	26.1	26.1	26.1
Fall	-	-	-	-

Recent analysis of dust concentration and prevailing wind conditions (Kavouras et al., 2005) indicated that the dust concentrations were associated with strong winds (WS4, surface wind speed > 26 miles/hour) from the S/SW sector and to a lesser extend with low wind speed (WS2, surface wind speed from 14 to 20 miles/hour) from both S/SW and N/NE corridors (Figure 6.10), providing information about the orientation of possible windblown dust sources with respect to the White Mountain site.

Figure 6-10 Polar plots of standardized regression coefficients for Salt Creek Wilderness



6.2.1 WDI index

The WDI index during the 2001-2003 worst dust days period for White Mountain Wilderness area and trajectory speeds higher than 20 and 26 miles/hour are presented in Figures 6.11 and 6.12, respectively. The WDI index contour plots for the same parameters using land use and land cover background are presented in Figures 6.13 and 6.14, in order to obtain more information about the type of activities at highlighted areas.

Figure 6-11 Spatial distribution of WDI for White Mountain Wilderness area (2001-2003 period, traj. speed > 20 miles/hour)

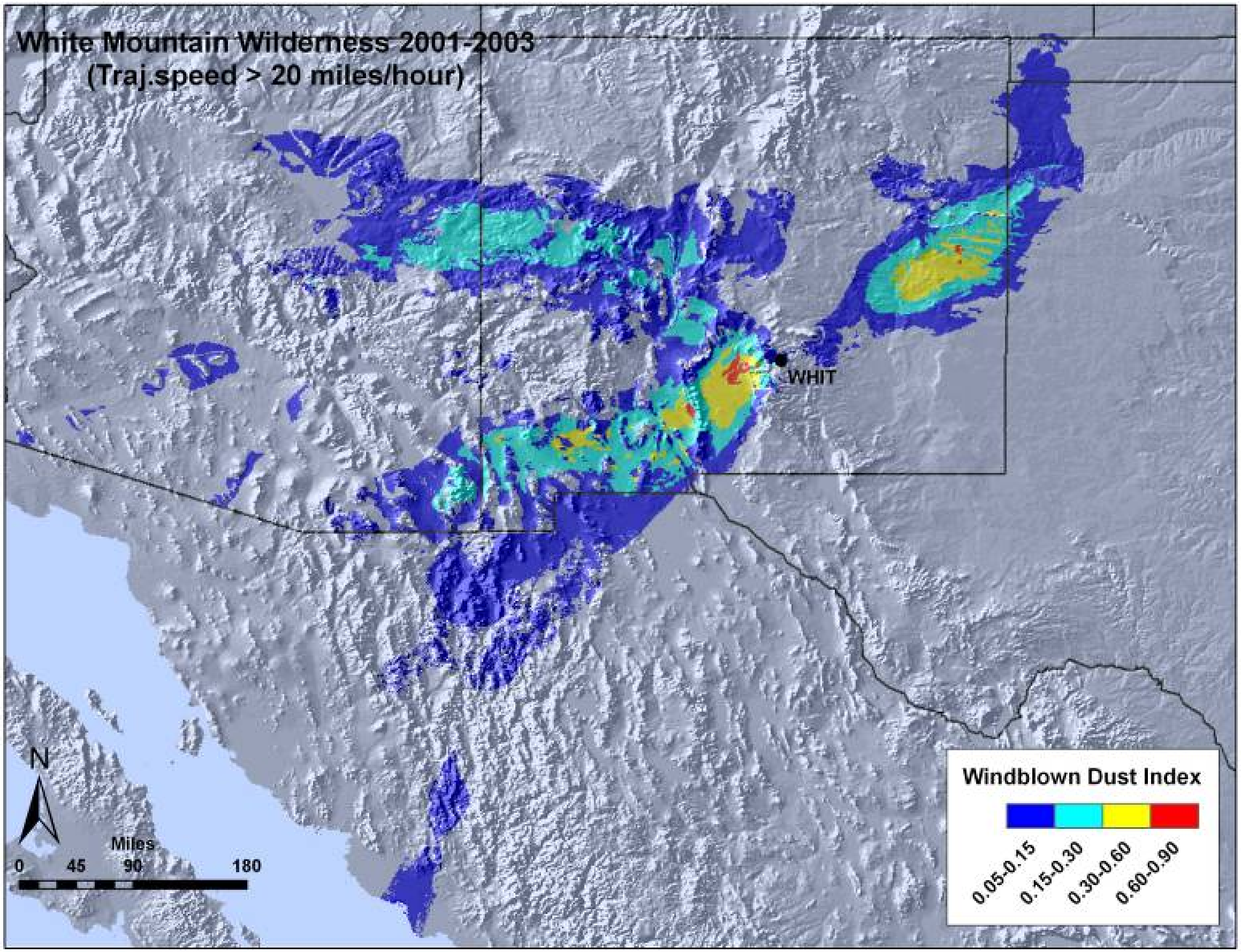


Figure 6-12 Spatial distribution of WDI for White Mountain Wilderness area (2001-2003 period, traj. speed > 26 miles/hour)

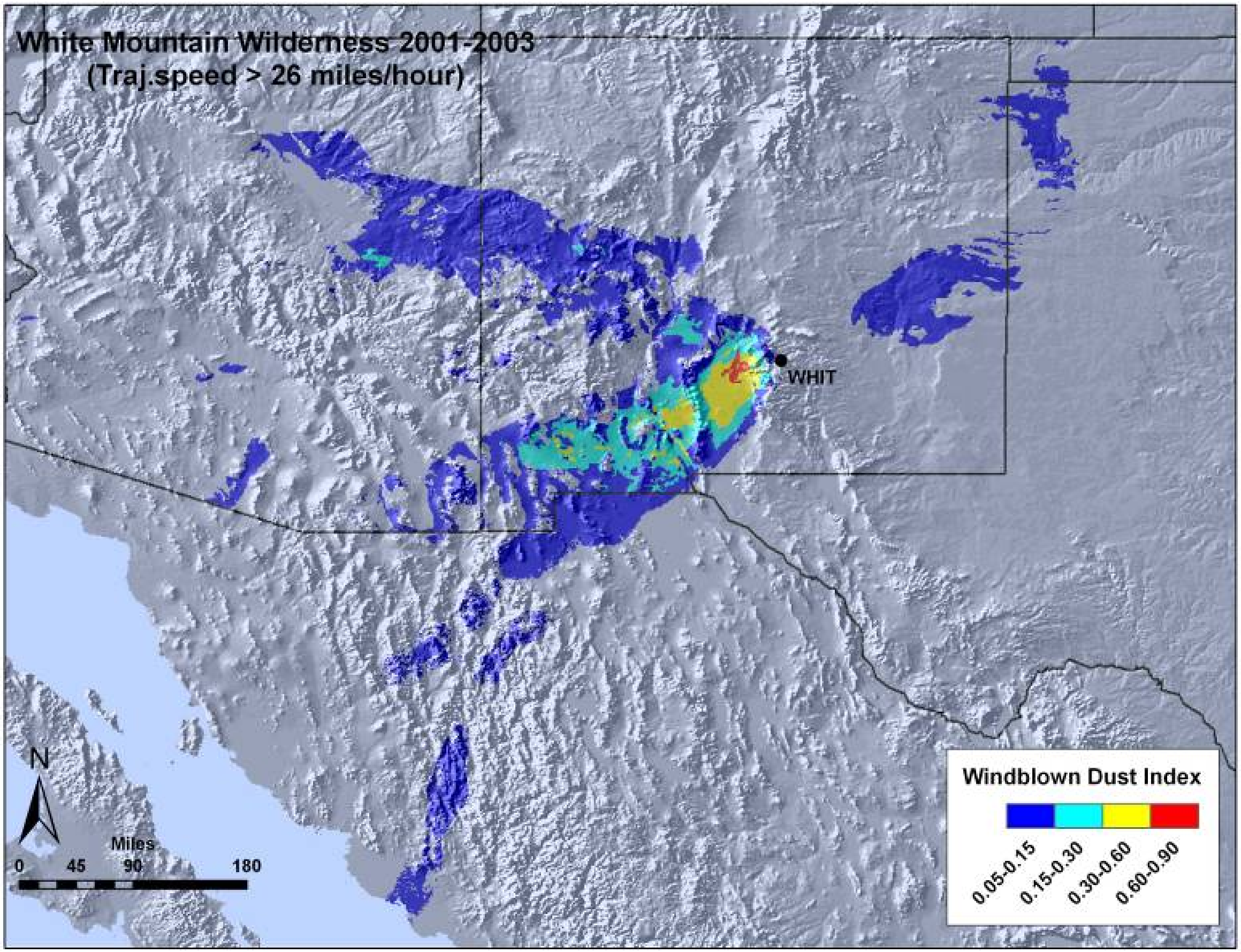


Figure 6-13 Contour plot of WDI for White Mountain Wilderness area (2001-2003 period, traj. speed > 20 miles/hour)

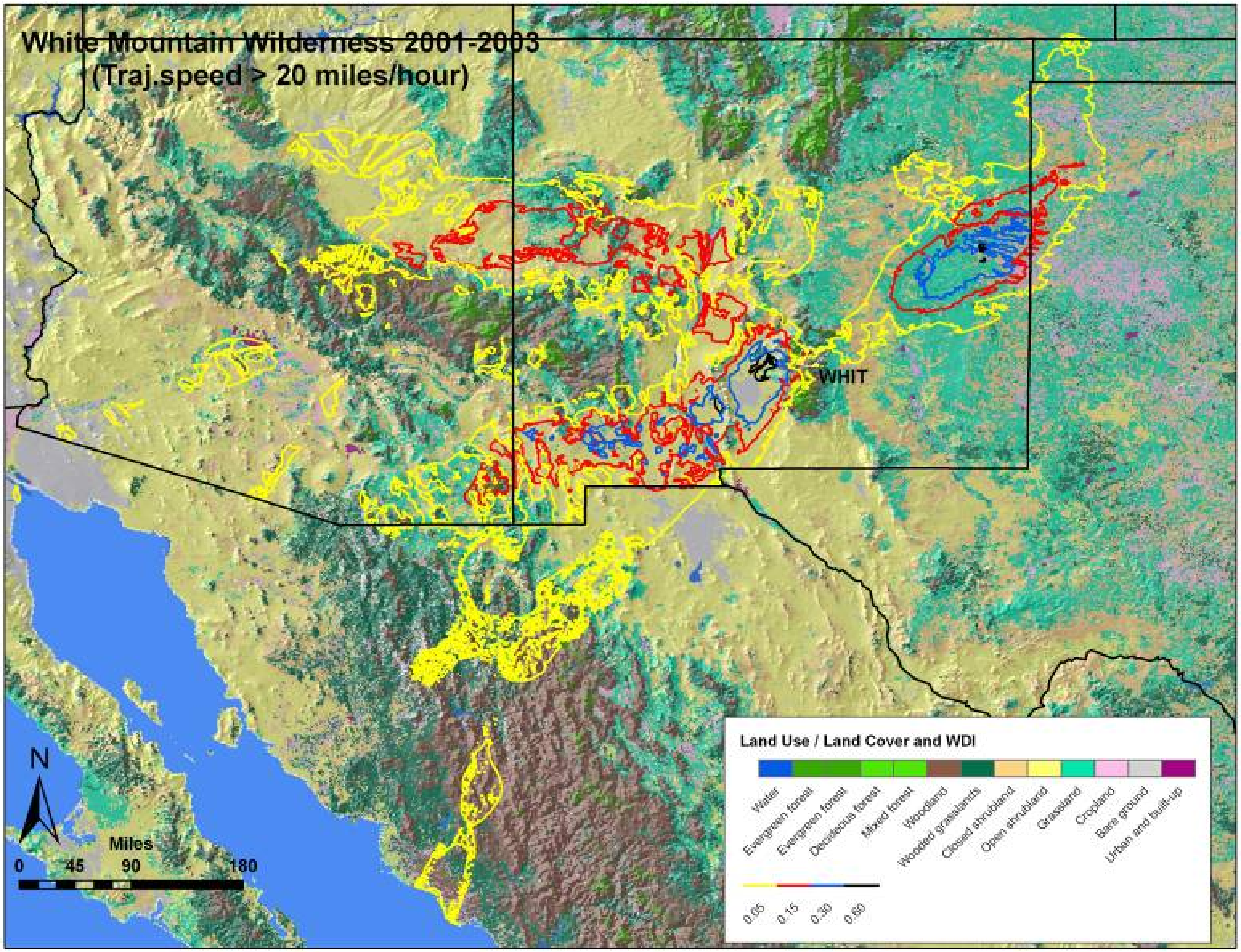
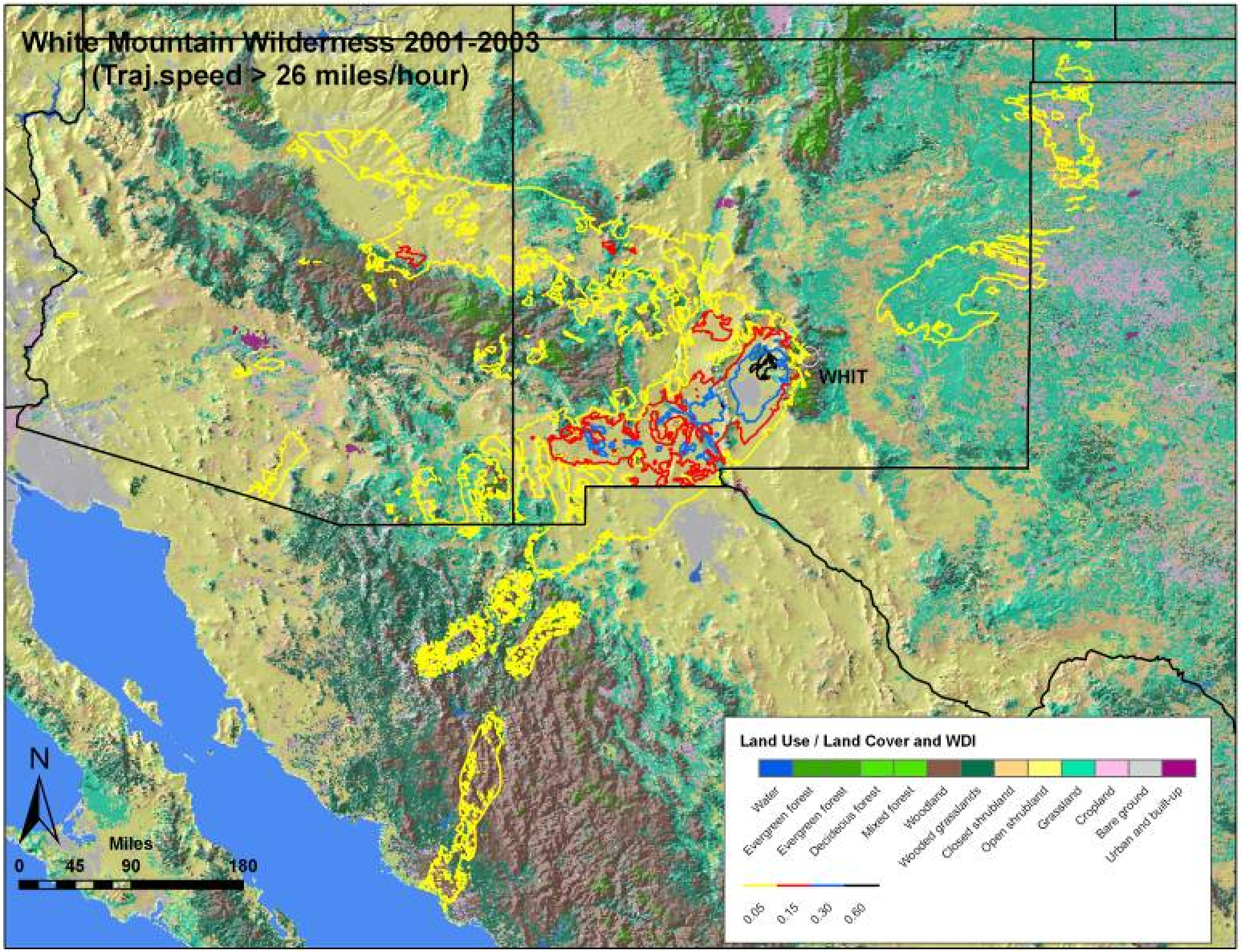


Figure 6-14 Contour plot of WDI for White Mountain Wilderness area (2001-2003 period, traj. speed > 26 miles/hour)



6.2.2 WDI/distance ratio

The WDI/distance (from the site) ratios of each cell during the 2001-2003 worst dust days period for White Mountain Wilderness area and trajectory speeds higher than 20 and 26 miles/hour are presented in Figures 6.15 and 6.16, respectively. The WDI/distance contour plots for the same parameters using land use and land cover background are presented in Figures 6.17 and 6.18, in order to obtain more information about the type of activities at highlighted areas.

Figure 6-15 Spatial distribution of WDI/distance ratio for White Mountain Wilderness area (2001-2003 period, traj. speed > 20 miles/hour)

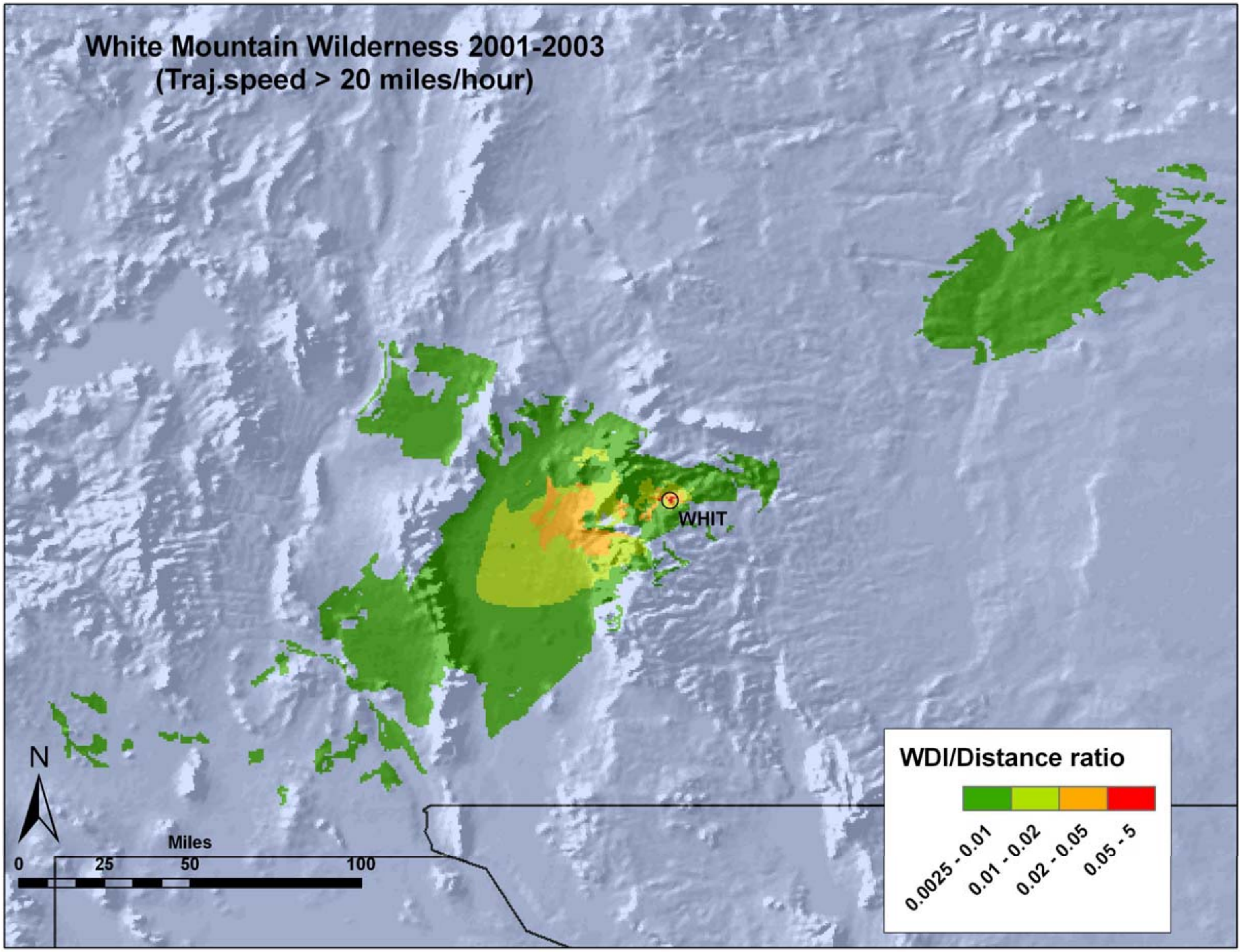


Figure 6-16 Spatial distribution of WDI/distance ratio for White Mountain Wilderness area (2001-2003 period, traj. speed > 26 miles/hour)

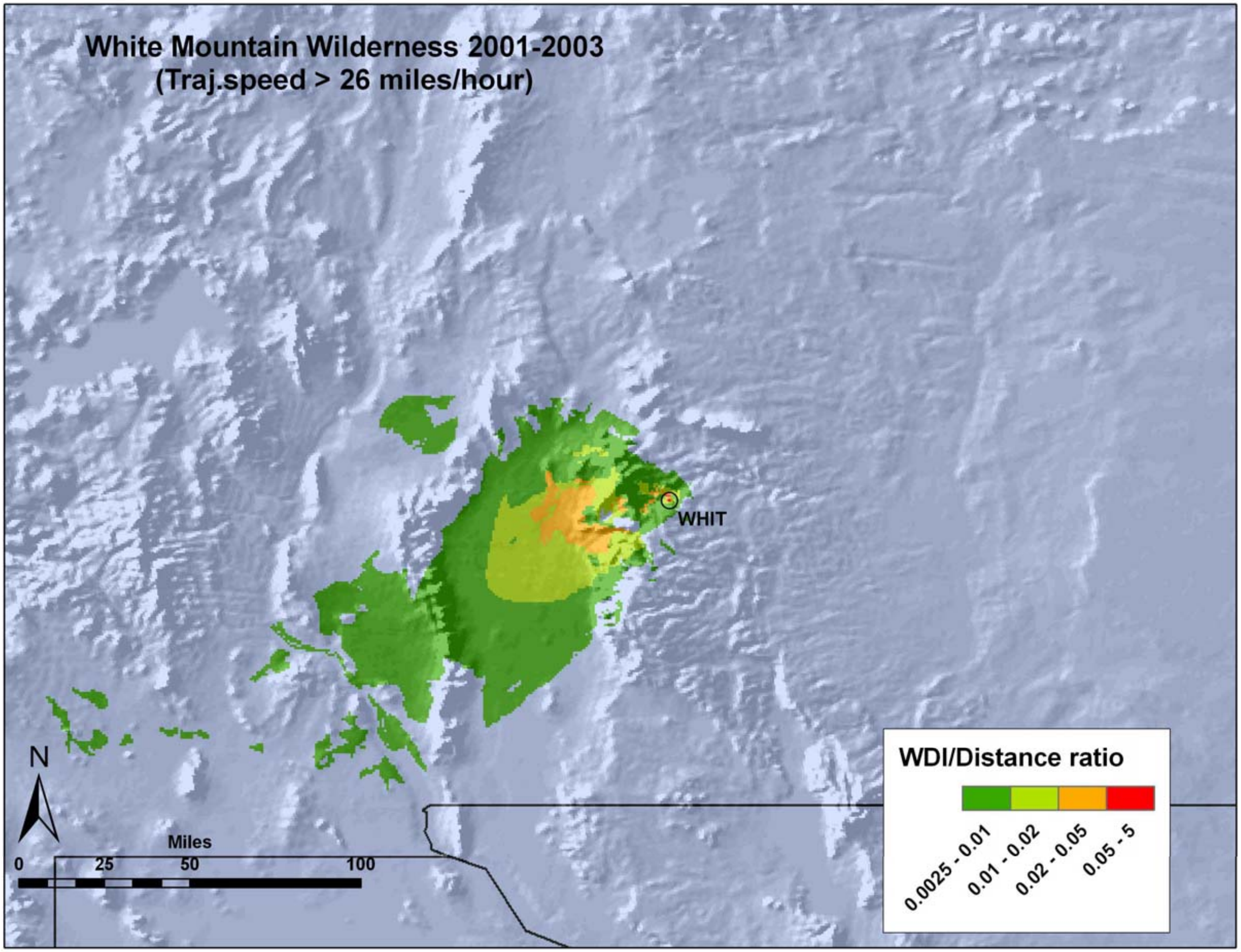


Figure 6-17 Contour plot of WDI/distance for White Mountain Wilderness area (2001-2003 period, traj. speed > 20 miles/hour)

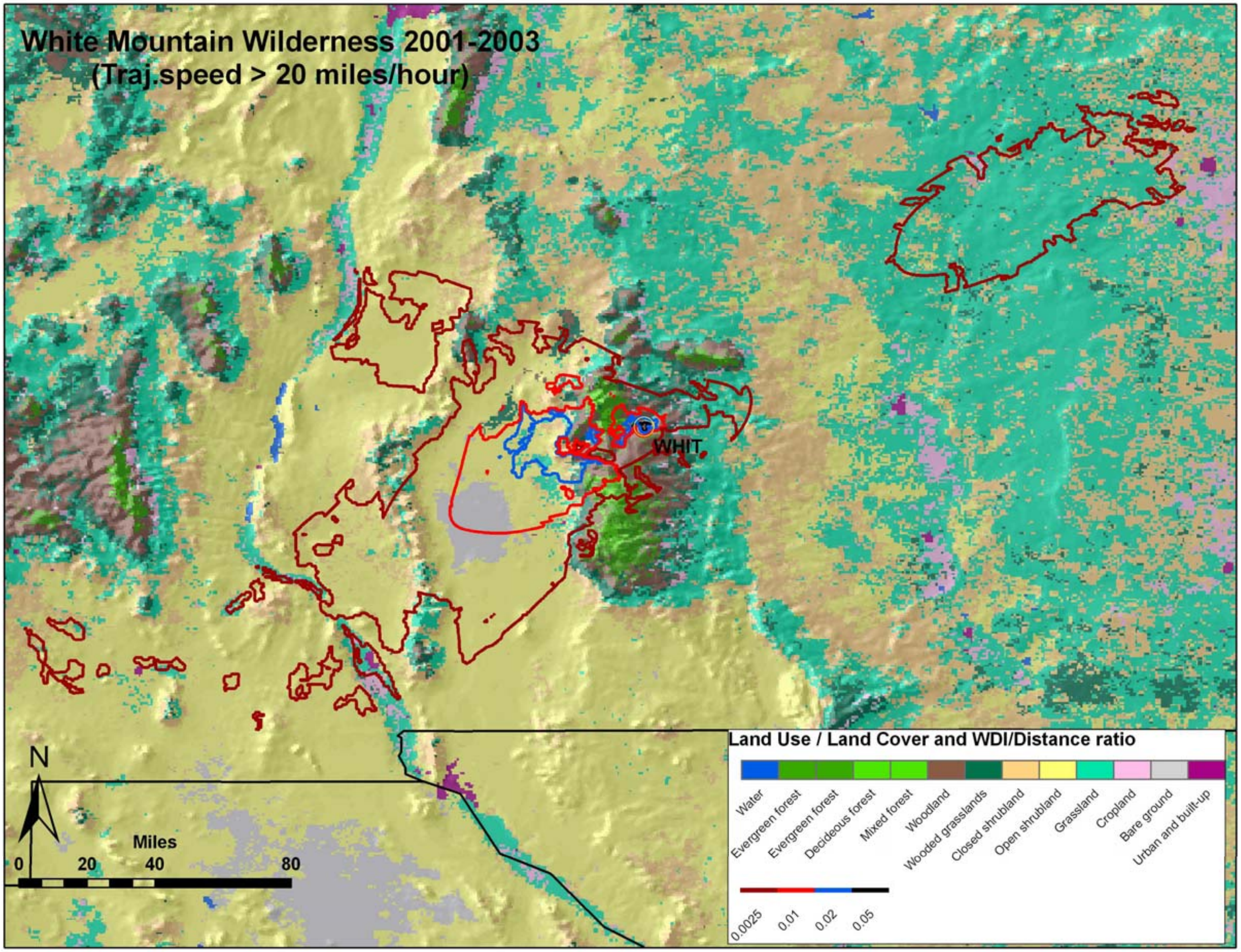
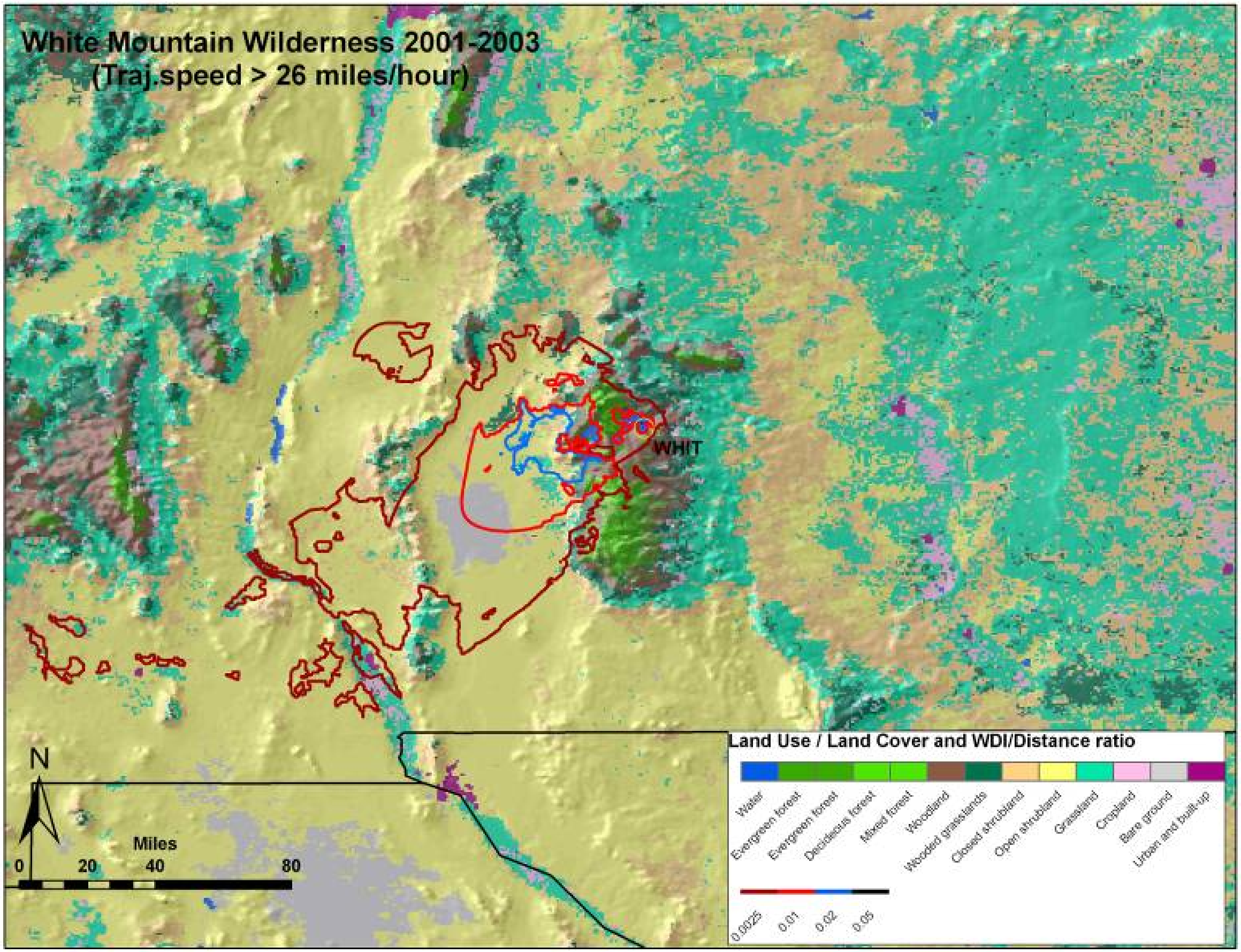


Figure 6-18 Contour plot of WDI/distance for White Mountain Wilderness area (2001-2003 period, traj. speed > 26 miles/hour)



6.3 Annual and seasonal variations

In addition, to WDI and WDI/distance plots for the entire 2001-2003 period, WDI and WDI/distance maps were prepared for each year (2001, 2002 and 2003) and season (winter (Dec./Jan./Feb.), spring (Mar./Apr./May), summer (Jun./Jul./Aug) and fall (Sep./Oct./Nov.). These maps provide information on the annual and seasonal variations of possible source areas. The maps are presented in Figures 6-19 through 6-66.

Figure 6-19 Spatial distribution of WDI for Salt Creek Wilderness (2001, Traj. speed > 20 miles/hour)

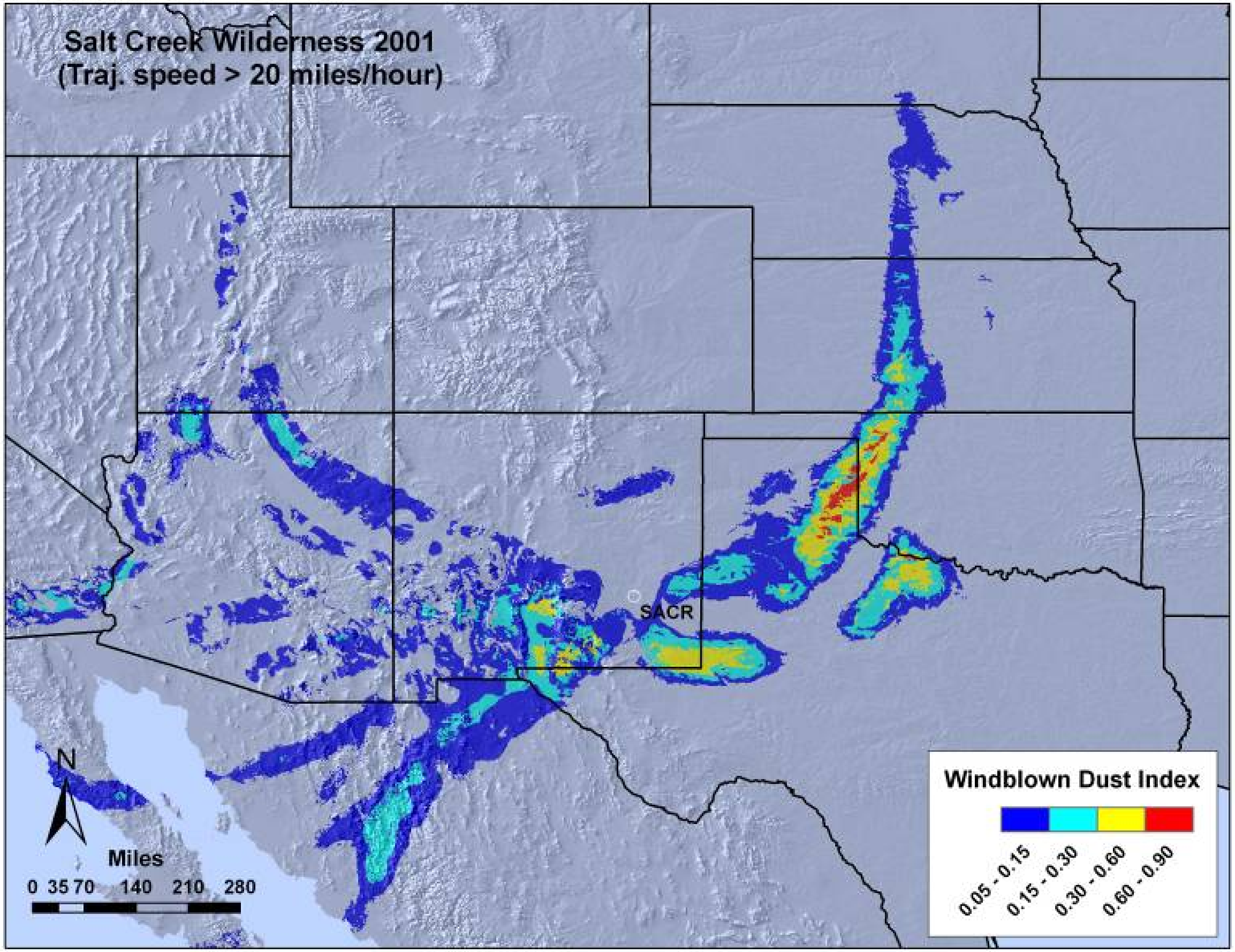


Figure 6-20 Spatial distribution of WDI for Salt Creek Wilderness (2002, Traj. speed > 20 miles/hour)

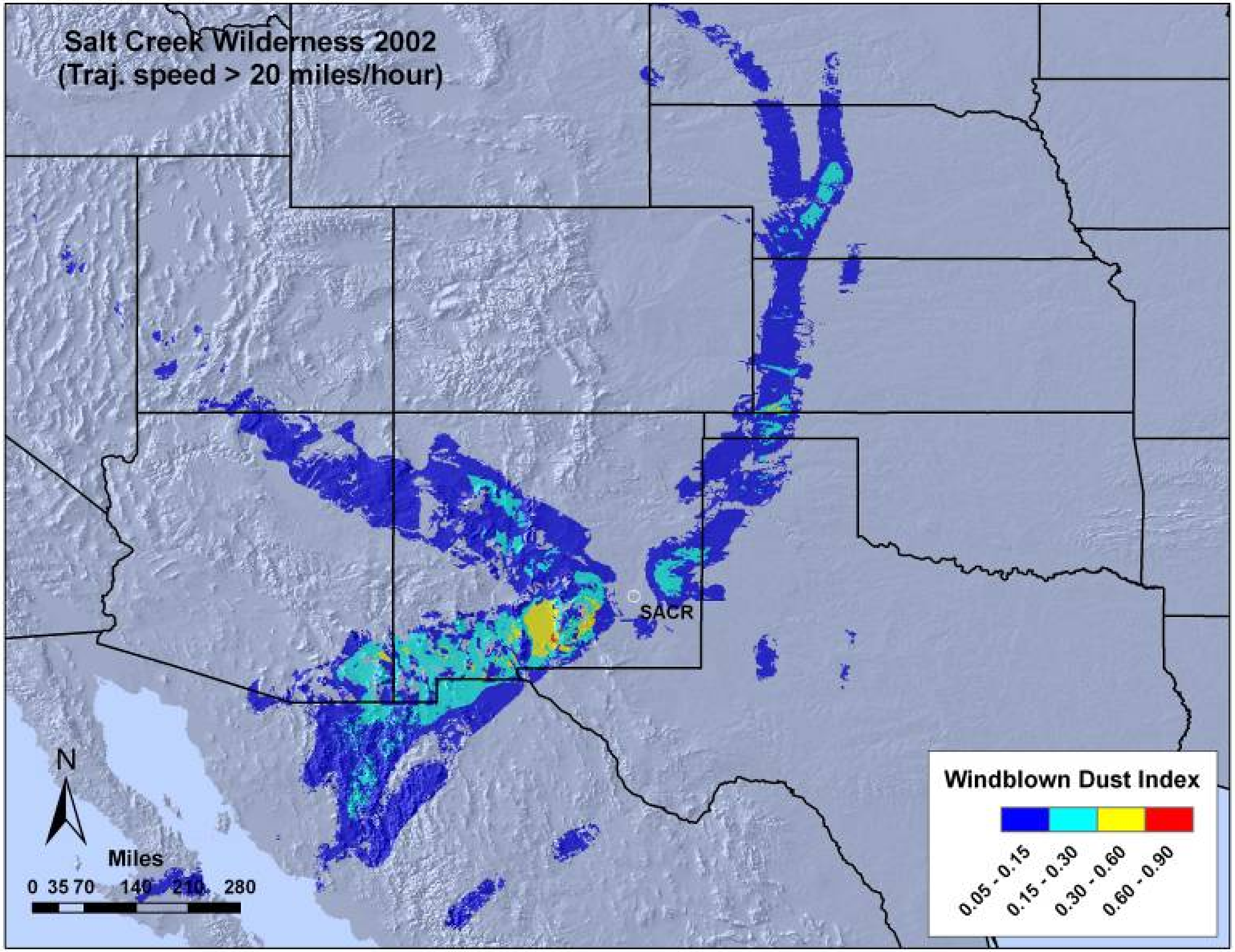


Figure 6-21 Spatial distribution of WDI for Salt Creek Wilderness (2003, Traj. speed > 20 miles/hour)

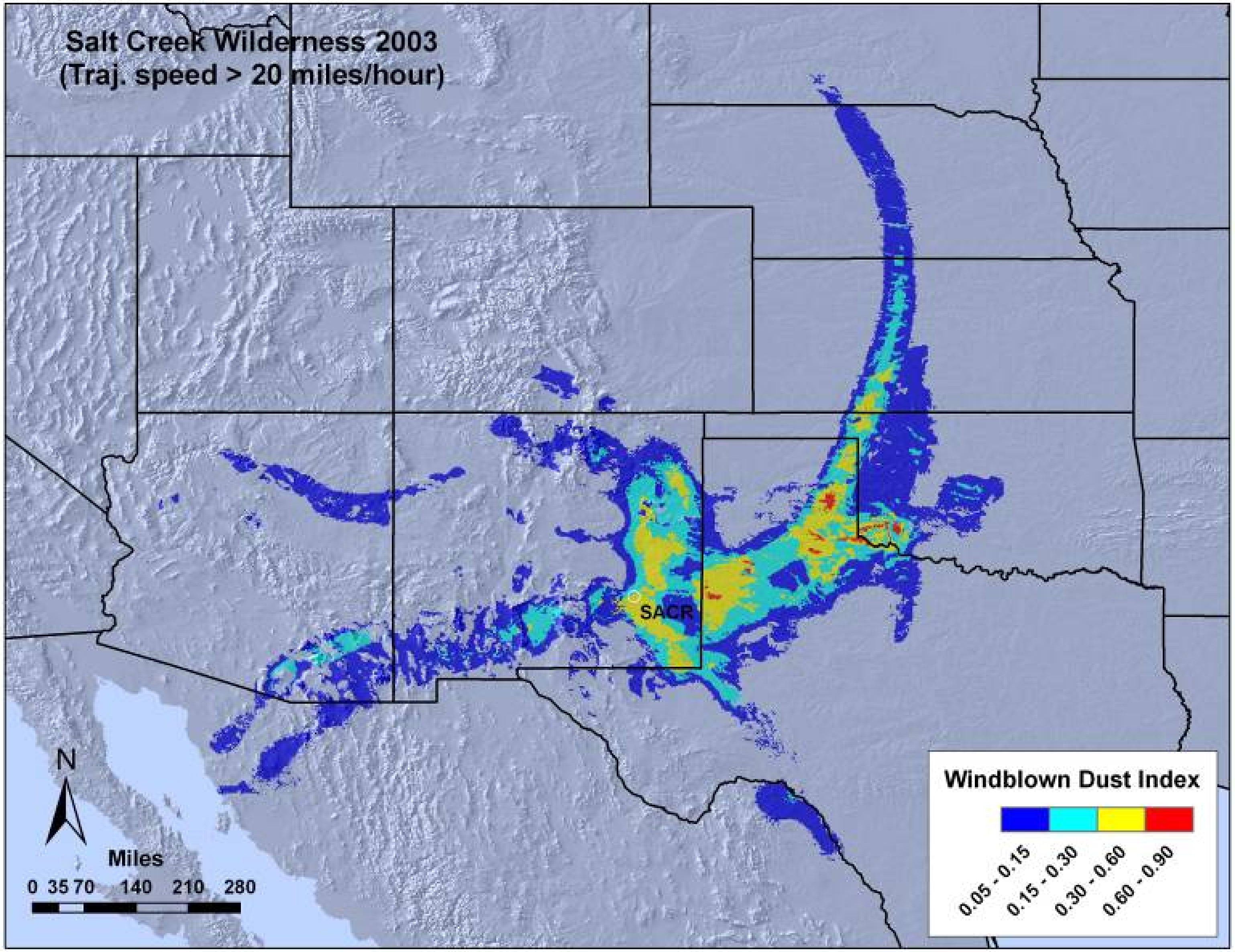


Figure 6-22 Spatial distribution of WDI for Salt Creek Wilderness (2001-2003, Winter, Traj. speed > 20 miles/hour)

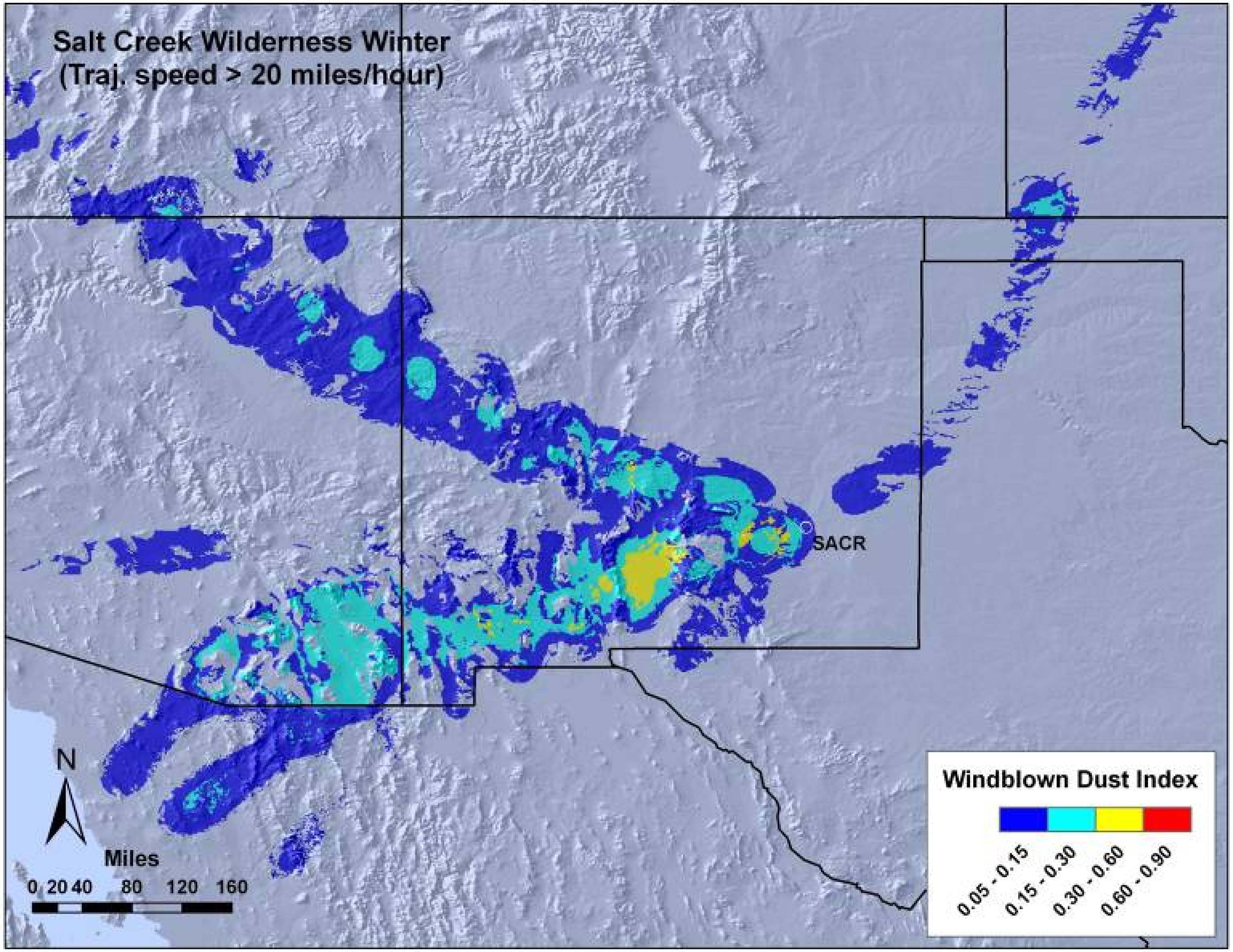


Figure 6-23 Spatial distribution of WDI for Salt Creek Wilderness (2001-2003, Spring, Traj. speed > 20 miles/hour)

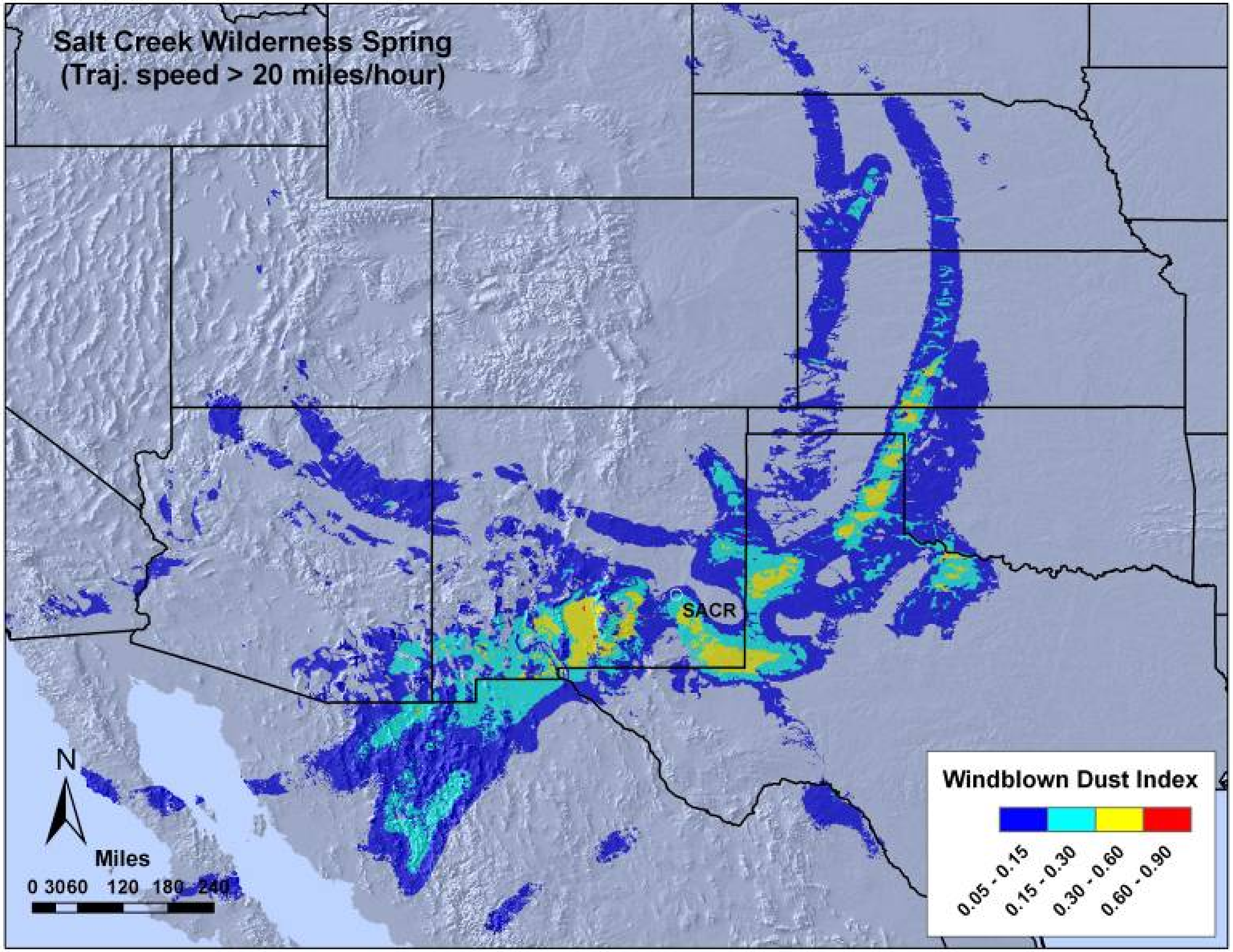


Figure 6-24 Spatial distribution of WDI for Salt Creek Wilderness (2001-2003, Summer, Traj. speed > 20 miles/hour)

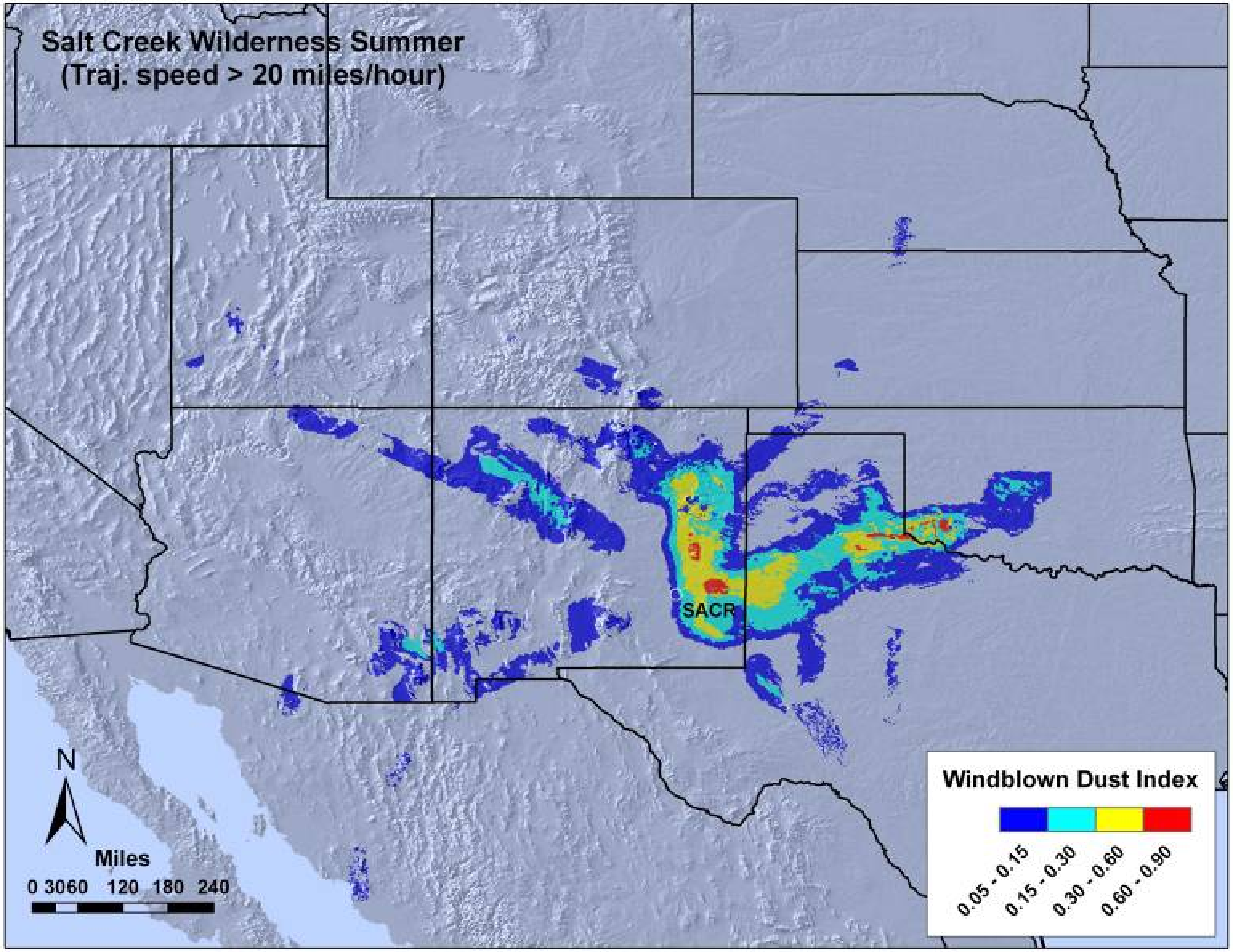


Figure 6-25 Spatial distribution of WDI for Salt Creek Wilderness (2001-2003, Fall, Traj. speed > 20 miles/hour)

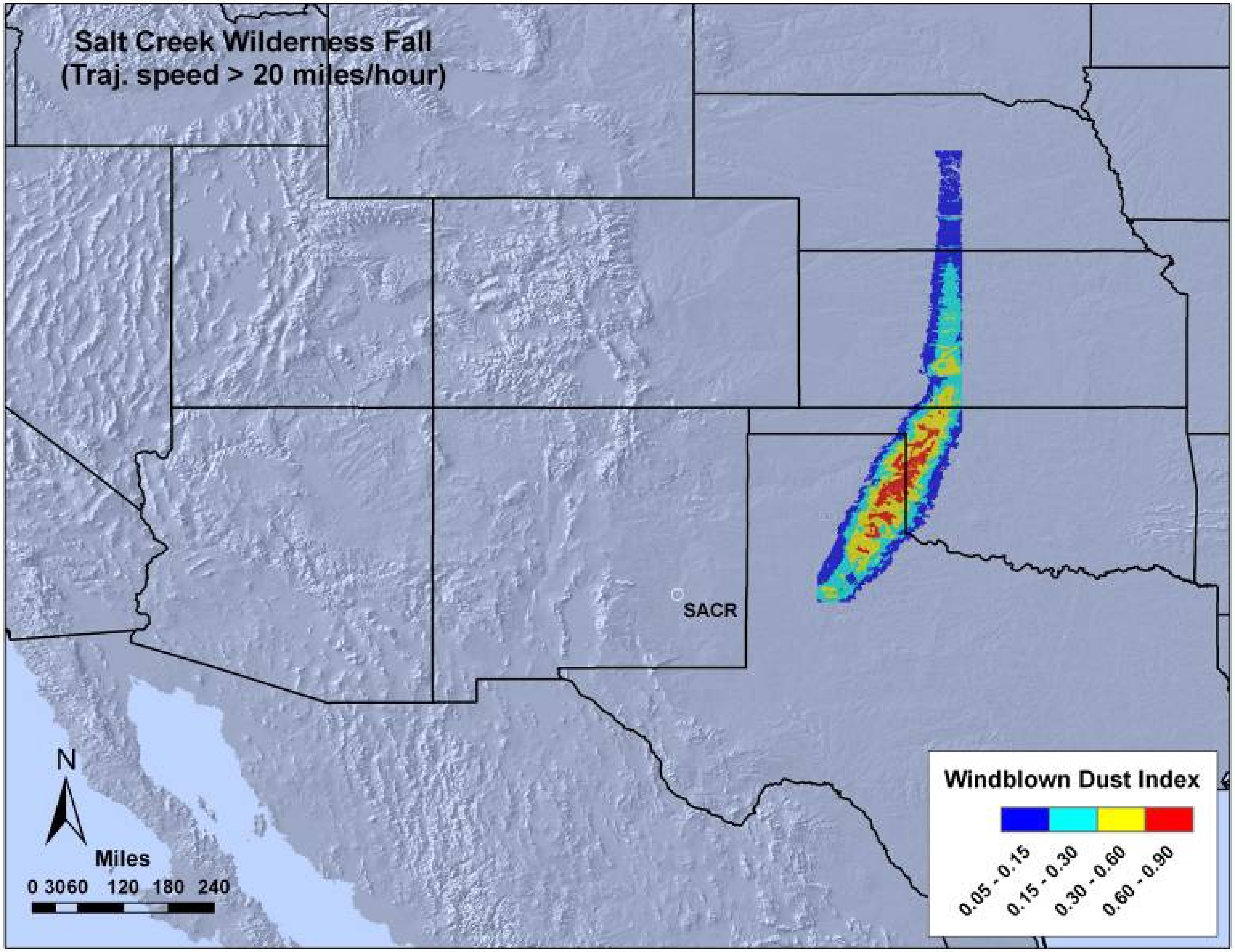


Figure 6-26 Contour plot of WDI for Salt Creek Wilderness (2001, Traj. speed > 20 miles/hour)

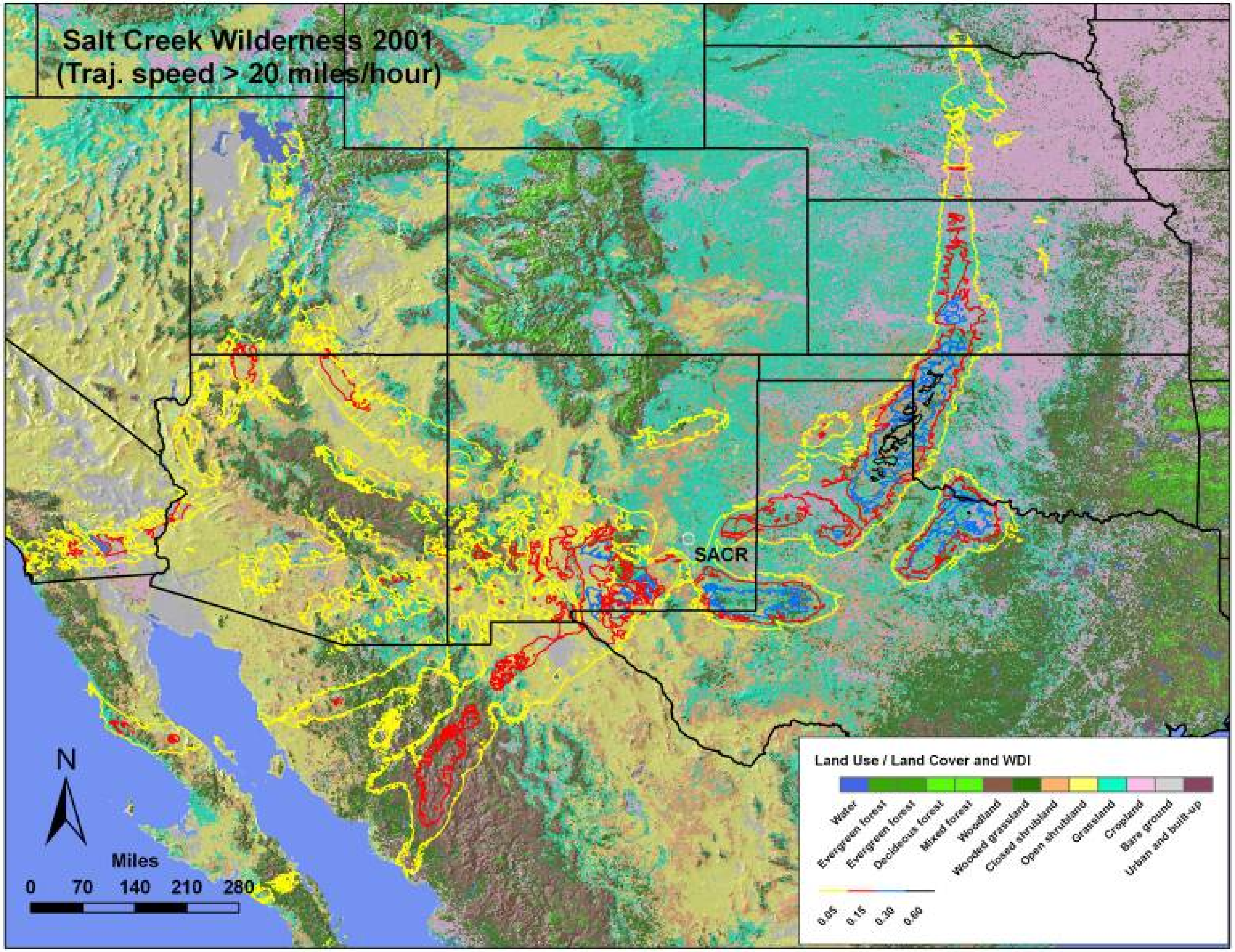


Figure 6-27 Contour plot of WDI for Salt Creek Wilderness (2002, Traj. speed > 20 miles/hour)

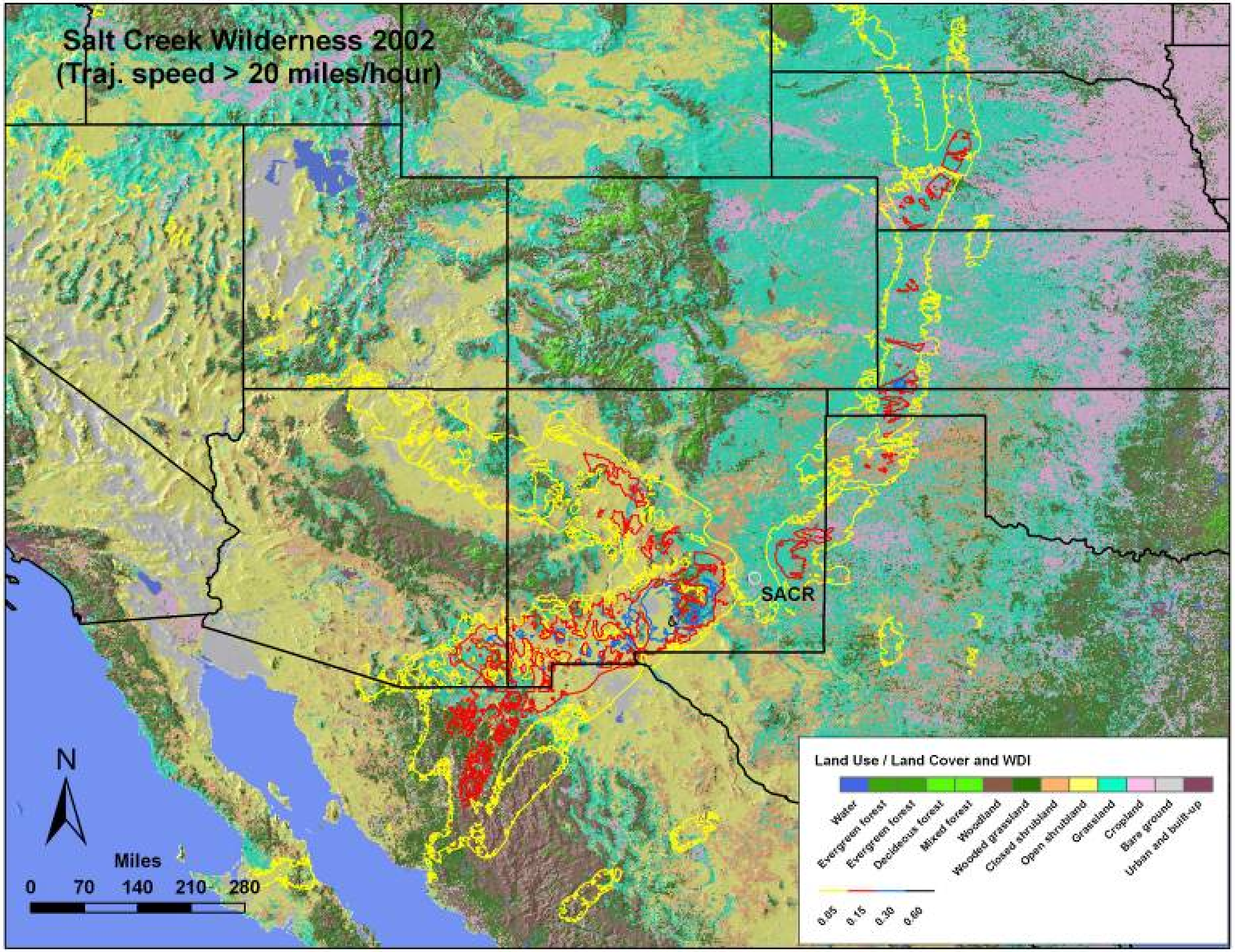


Figure 6-28 Contour plot of WDI for Salt Creek Wilderness (2003, Traj. speed > 20 miles/hour)

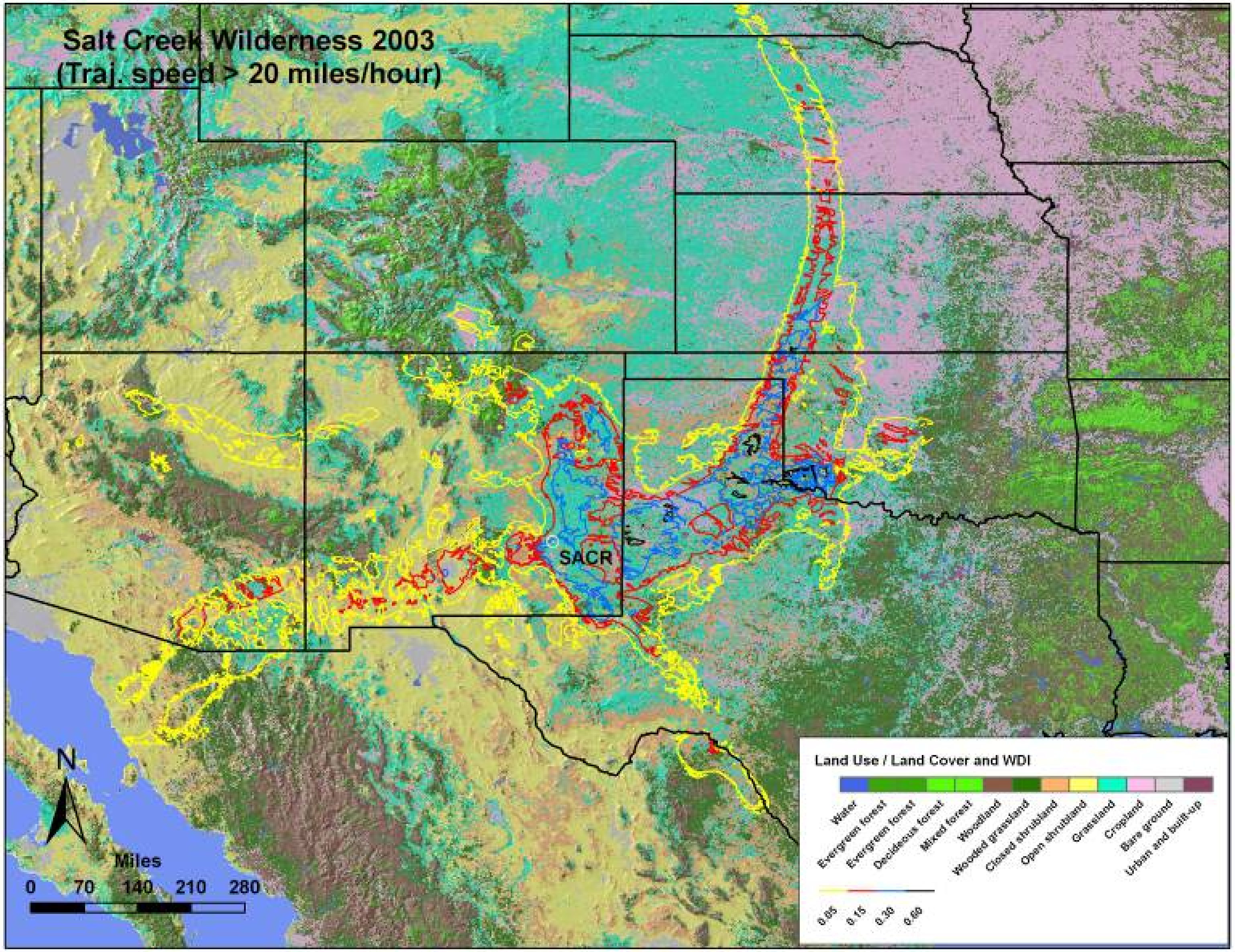


Figure 6-29 Contour plot of WDI for Salt Creek Wilderness (2001-2003, Winter. Traj. speed > 20 miles/hour)

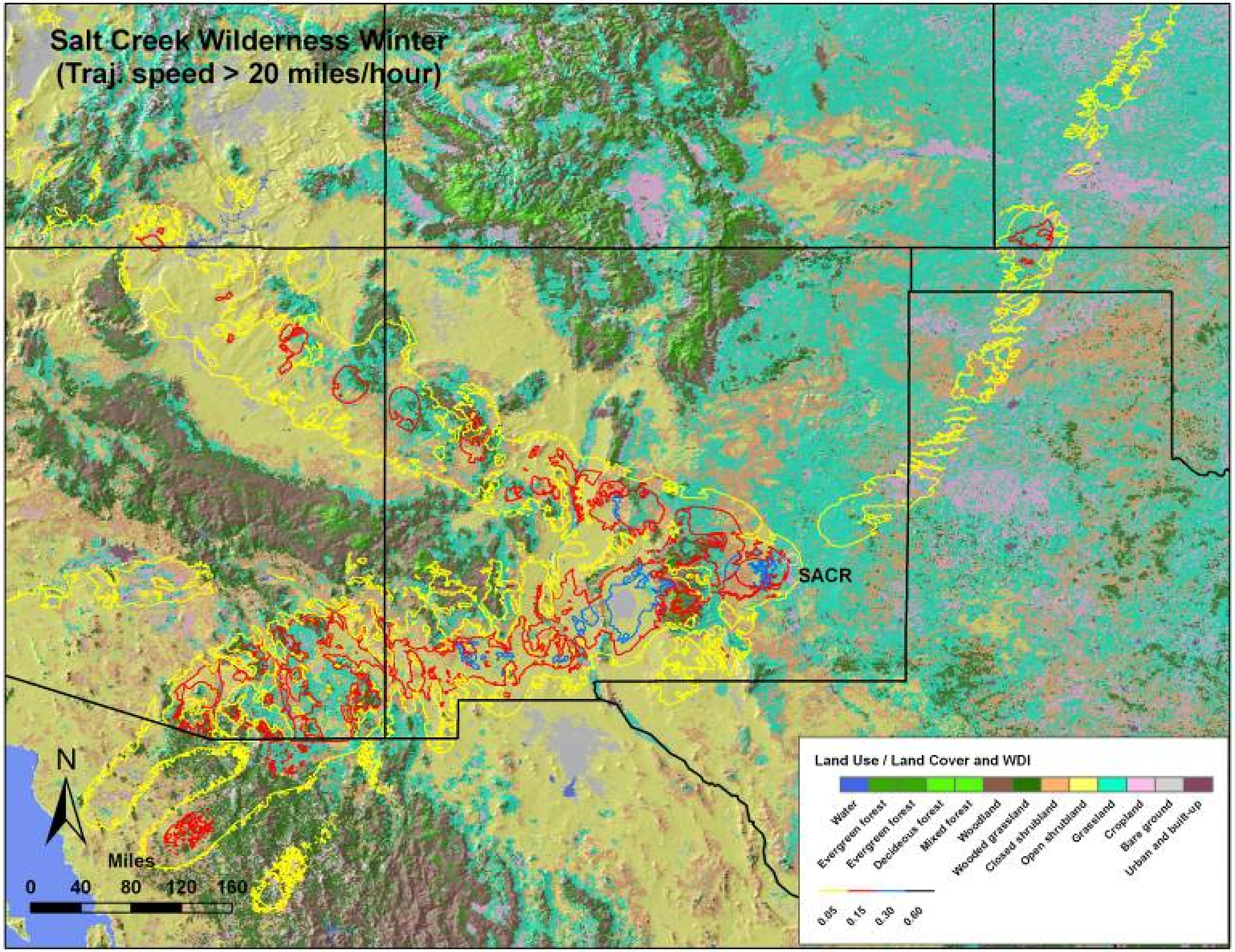


Figure 6-30 Contour plot of WDI for Salt Creek Wilderness (2001-2003, Spring. Traj. speed > 20 miles/hour)

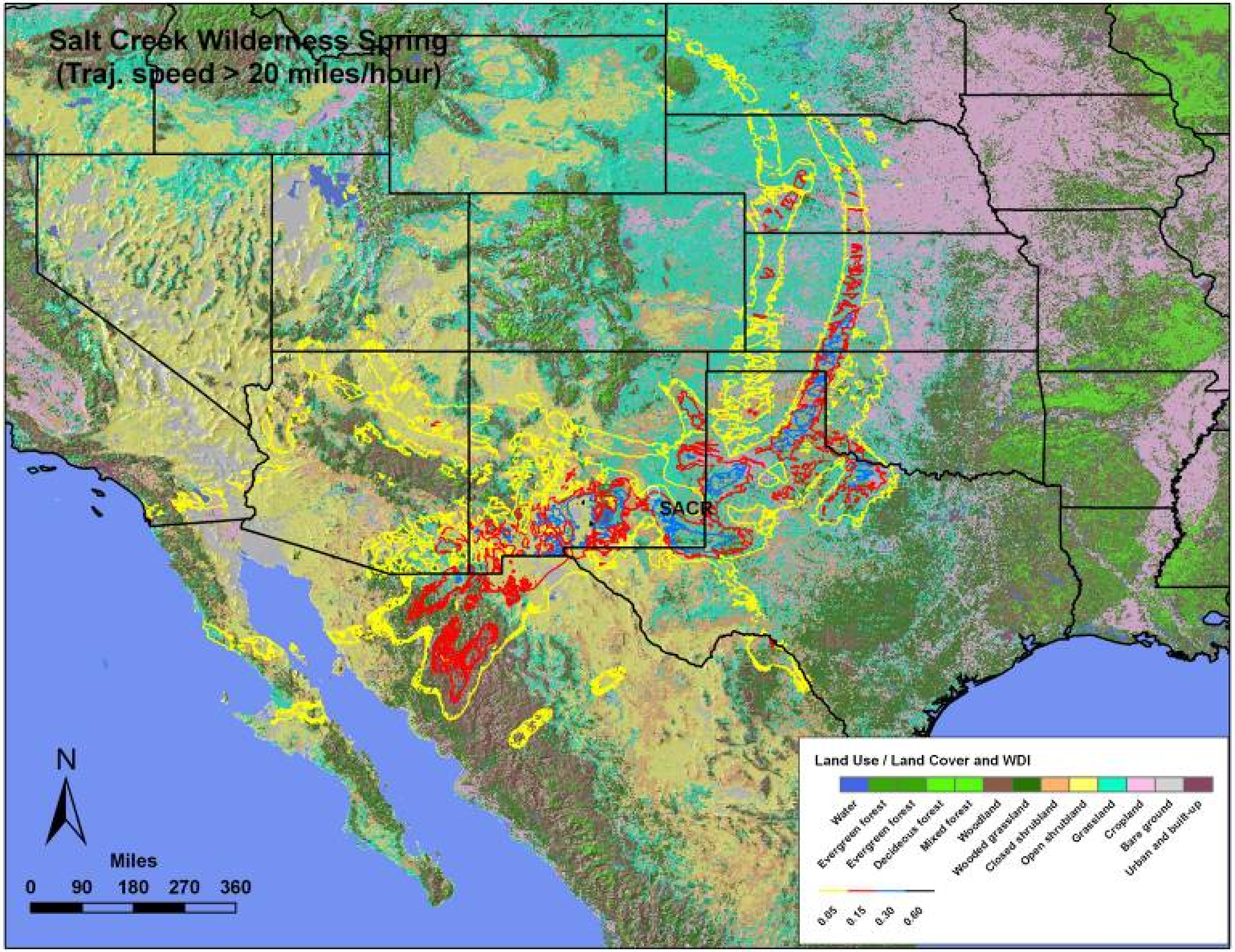


Figure 6-31 Contour plot of WDI for Salt Creek Wilderness (2001-2003, Summer, Traj. speed > 20 miles/hour)

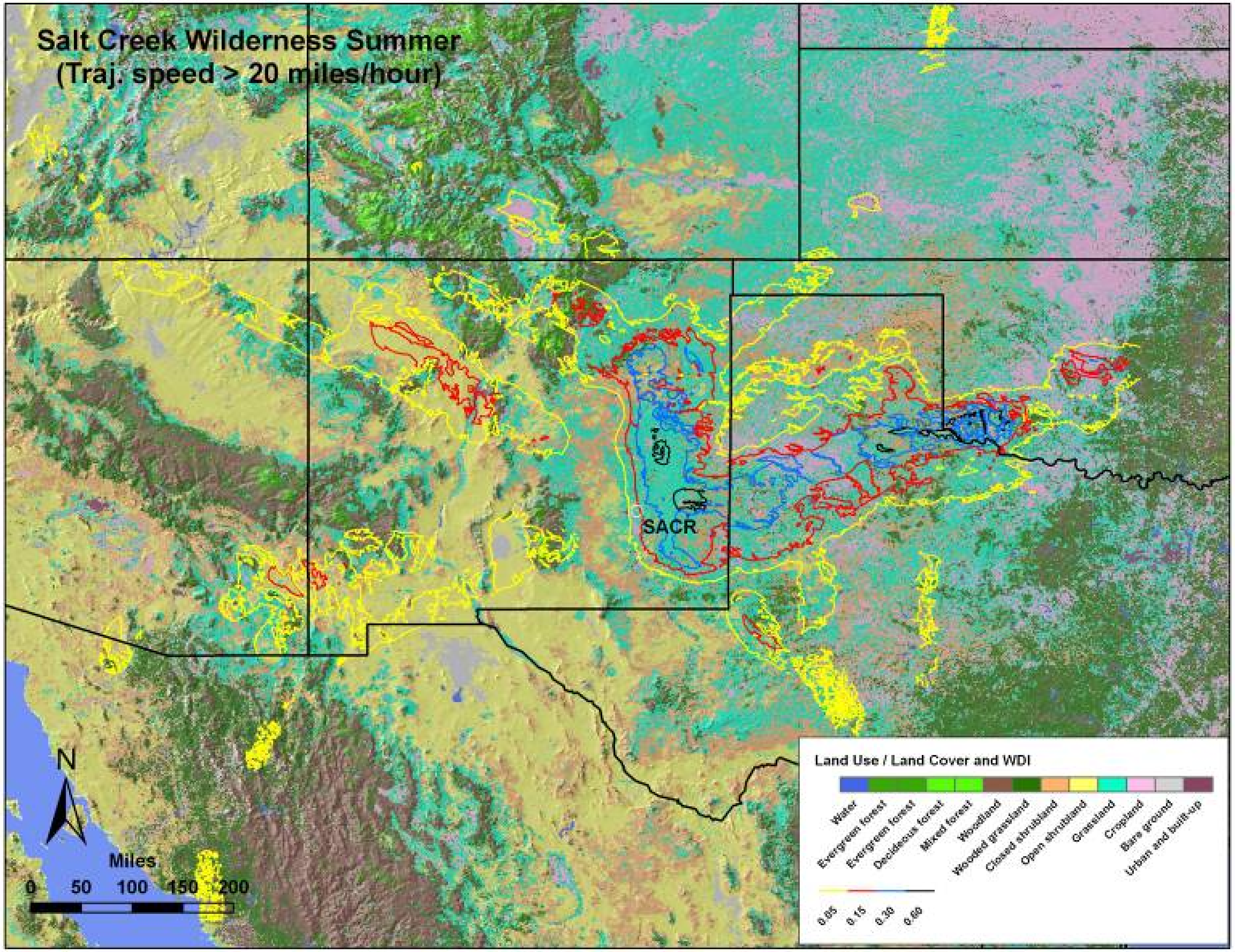


Figure 6-32 Contour plot of WDI for Salt Creek Wilderness (2001-2003, Winter. Traj. speed > 20 miles/hour)

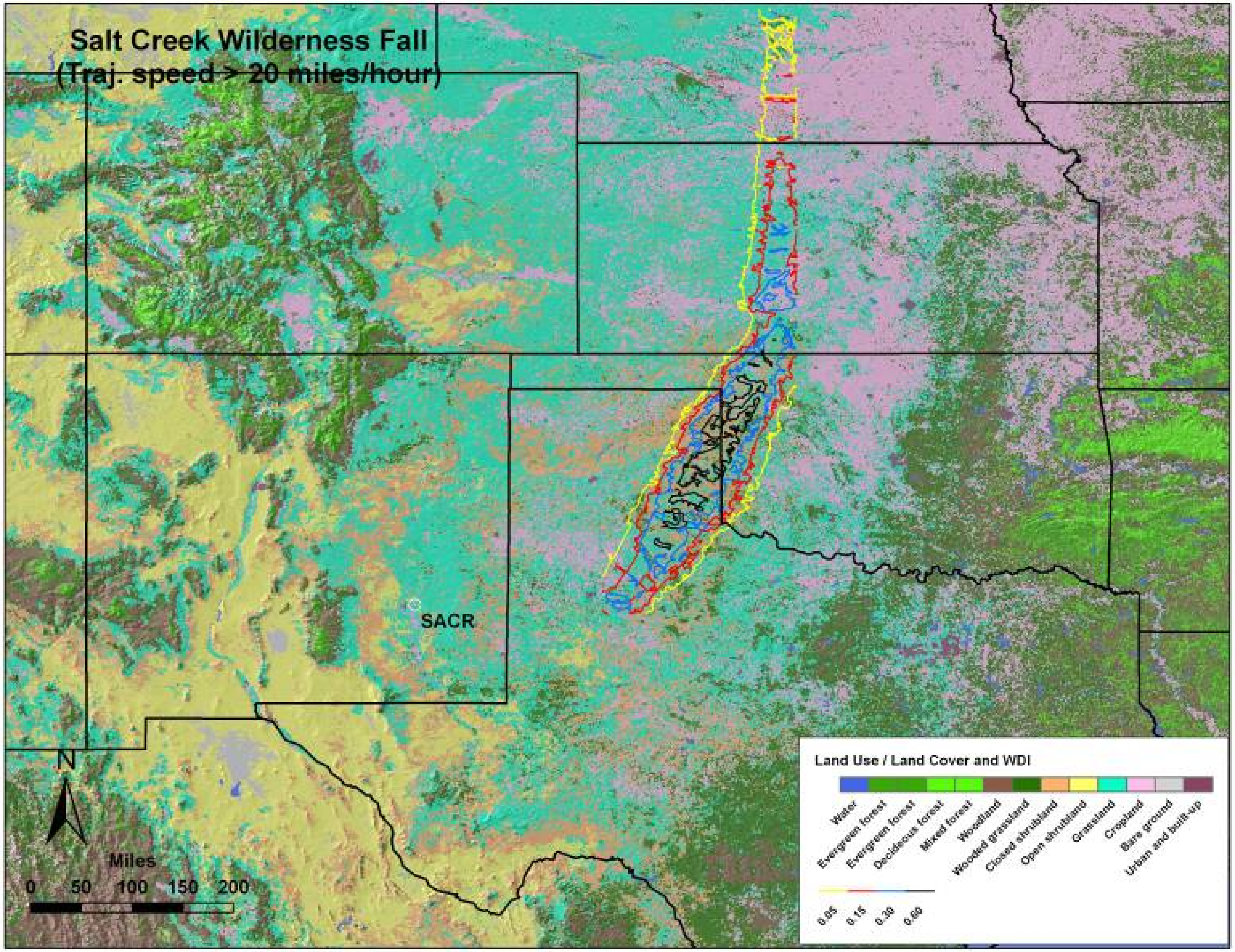


Figure 6-33 Spatial distribution of WDI/distance for Salt Creek Wilderness (2001, Traj. speed > 20 miles/hour)

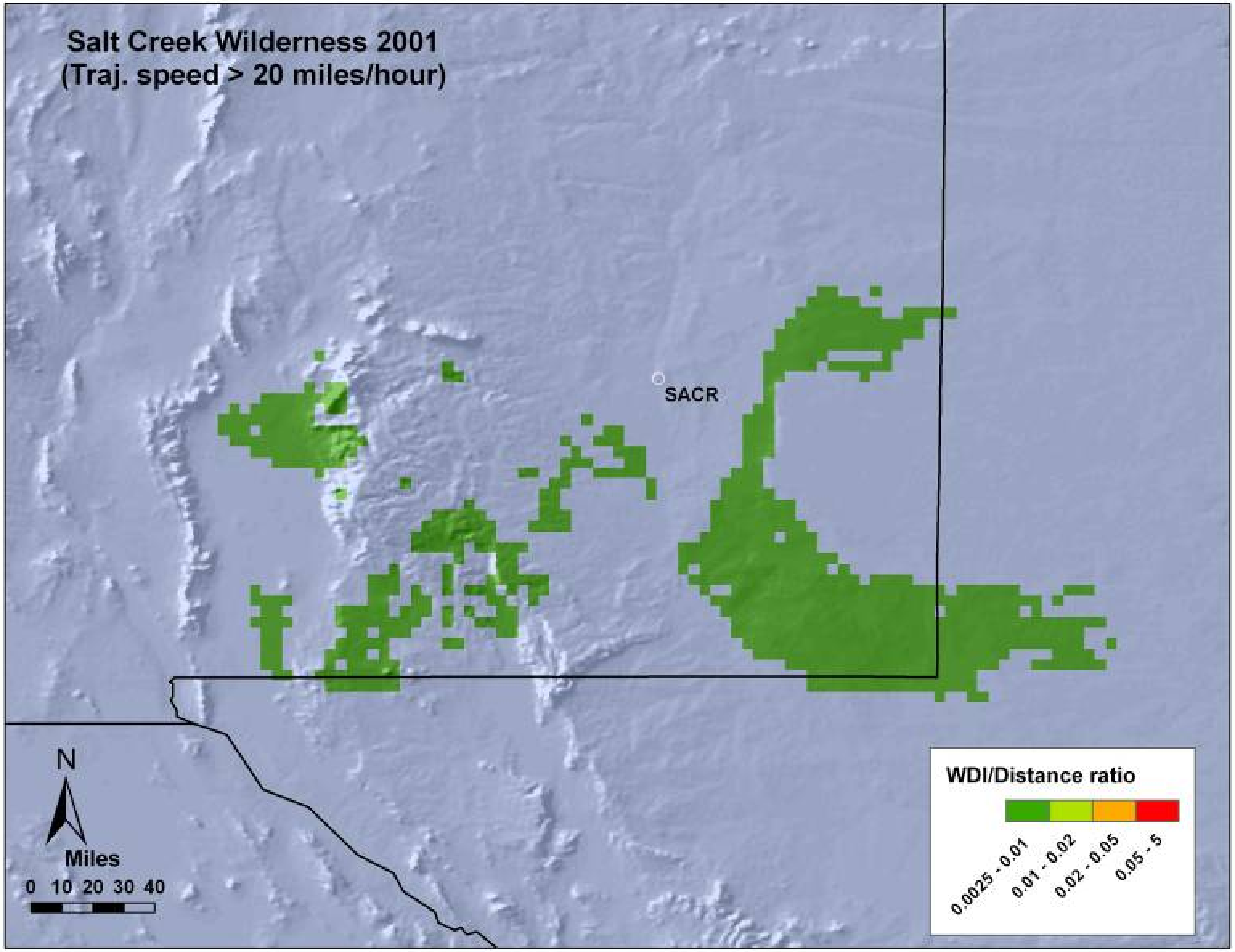


Figure 6-34 Spatial distribution of WDI/distance for Salt Creek Wilderness (2002, Traj. speed > 20 miles/hour)

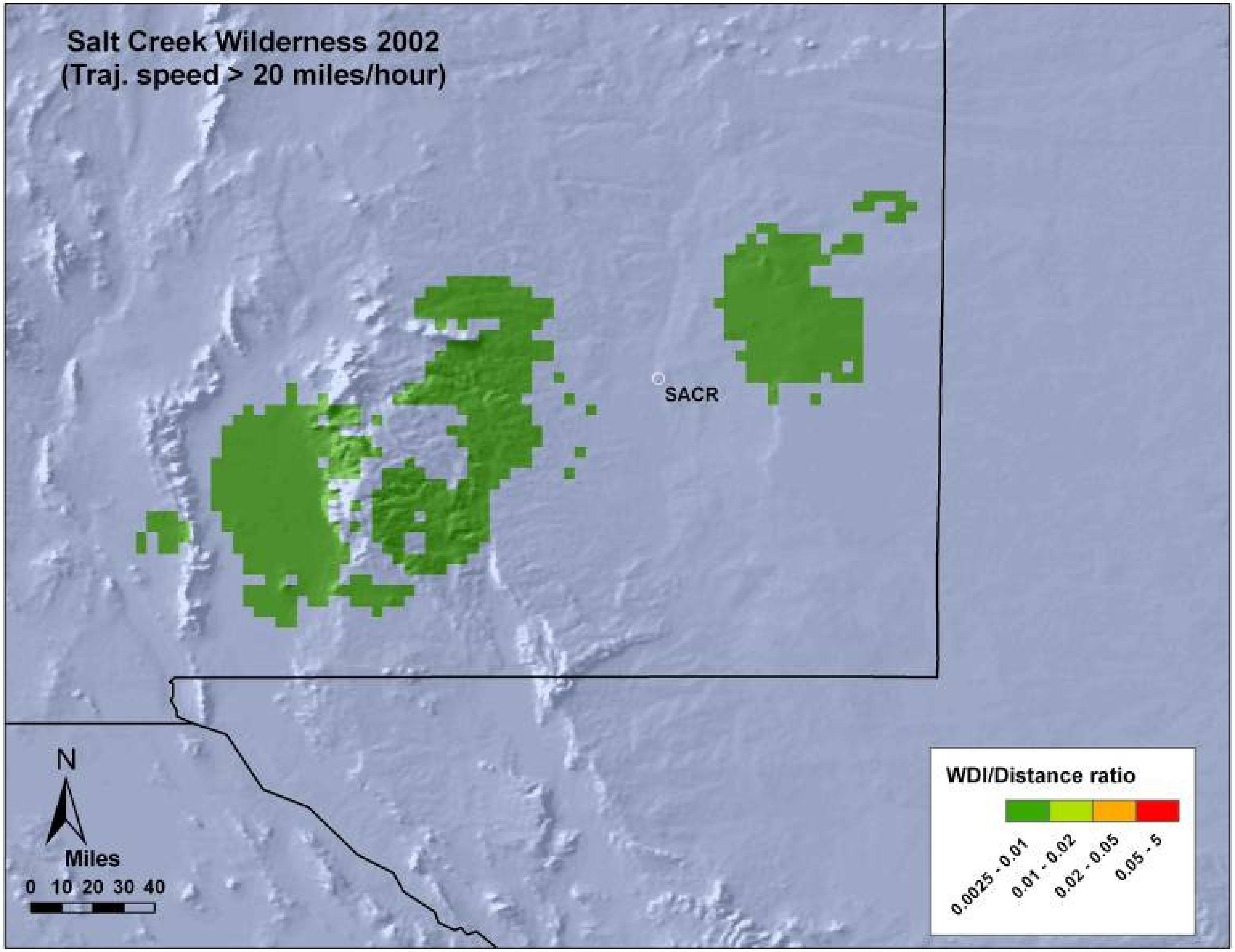


Figure 6-35 Spatial distribution of WDI/distance for Salt Creek Wilderness (2003, Traj. speed > 20 miles/hour)

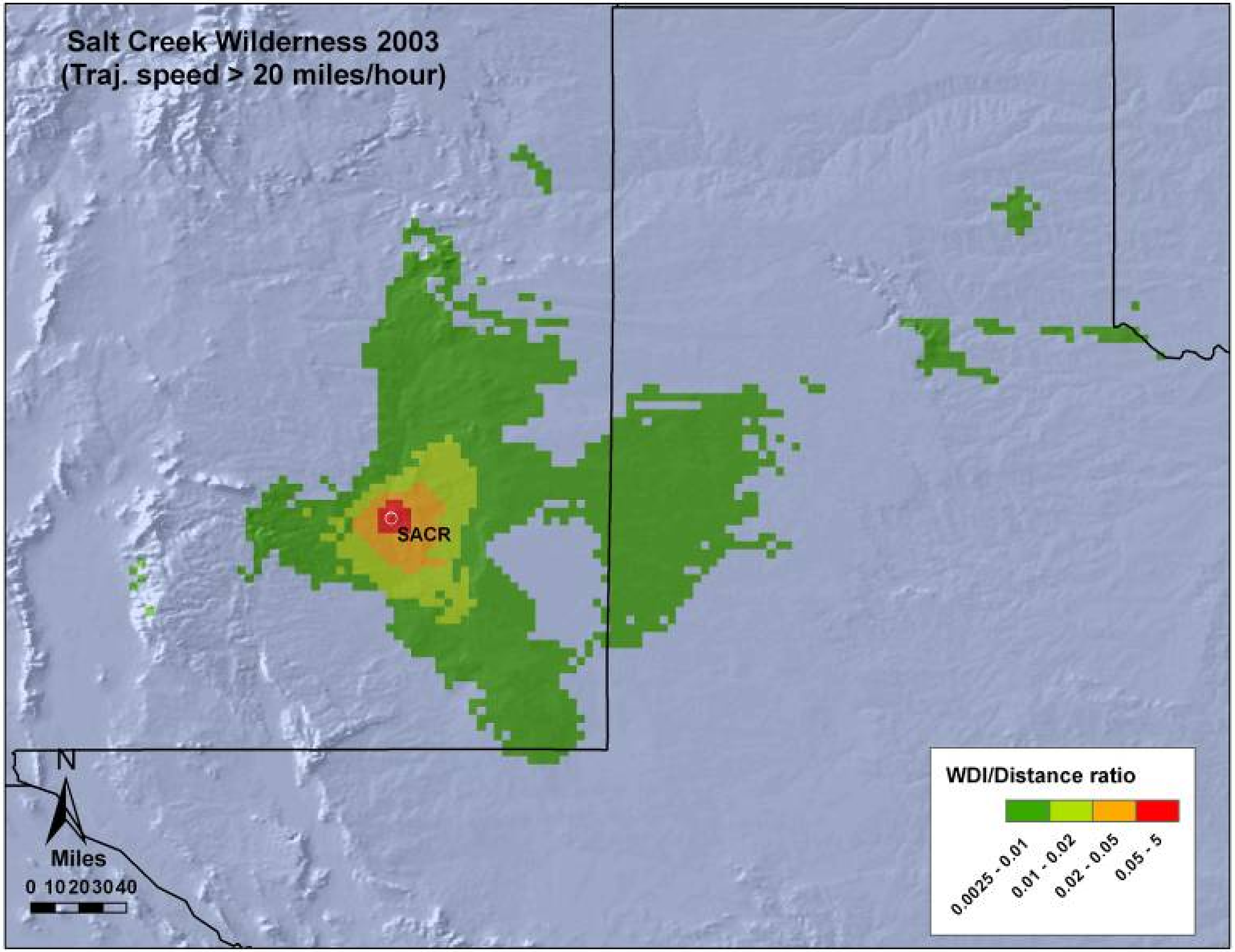


Figure 6-36 Spatial distribution of WDI/distance for Salt Creek Wilderness (2001-2003, Winter, Traj. speed > 20 miles/hour)

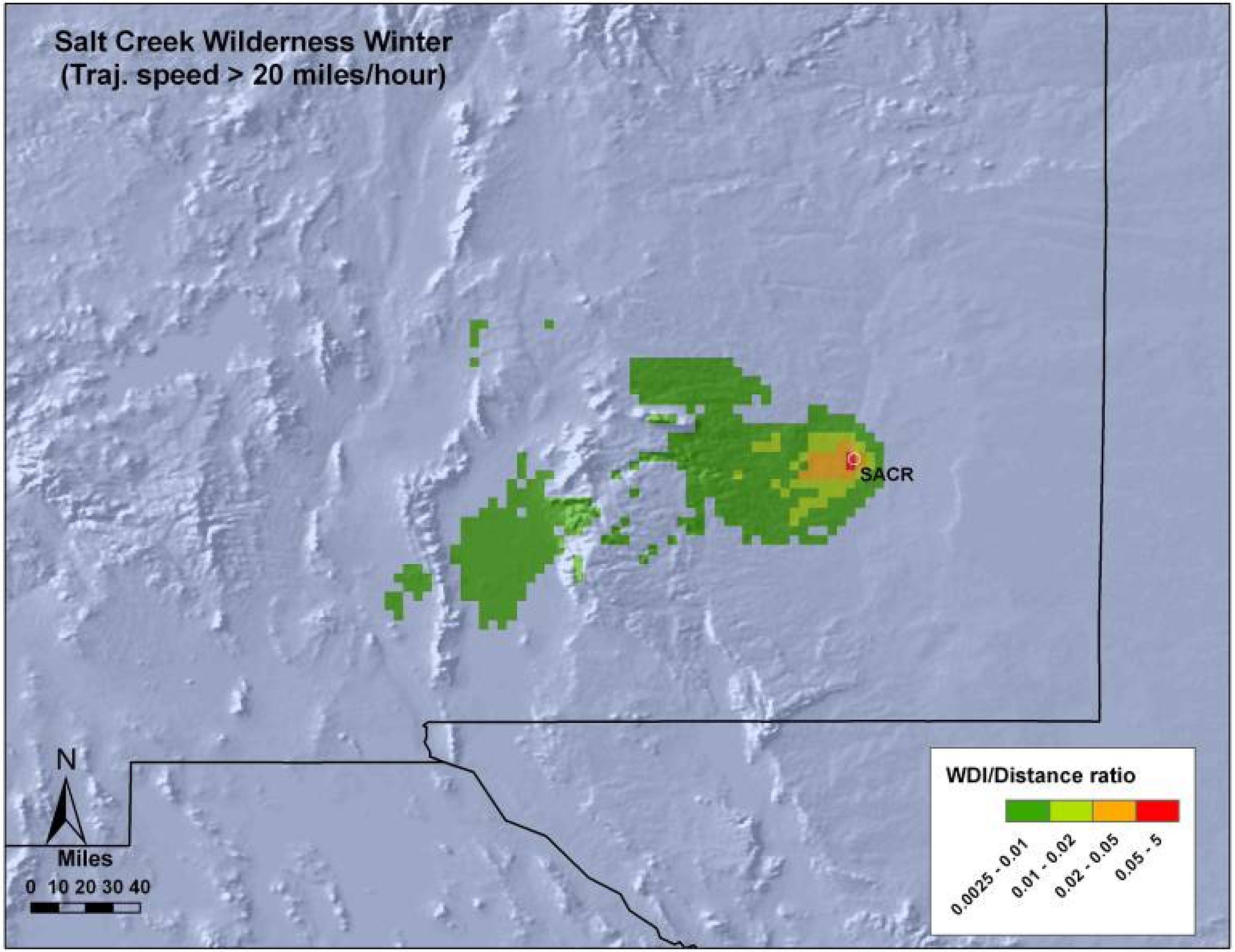


Figure 6-37 Spatial distribution of WDI/distance for Salt Creek Wilderness (2001-2003, Spring, Traj. speed > 20 miles/hour)

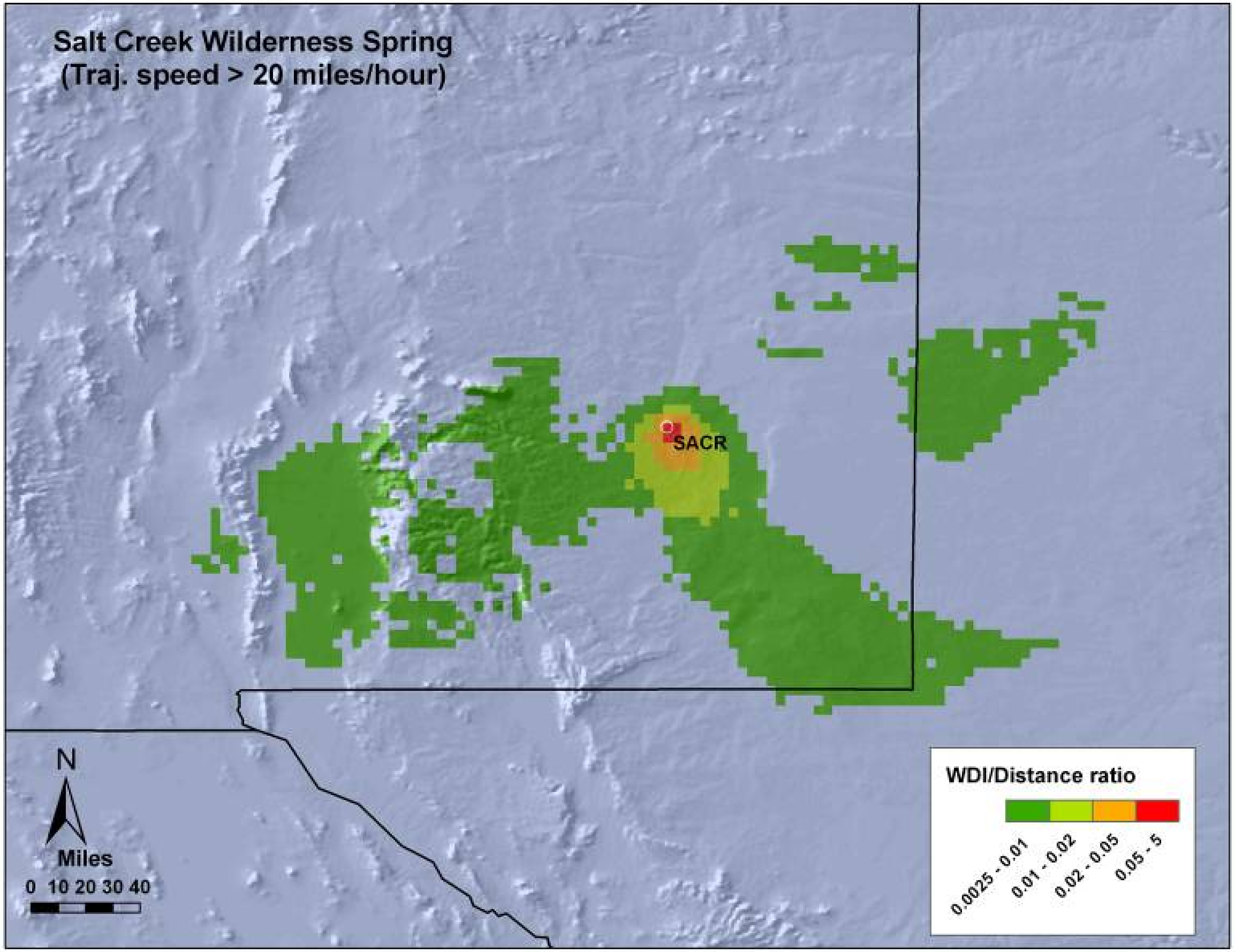


Figure 6-38 Spatial distribution of WDI/distance for Salt Creek Wilderness (2001-2003, Summer, Traj. speed > 20 miles/hour)

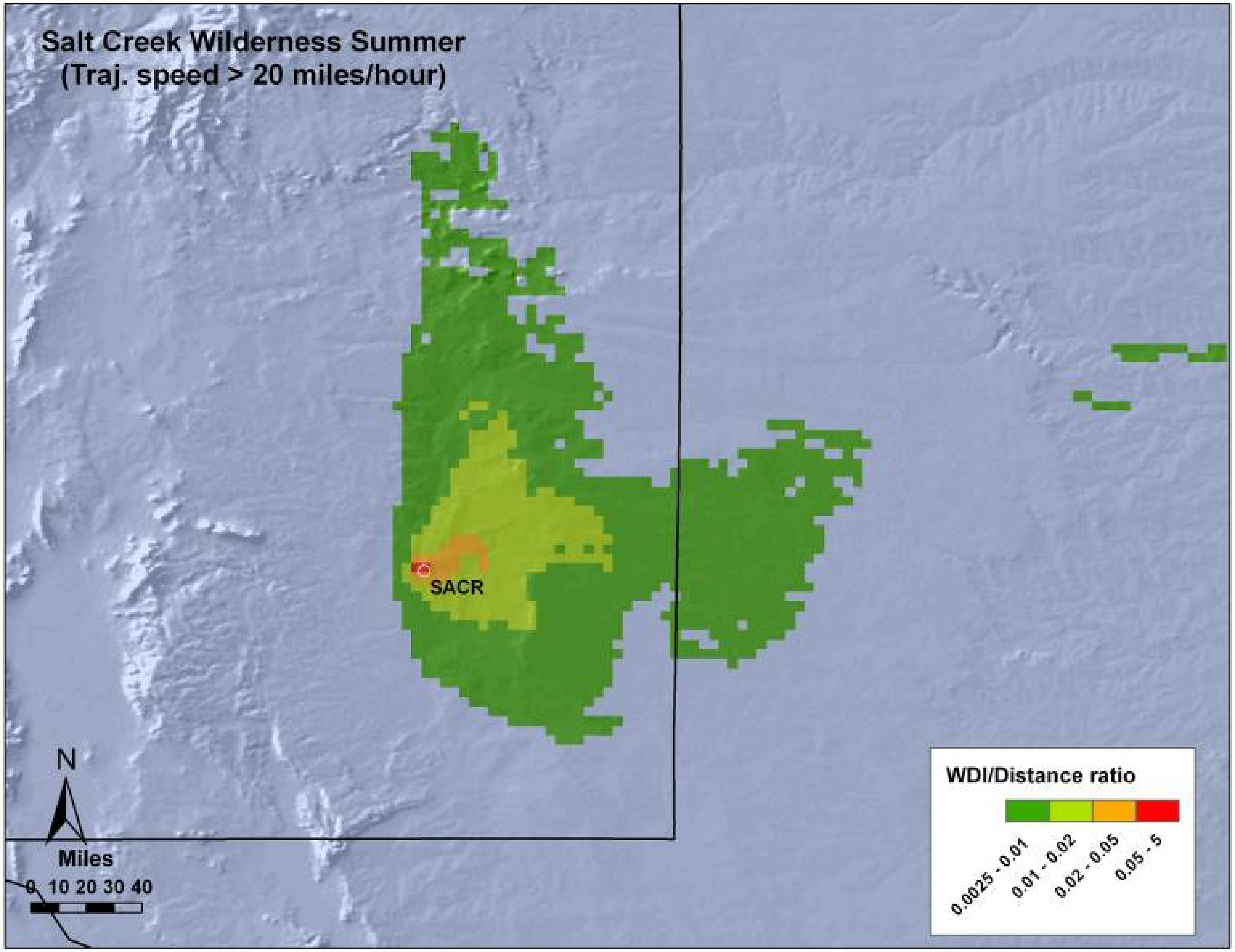


Figure 6-39 Spatial distribution of WDI/distance for Salt Creek Wilderness (2001-2003, Fall, Traj. speed > 20 miles/hour)

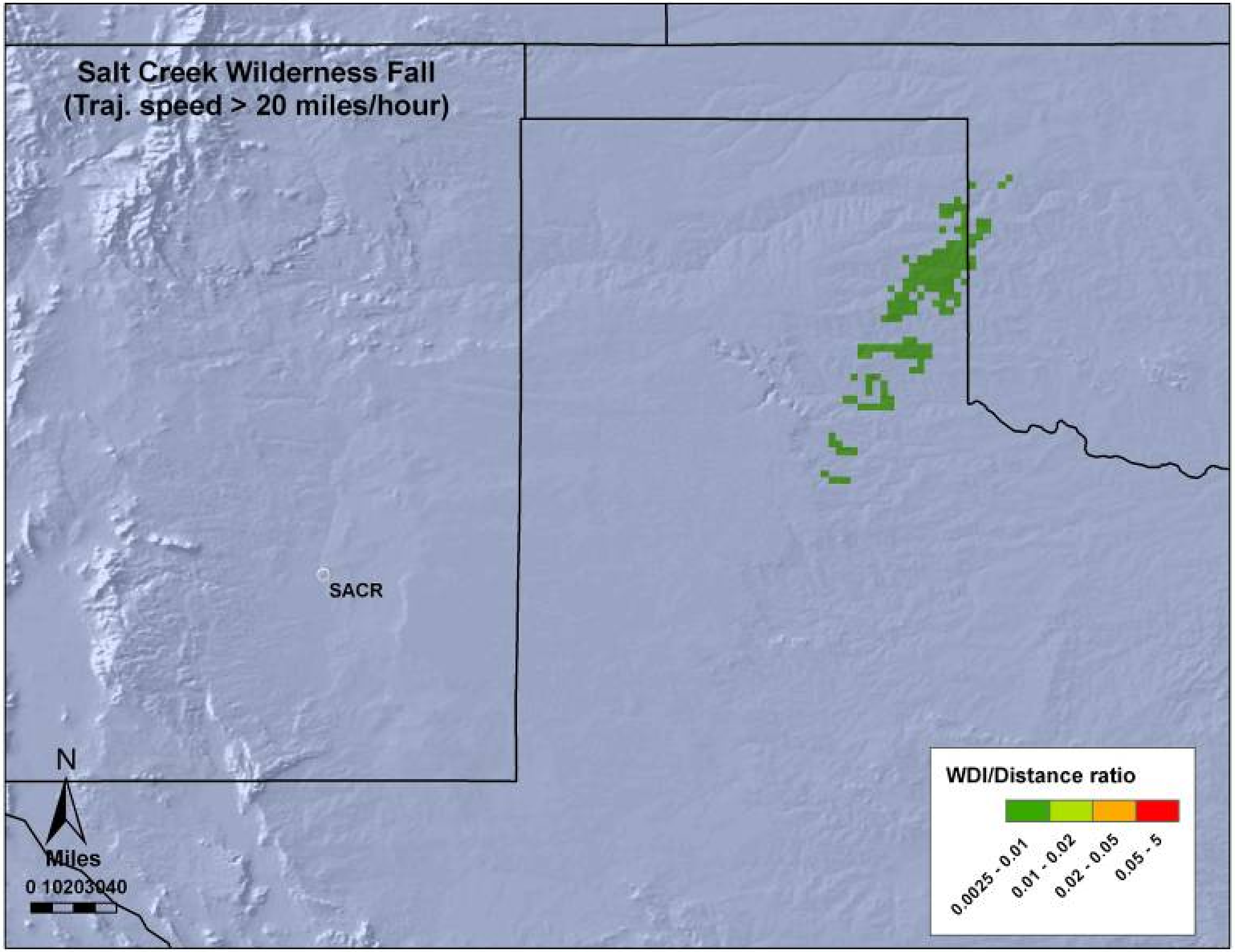


Figure 6-40 Contour plot of WDI/distance for Salt Creek Wilderness (2001, Traj. speed > 20 miles/hour)

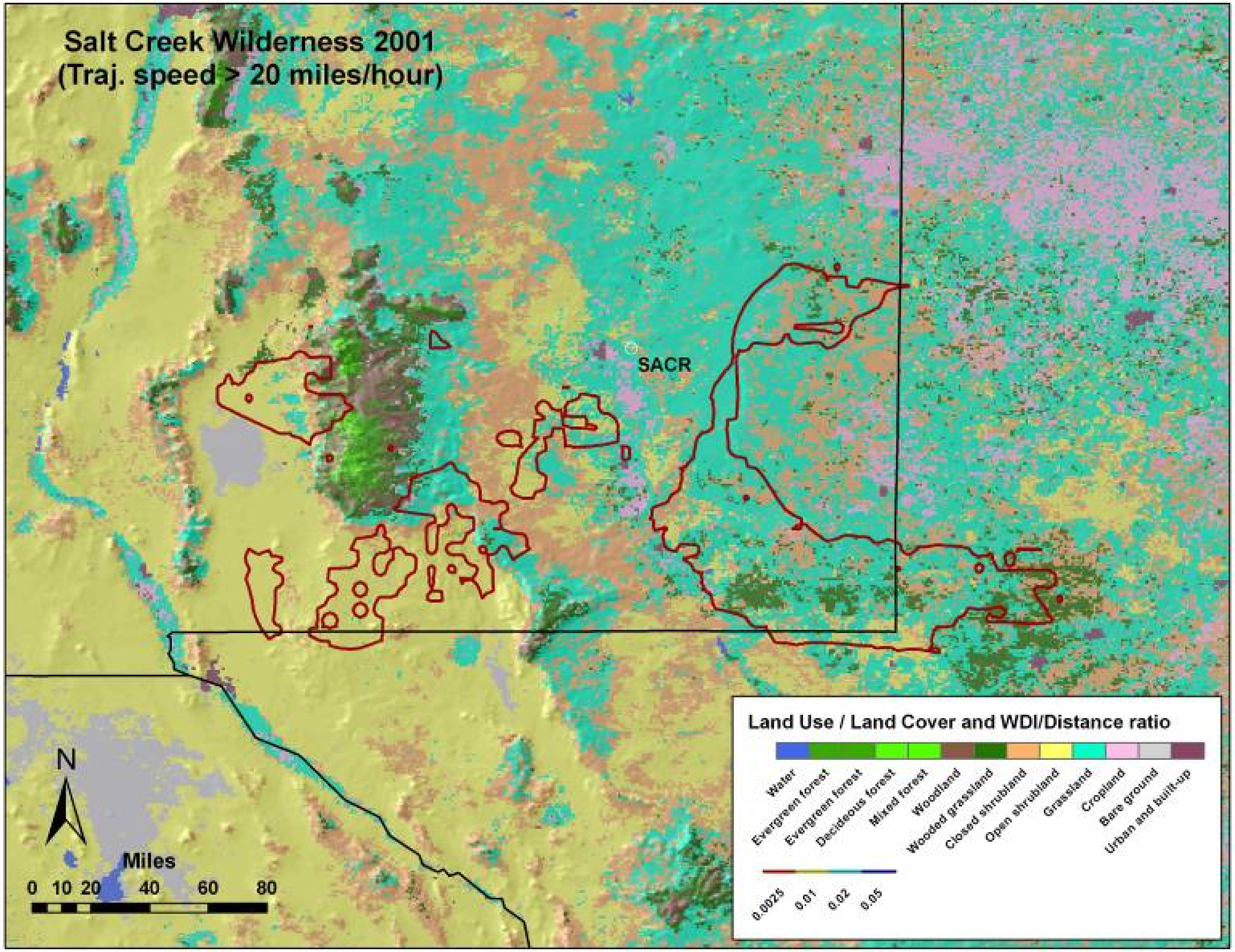


Figure 6-41 Contour plot of WDI/distance for Salt Creek Wilderness (2002, Traj. speed > 20 miles/hour)

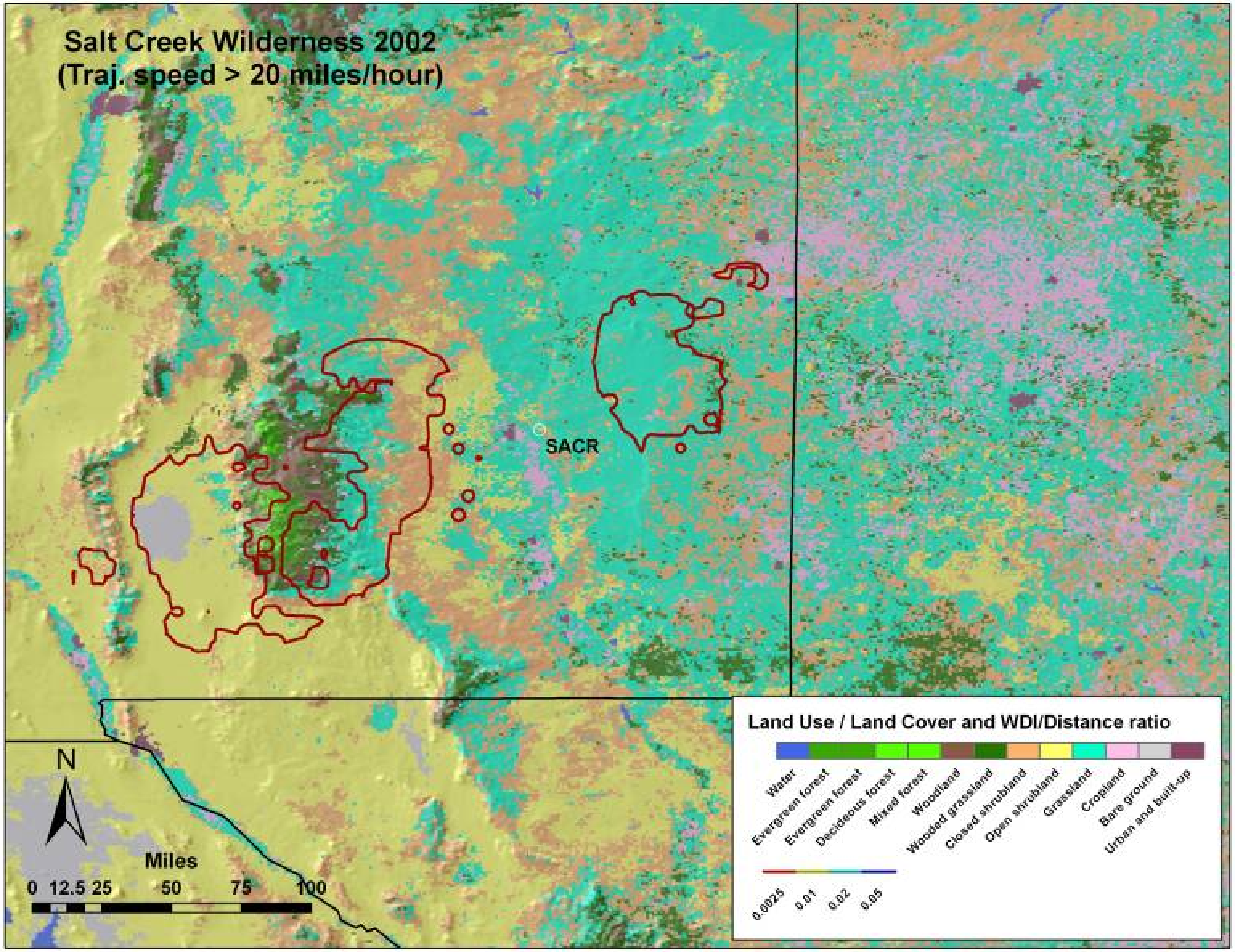


Figure 6-42 Contour plot of WDI/distance for Salt Creek Wilderness (2003, Traj. speed > 20 miles/hour)

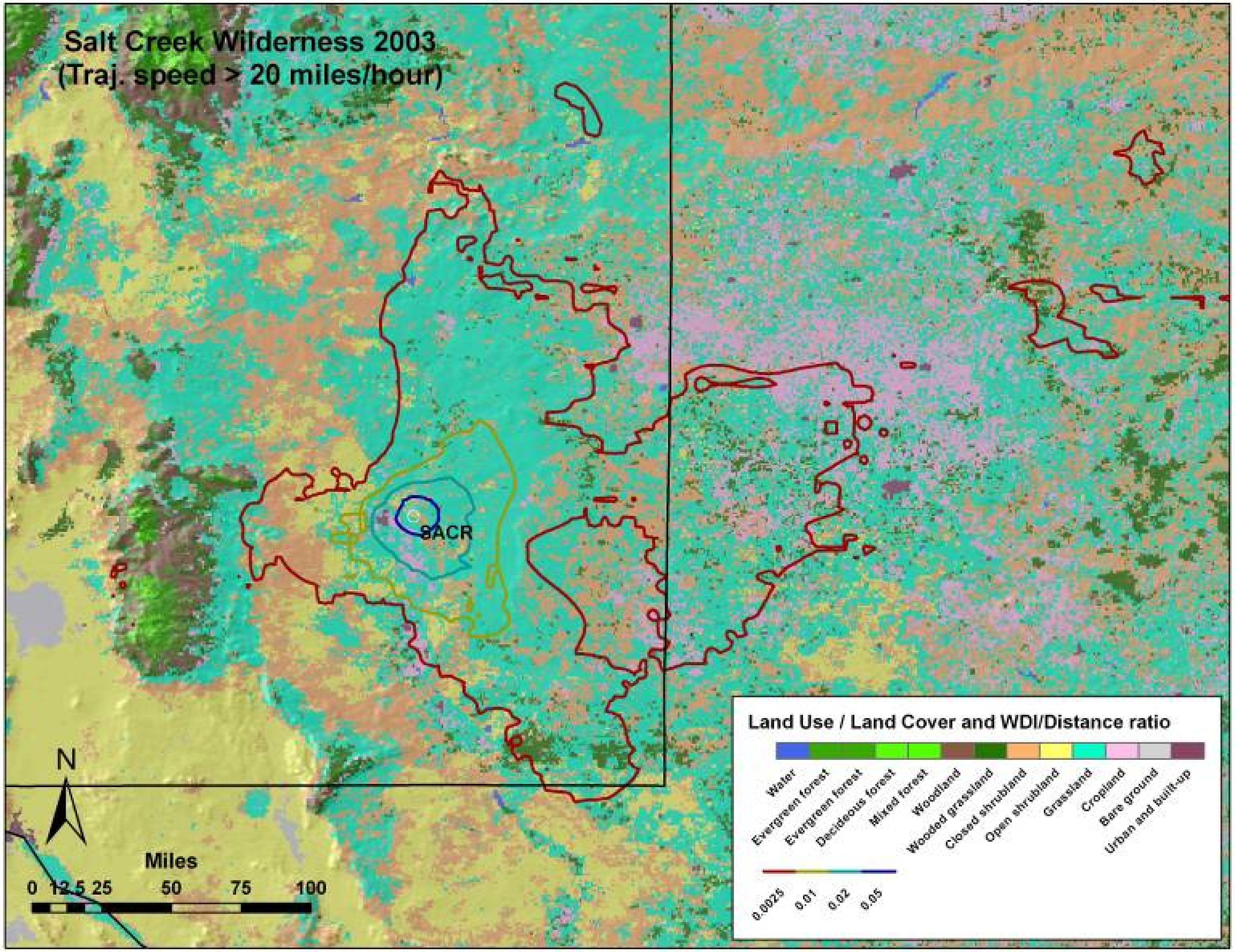


Figure 6-43 Contour plot of WDI/distance for Salt Creek Wilderness (2001-2003, Winter, Traj. speed > 20 miles/hour)

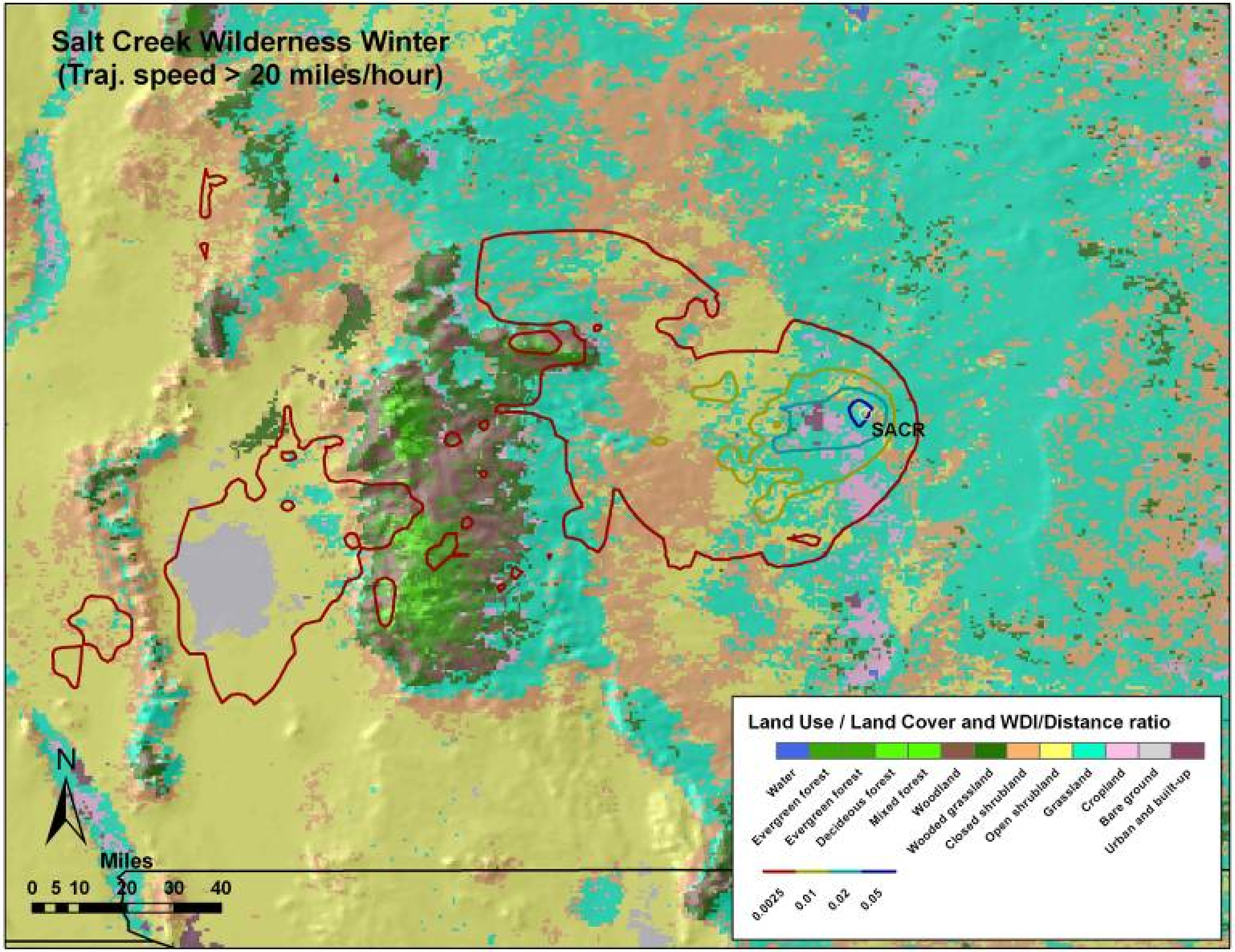


Figure 6-44 Contour plot of WDI/distance for Salt Creek Wilderness (2001-2003, Spring, Traj. speed > 20 miles/hour)

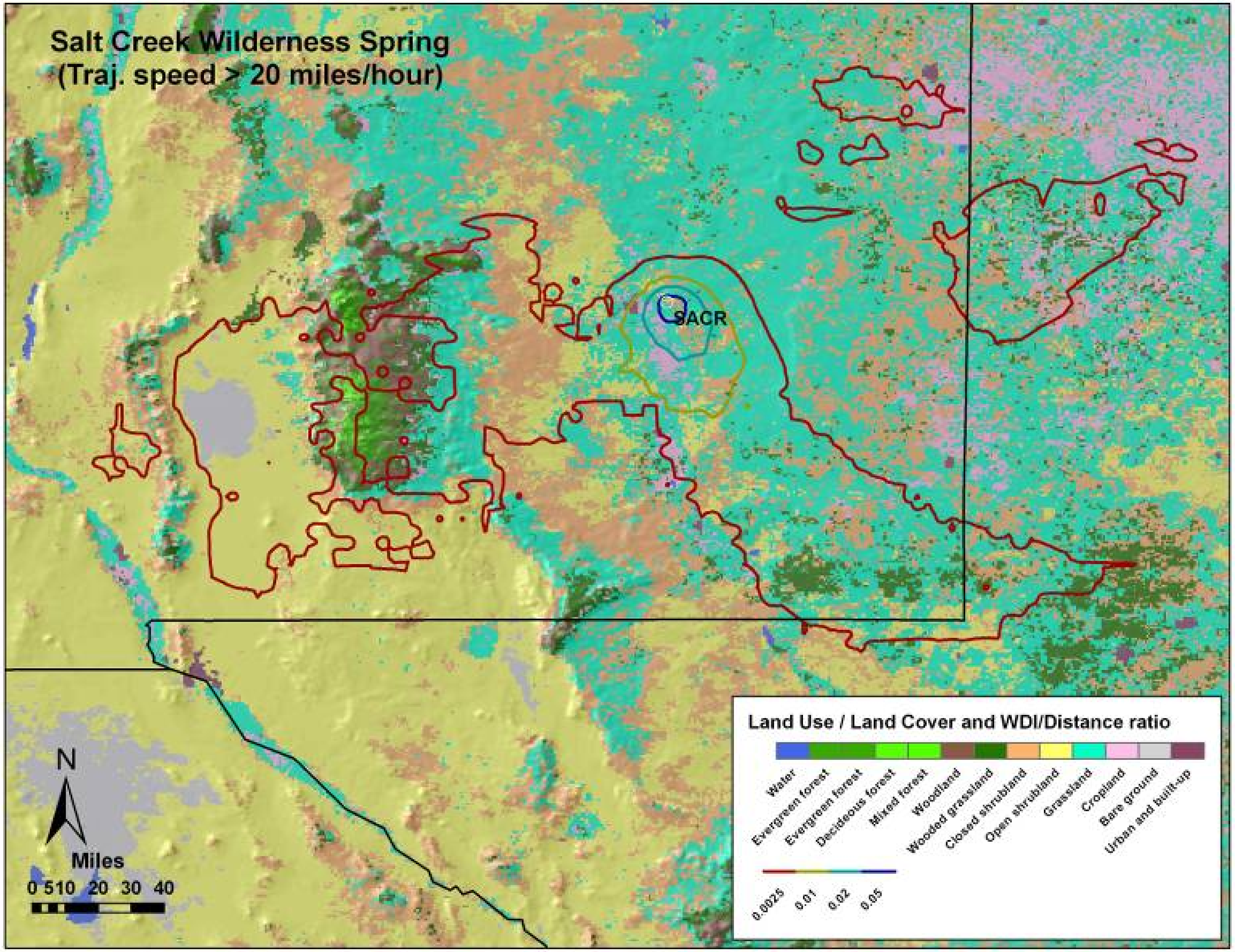


Figure 6-45 Contour plot of WDI/distance for Salt Creek Wilderness (2001-2003, Summer, Traj. speed > 20 miles/hour)

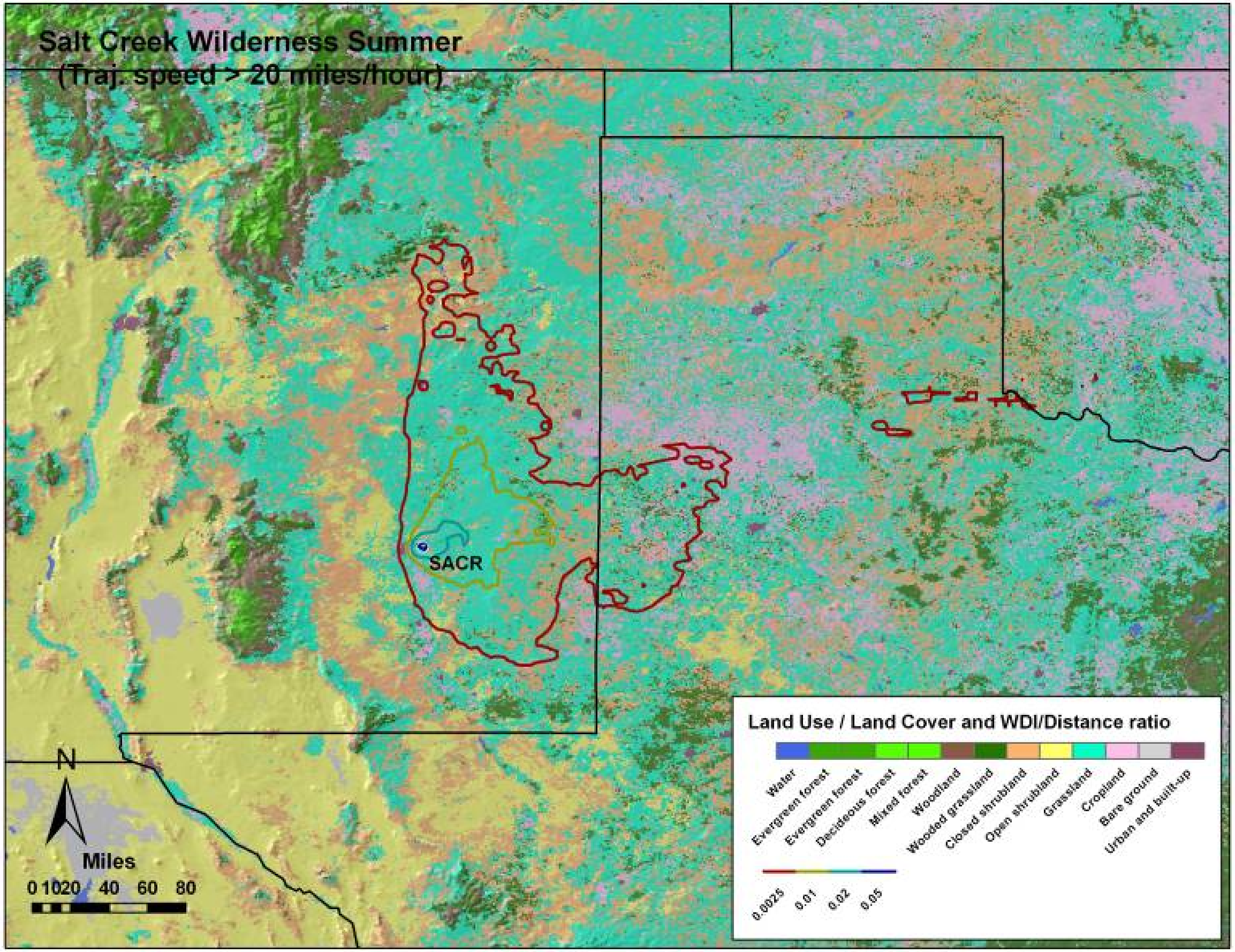


Figure 6-46 Contour plot of WDI/distance for Salt Creek Wilderness (2001-2003, Fall, Traj. speed > 20 miles/hour)

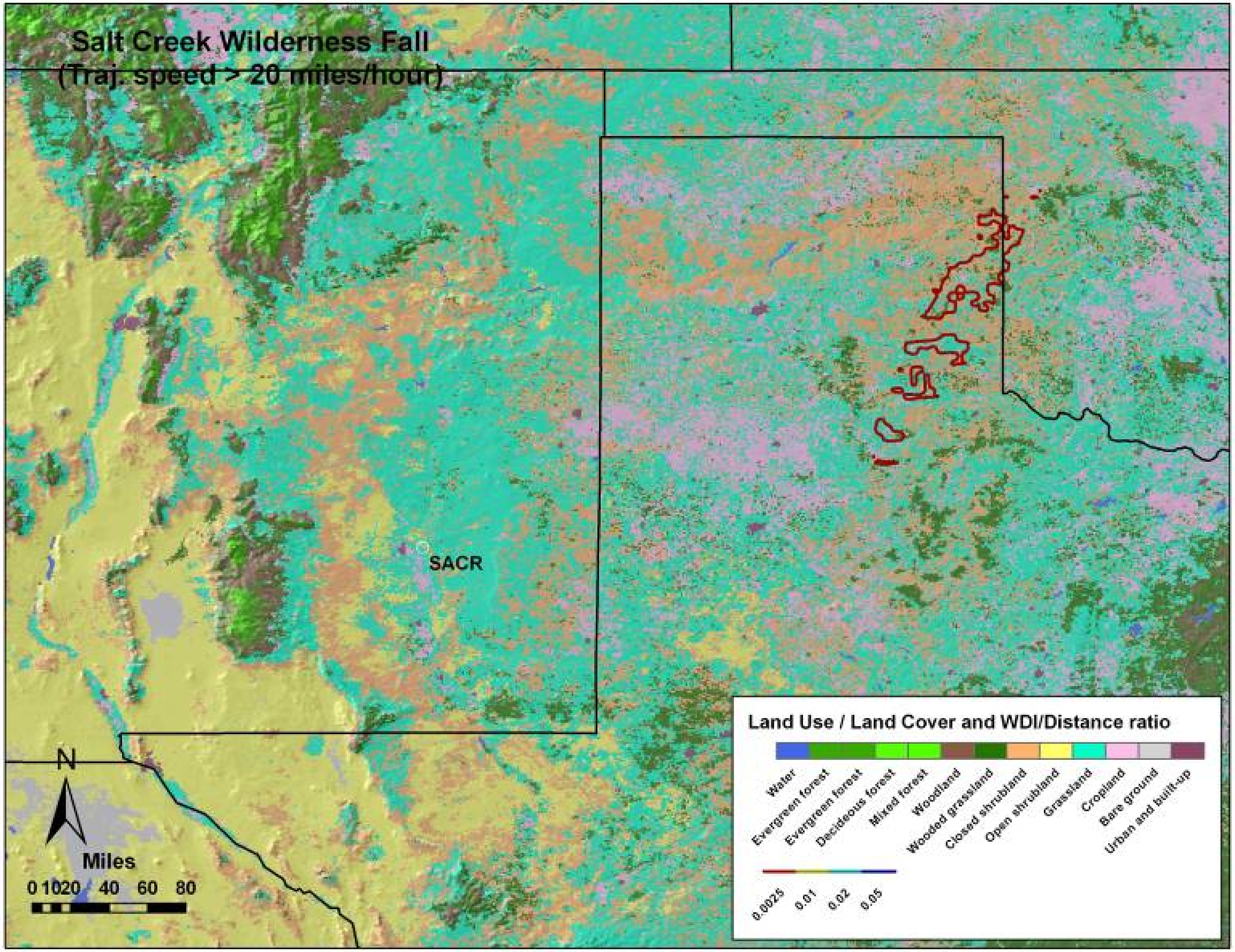


Figure 6-47 Spatial distribution of WDI for White Mountain Wilderness (2002, Traj. speed > 20 miles/hour)

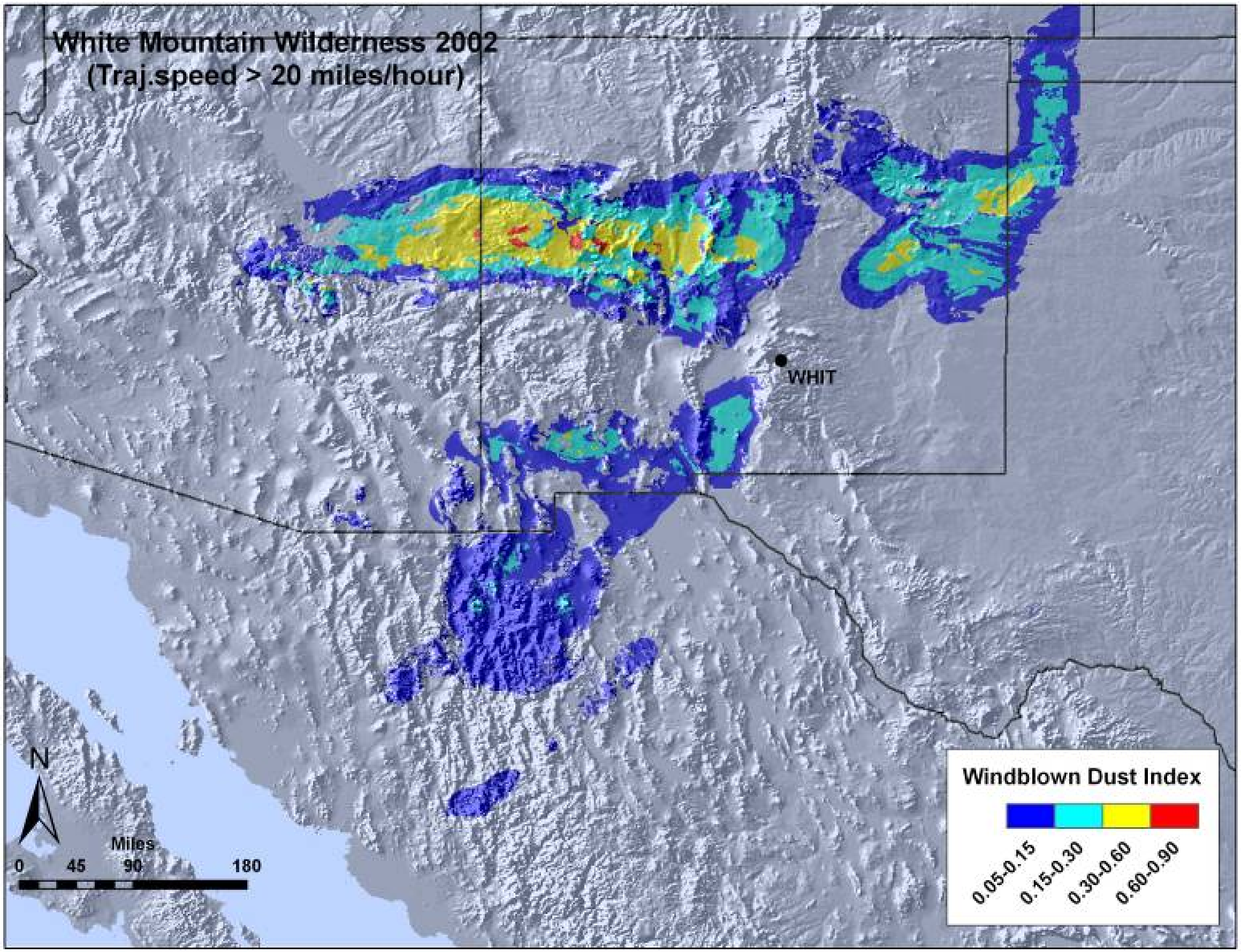


Figure 6-48 Spatial distribution of WDI for White Mountain Wilderness (2003, Traj. speed > 20 miles/hour)

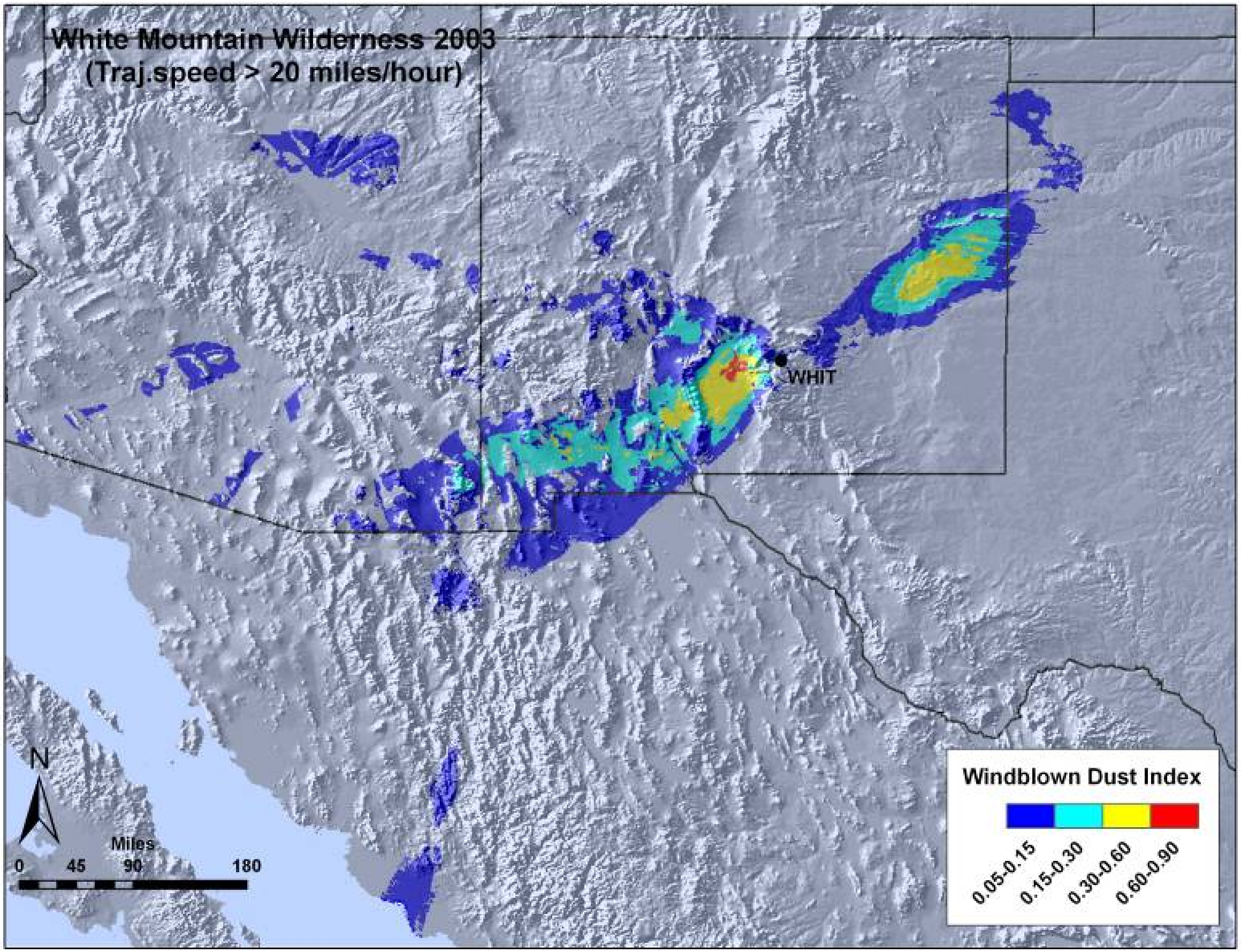


Figure 6-49 Spatial distribution of WDI for White Mountain Wilderness (2001-2003, Spring, Traj. speed > 20 miles/hour)

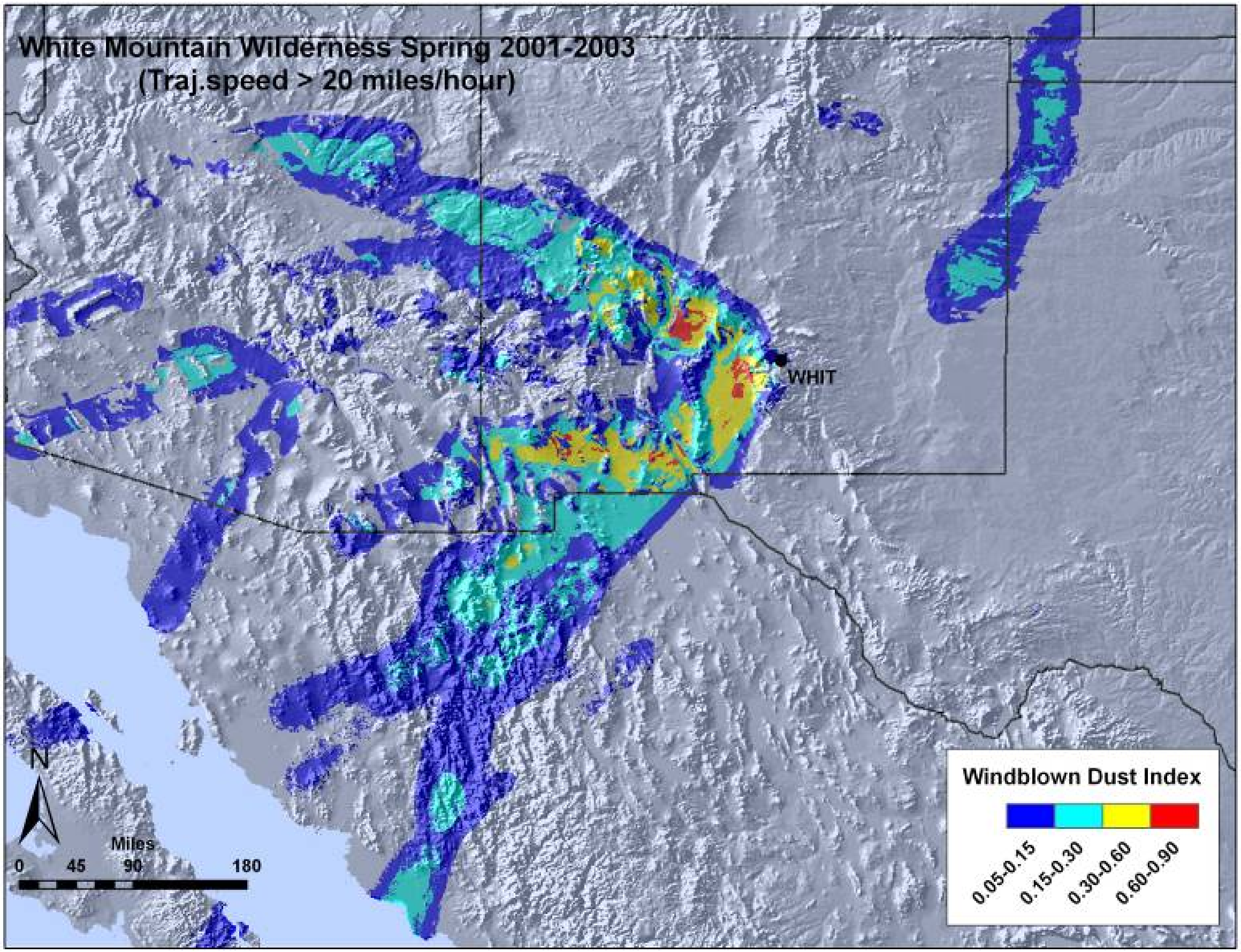


Figure 6-50 Spatial distribution of WDI for White Mountain Wilderness (2001-2003, Summer, Traj. speed > 20 miles/hour)

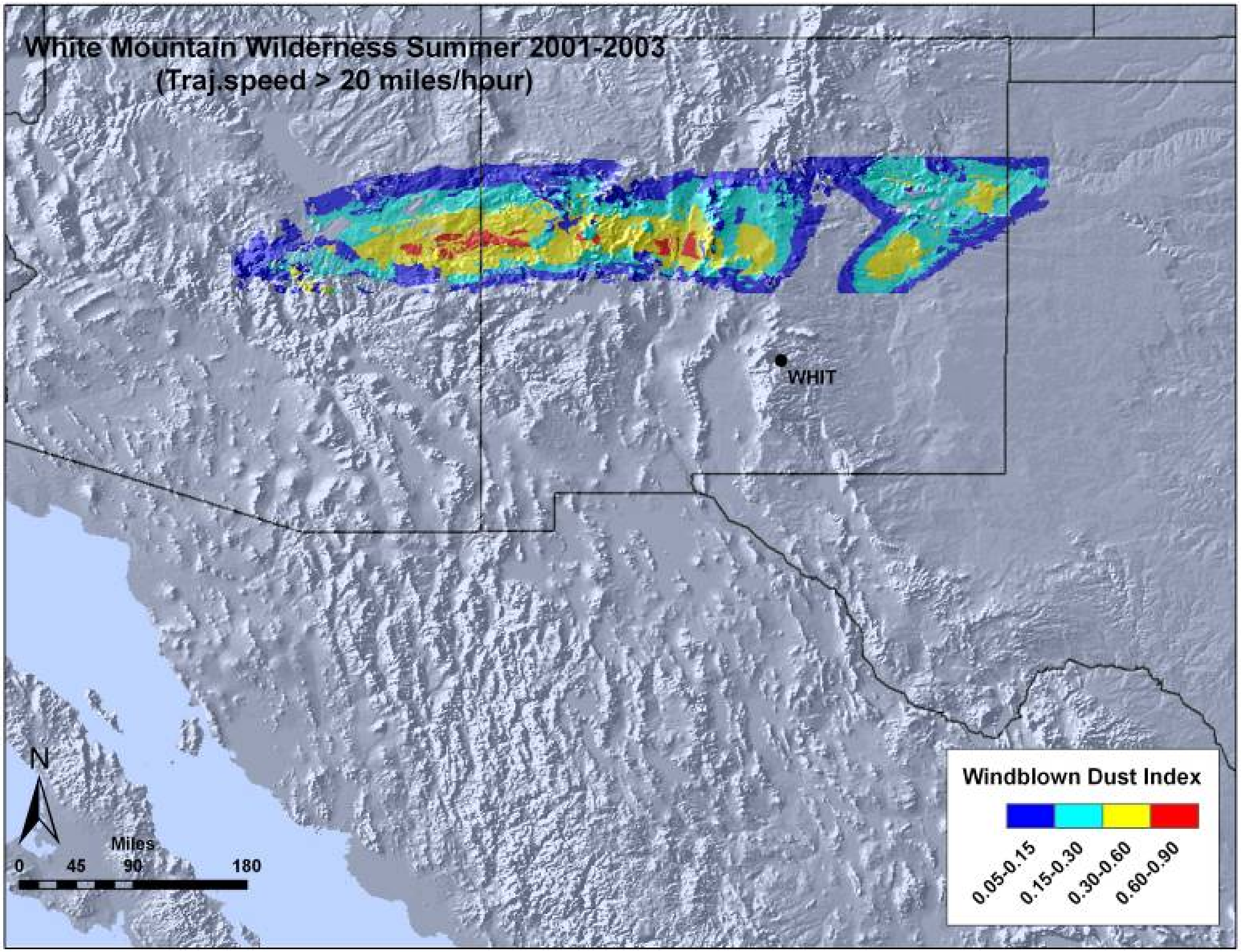


Figure 6-51 Spatial distribution of WDI for White Mountain Wilderness (2001-2003, Winter, Traj. speed > 20 miles/hour)

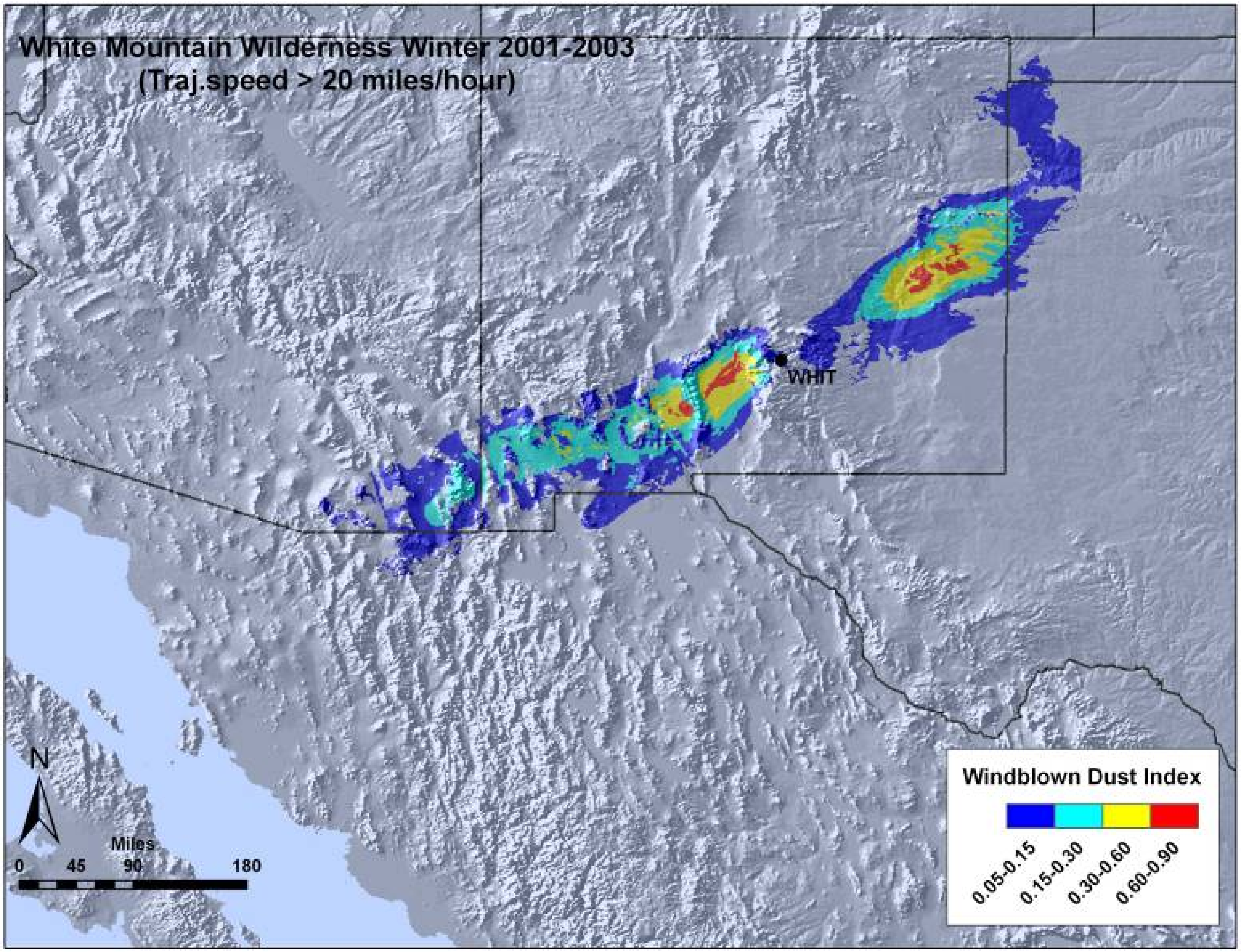


Figure 6-52 Contour plot of WDI for White Mountain Wilderness (2002, Traj. speed > 20 miles/hour)

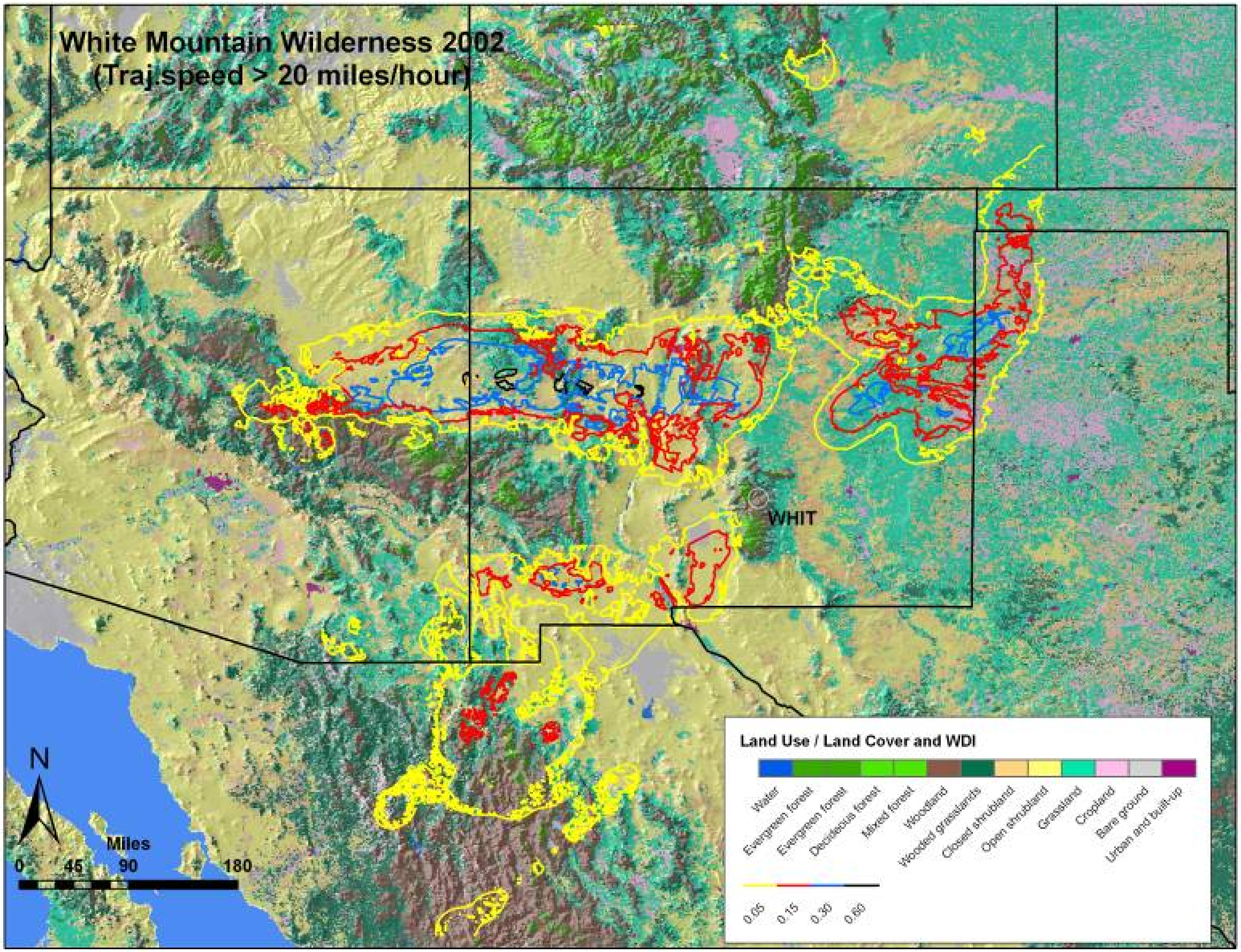


Figure 6-53 Contour plot of WDI for White Mountain Wilderness (2003, Traj. speed > 20 miles/hour)

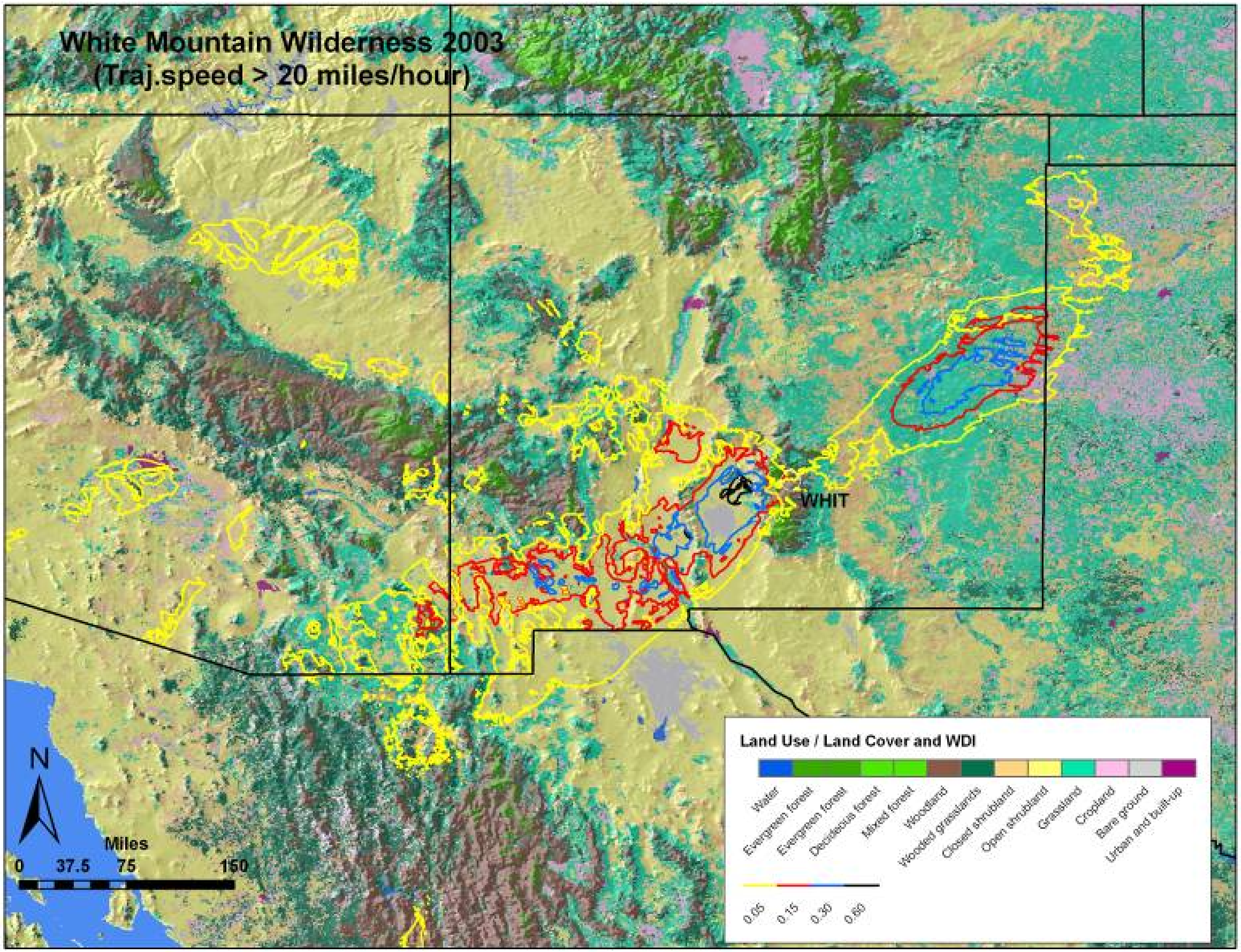


Figure 6-54 Contour plot of WDI for White Mountain Wilderness (2001-2003, Winter, Traj. speed > 20 miles/hour)

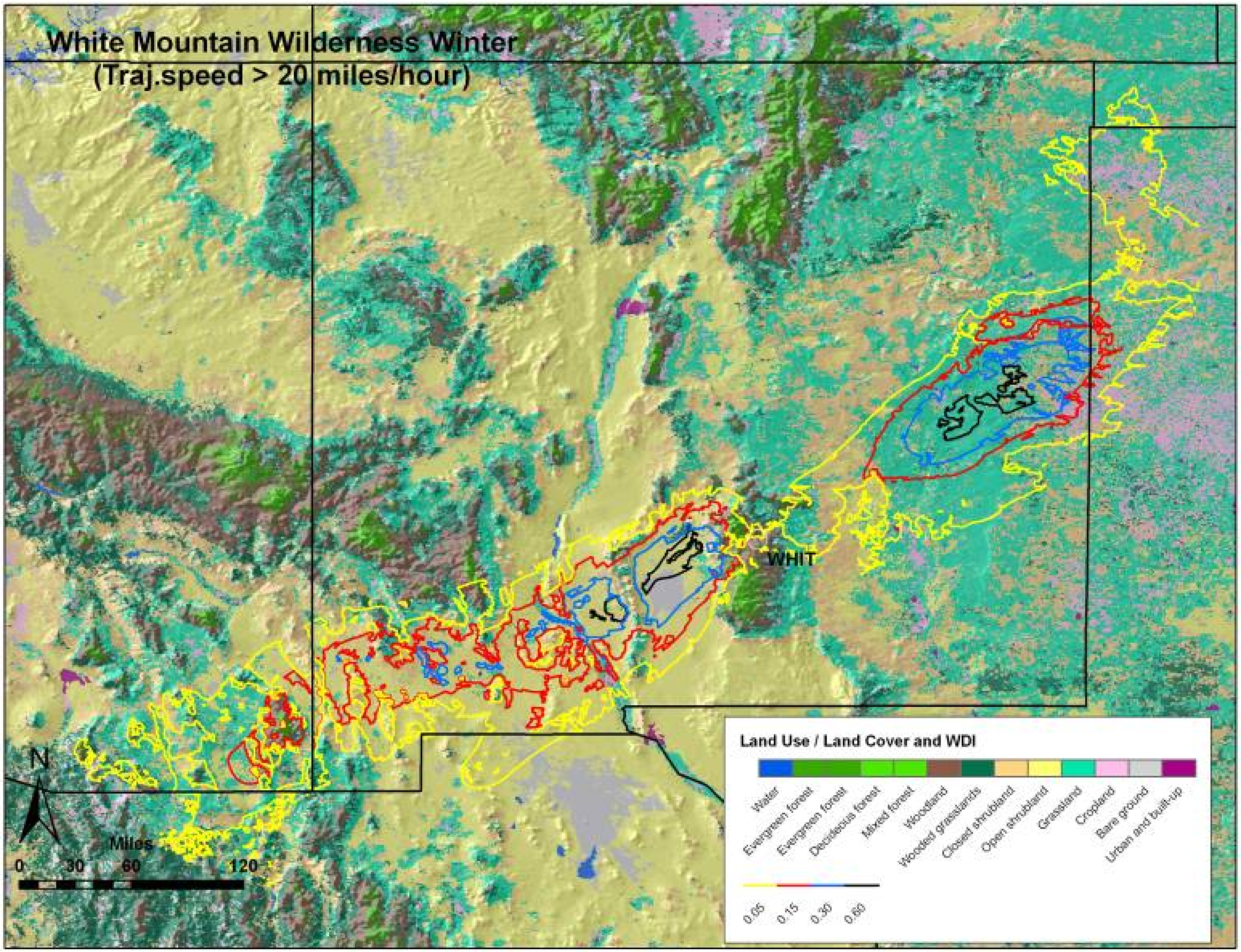


Figure 6-55 Contour plot of WDI for White Mountain Wilderness (2001-2003, Spring, Traj. speed > 20 miles/hour)

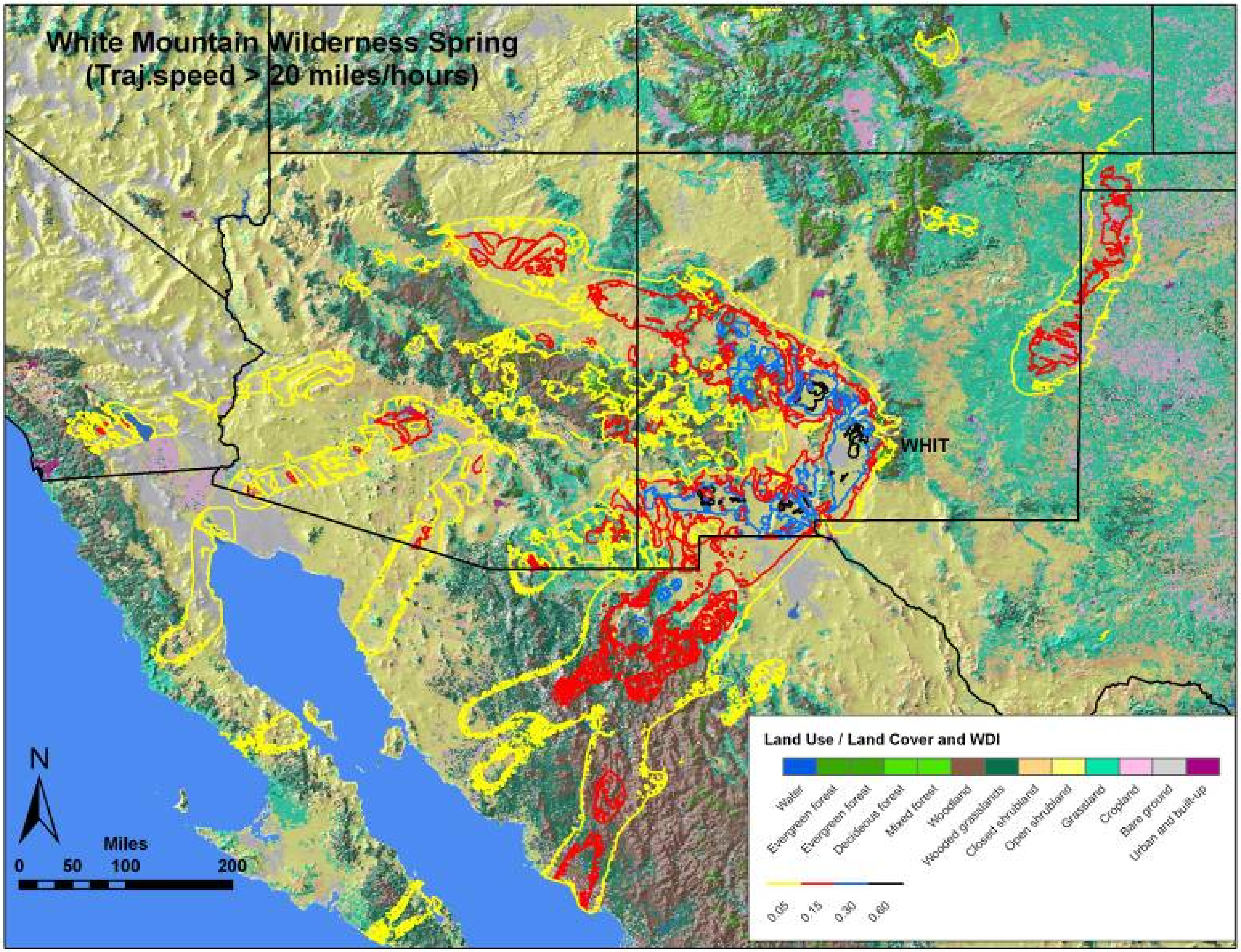


Figure 6-56 Contour plot of WDI for White Mountain Wilderness (2001-2003, Summer, Traj. speed > 20 miles/hour)

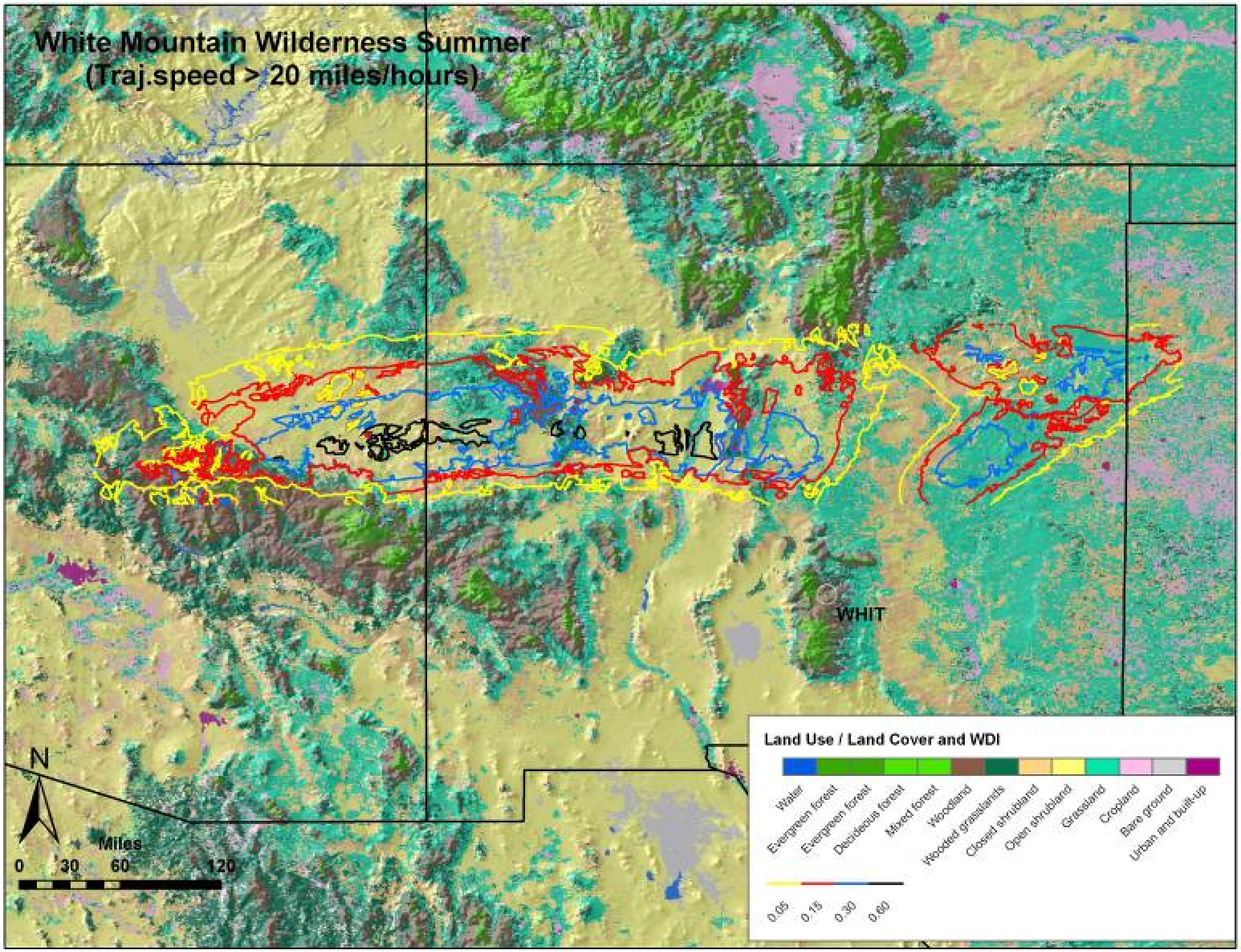


Figure 6-57 Spatial distribution of WDI/distance for White Mountain Wilderness (2002, Traj. speed > 20 miles/hour)

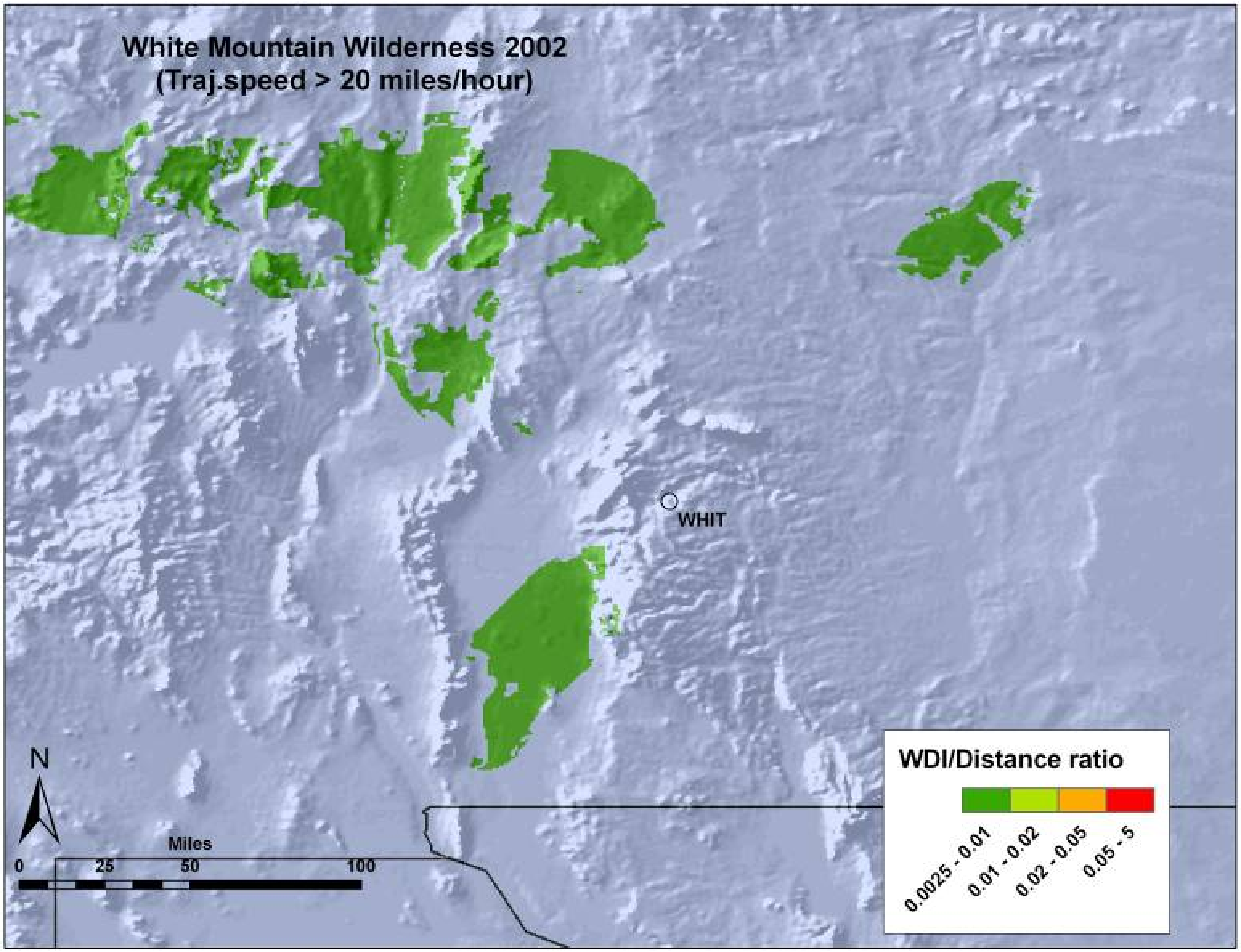


Figure 6-58 Spatial distribution of WDI/distance for White Mountain Wilderness (2003, Traj. speed > 20 miles/hour)

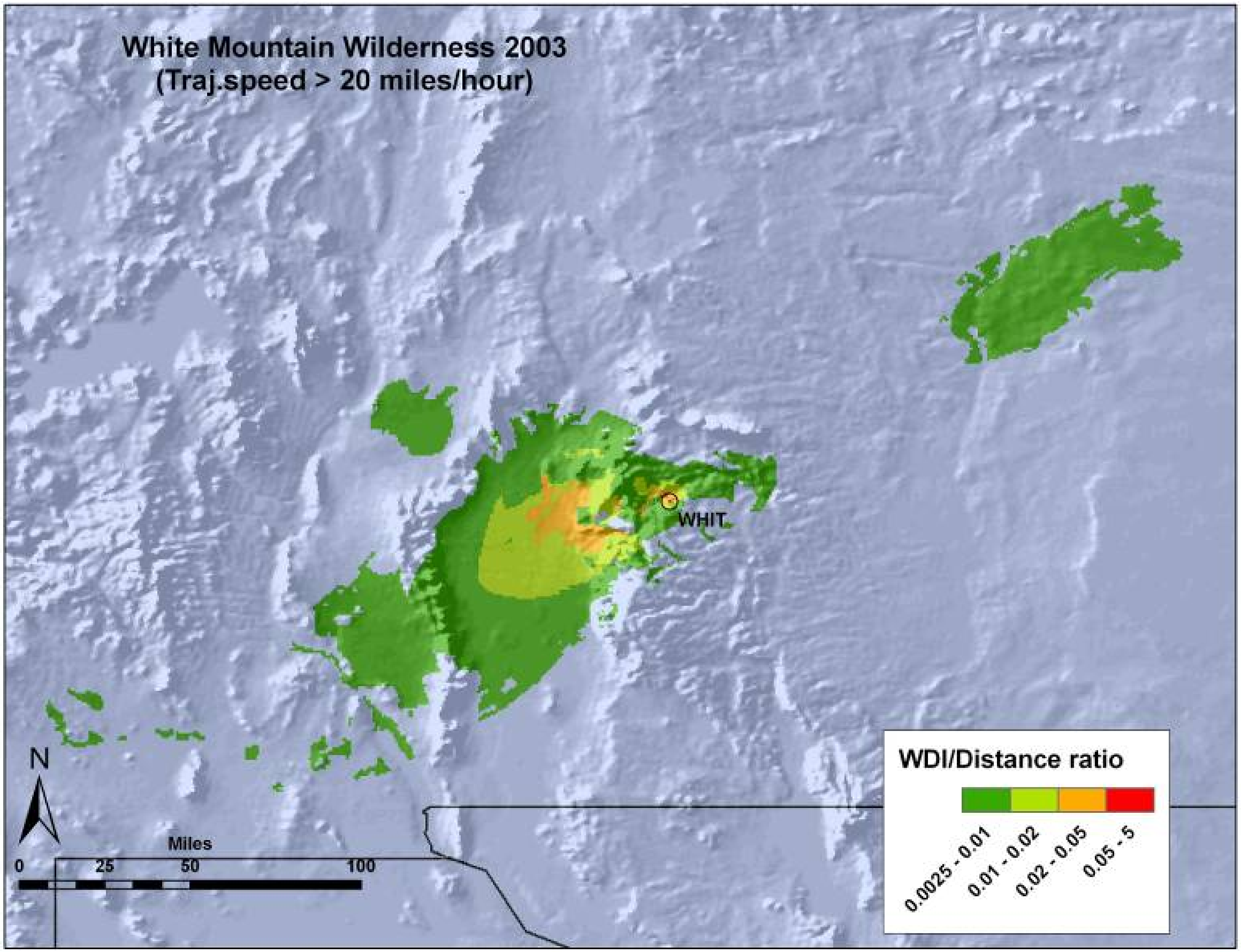


Figure 6-59 Spatial distribution of WDI/distance for White Mountain Wilderness (2001-2003, Winter, Traj. speed > 20 miles/hour)

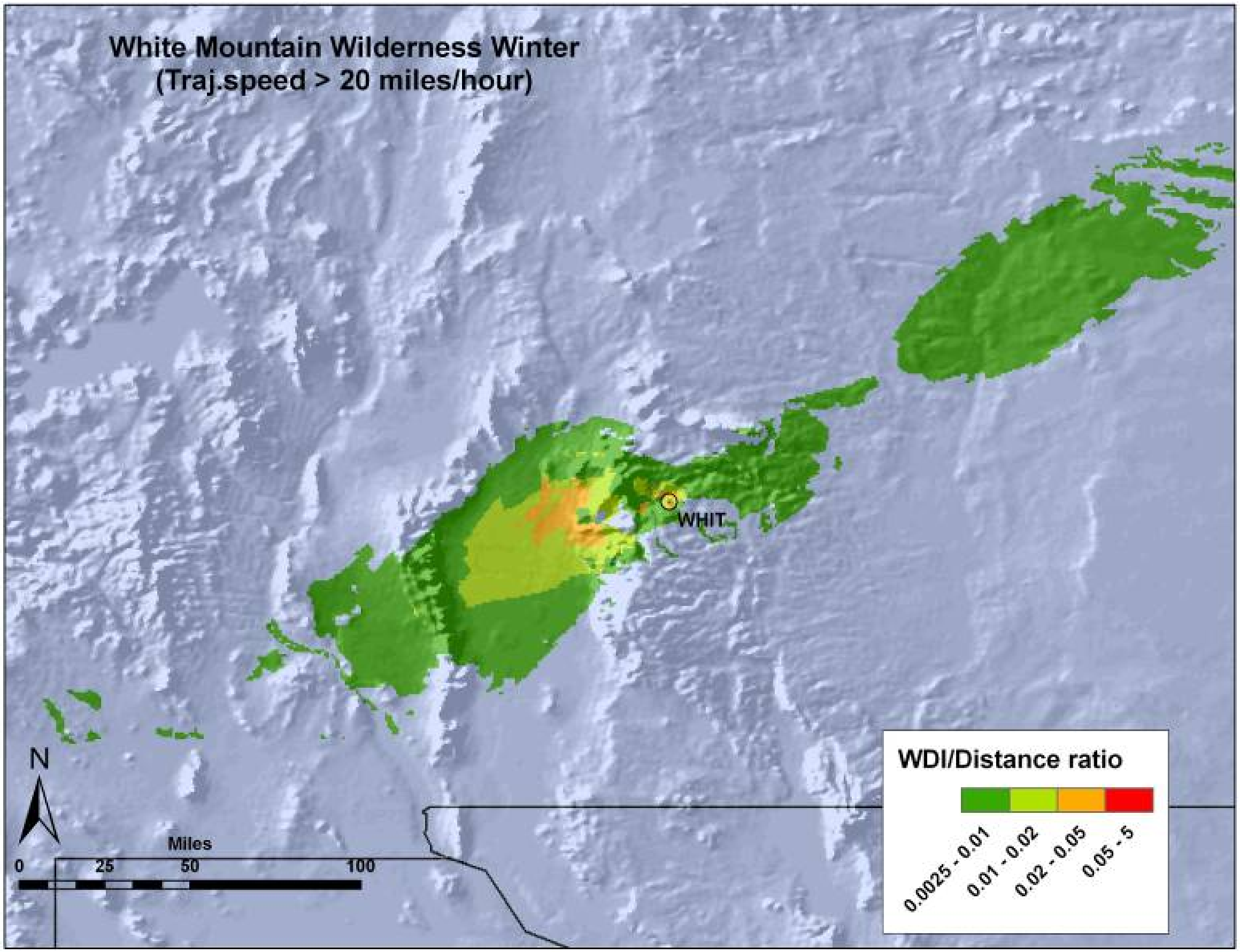


Figure 6-60 Spatial distribution of WDI/distance for White Mountain Wilderness (2001-2003, Spring, Traj. speed > 20 miles/hour)

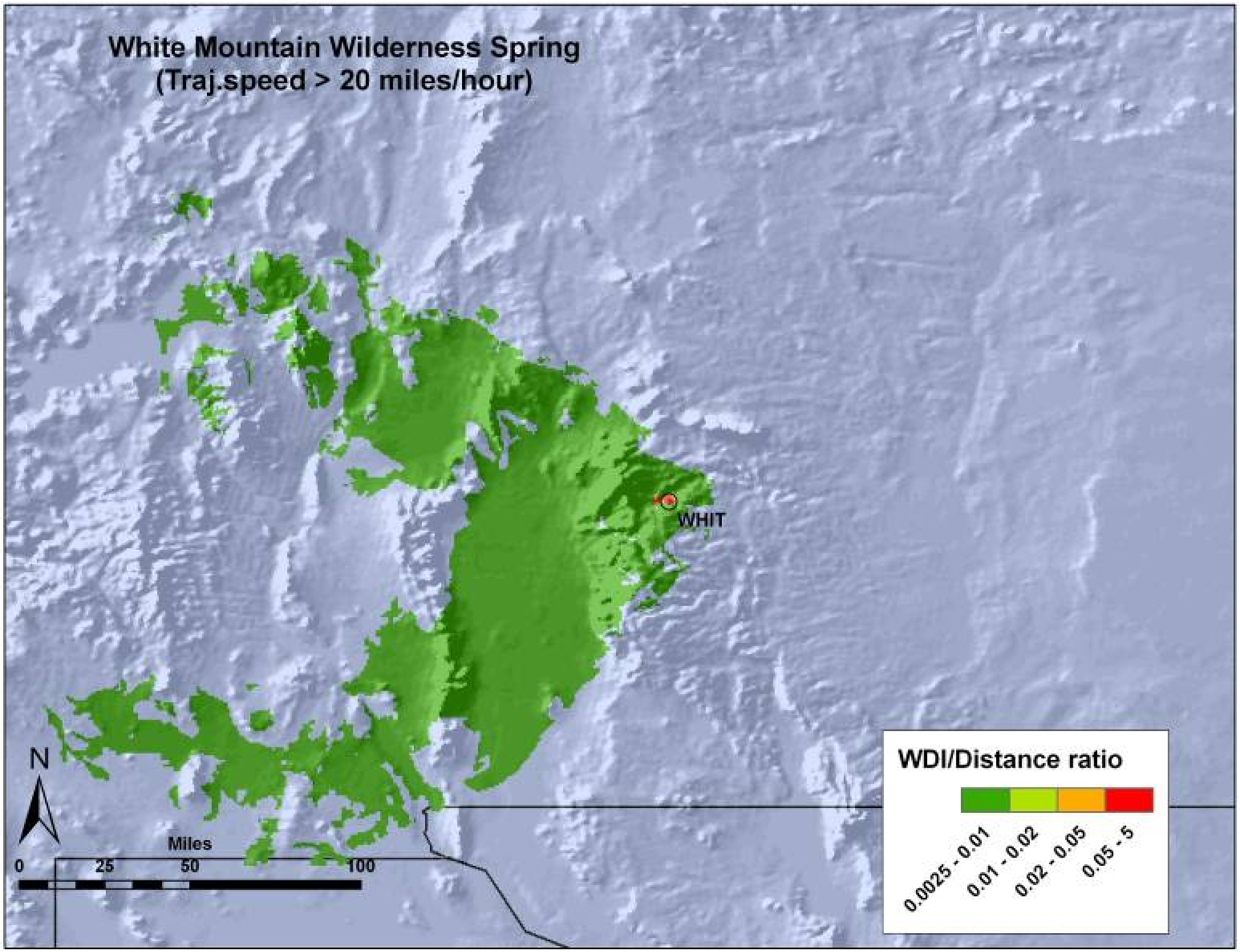


Figure 6-61 Spatial distribution of WDI/distance for White Mountain Wilderness (2001-2003, Summer, Traj. speed > 20 miles/hour)

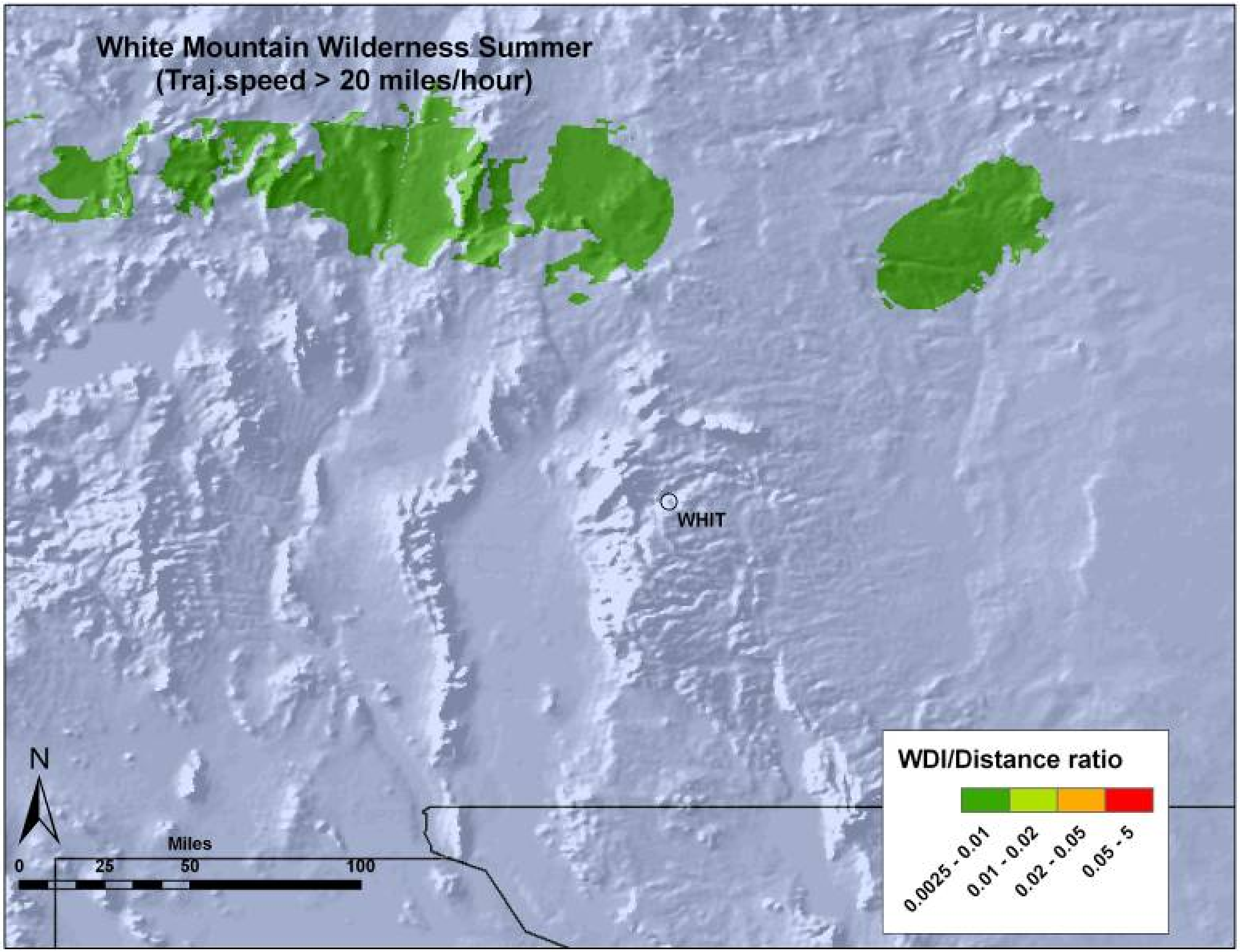


Figure 6-62 Contour plot of WDI/distance for Salt Creek Wilderness (2002, Traj. speed > 20 miles/hour)

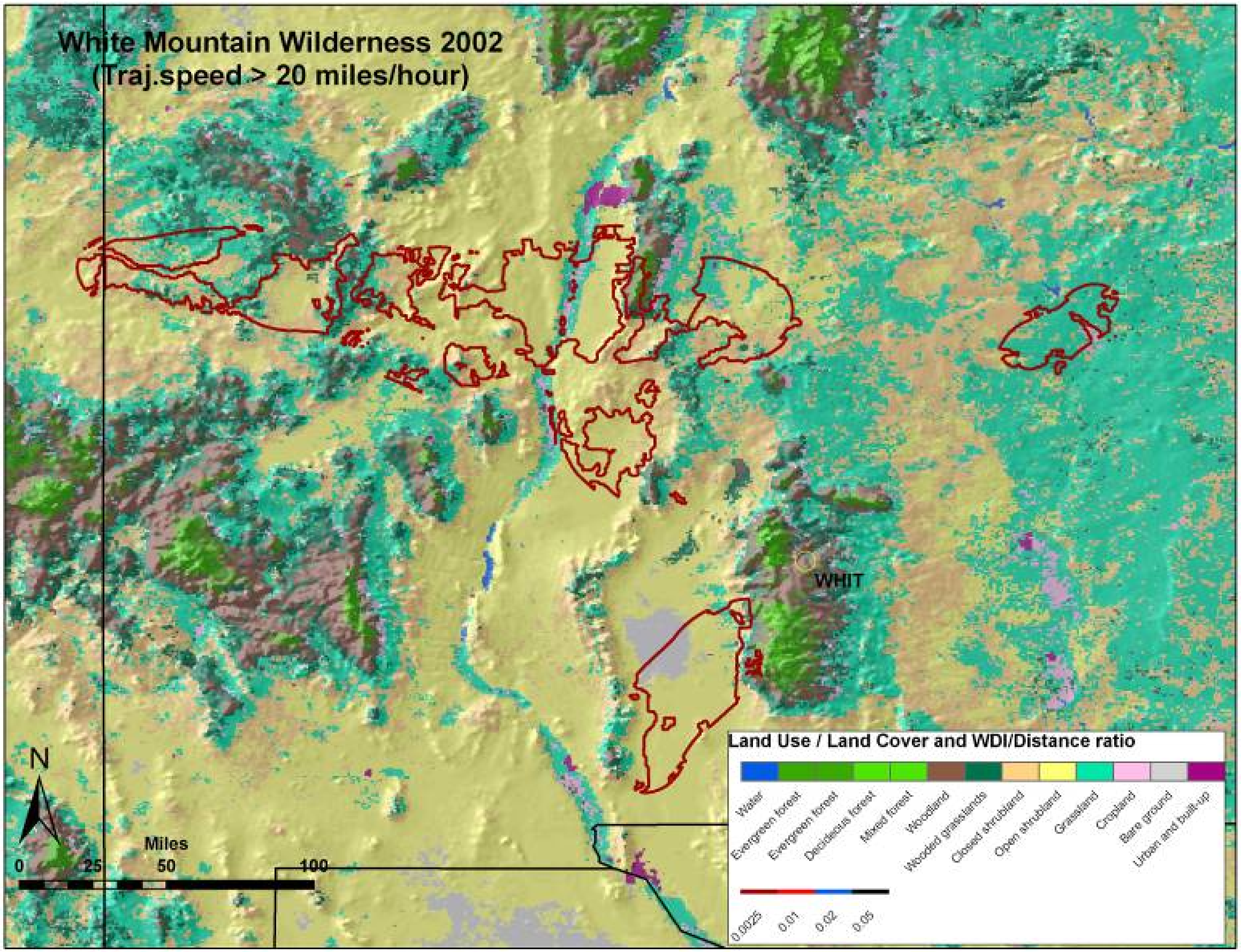


Figure 6-63 Contour plot of WDI/distance for Salt Creek Wilderness (2003, Traj. speed > 20 miles/hour)

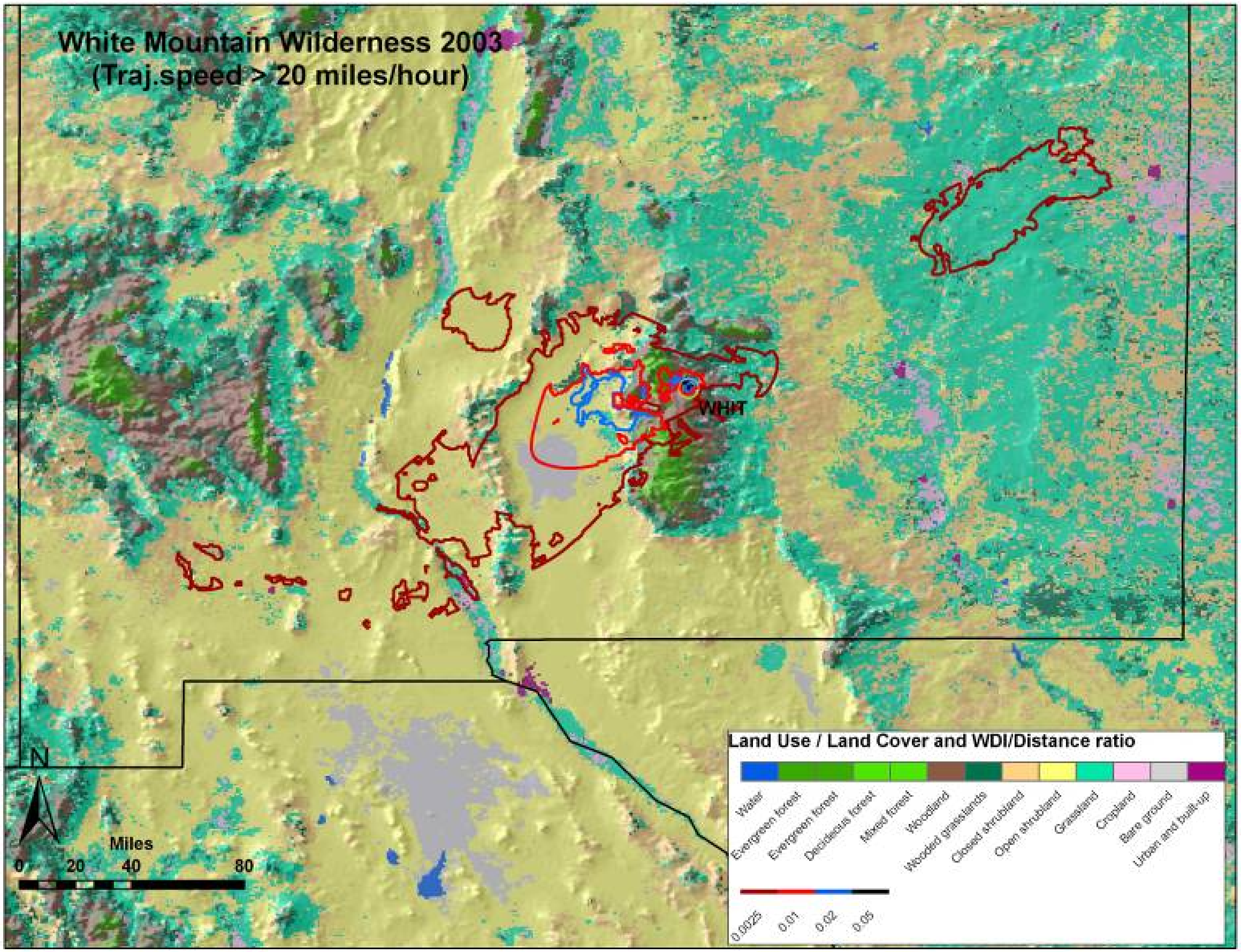


Figure 6-64 Contour plot of WDI/distance for White Mountain Wilderness (2001-2003, Winter, Traj. speed > 20 miles/hour)

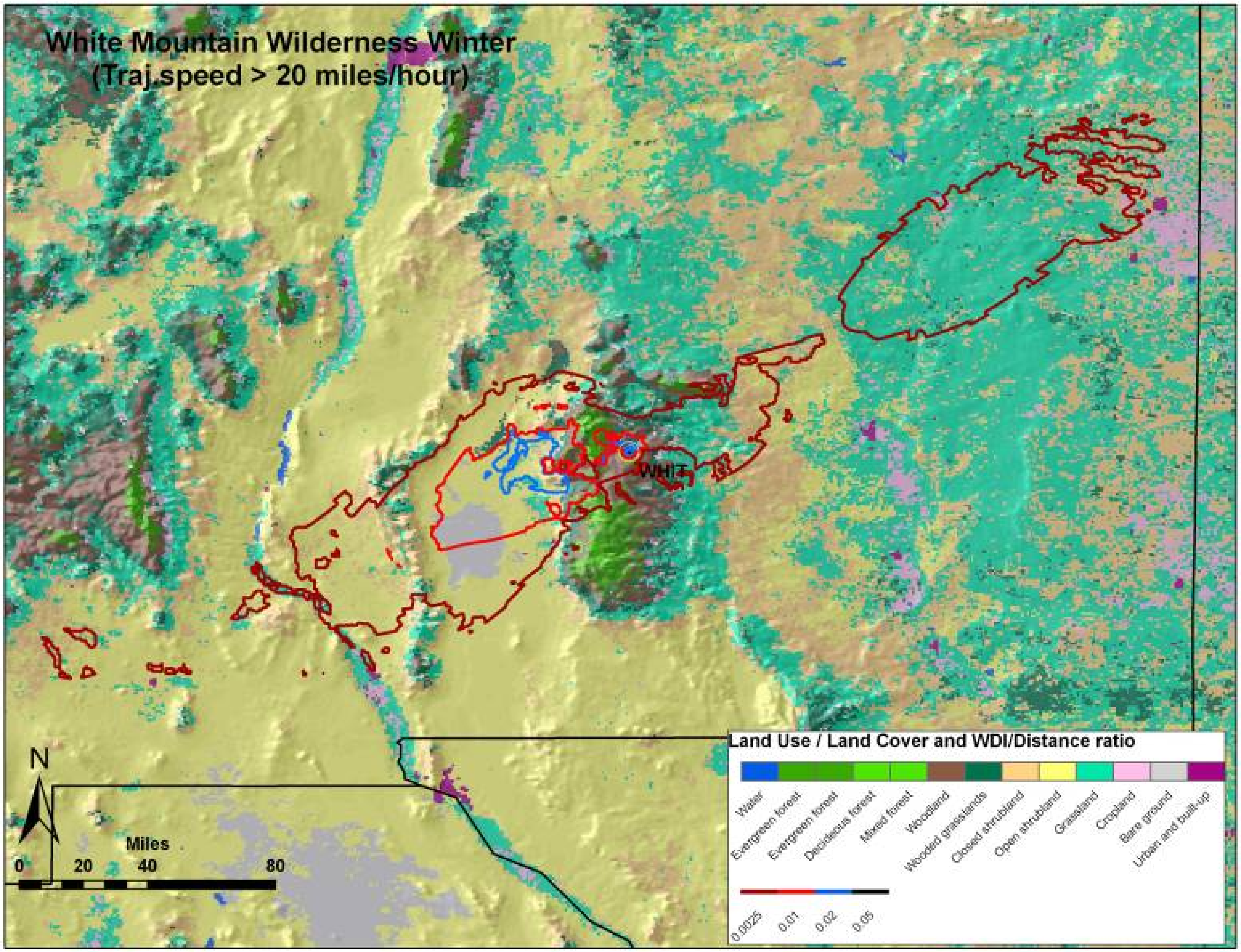


Figure 6-65 Contour plot of WDI/distance for White Mountain Wilderness (2001-2003, Spring, Traj. speed > 20 miles/hour)

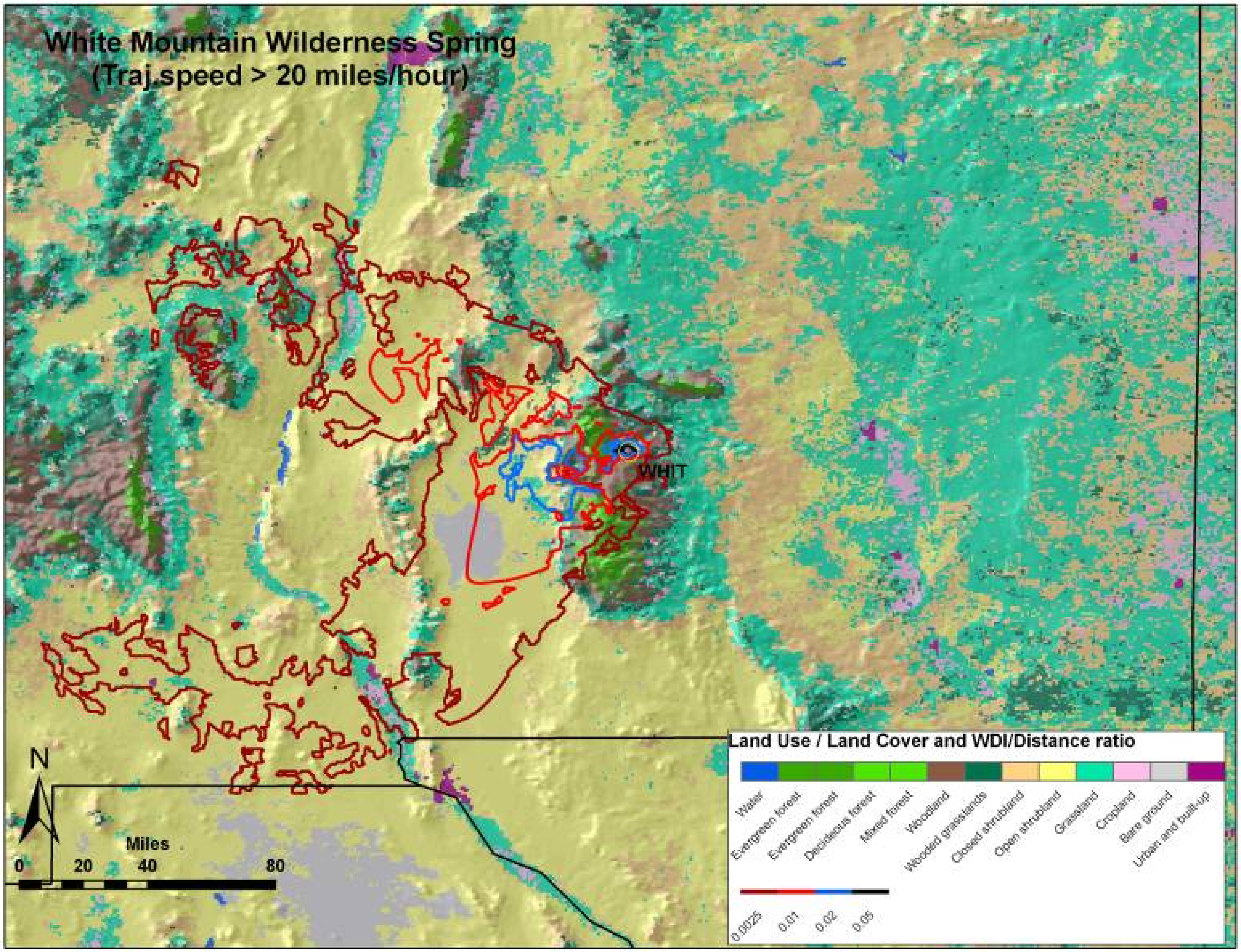
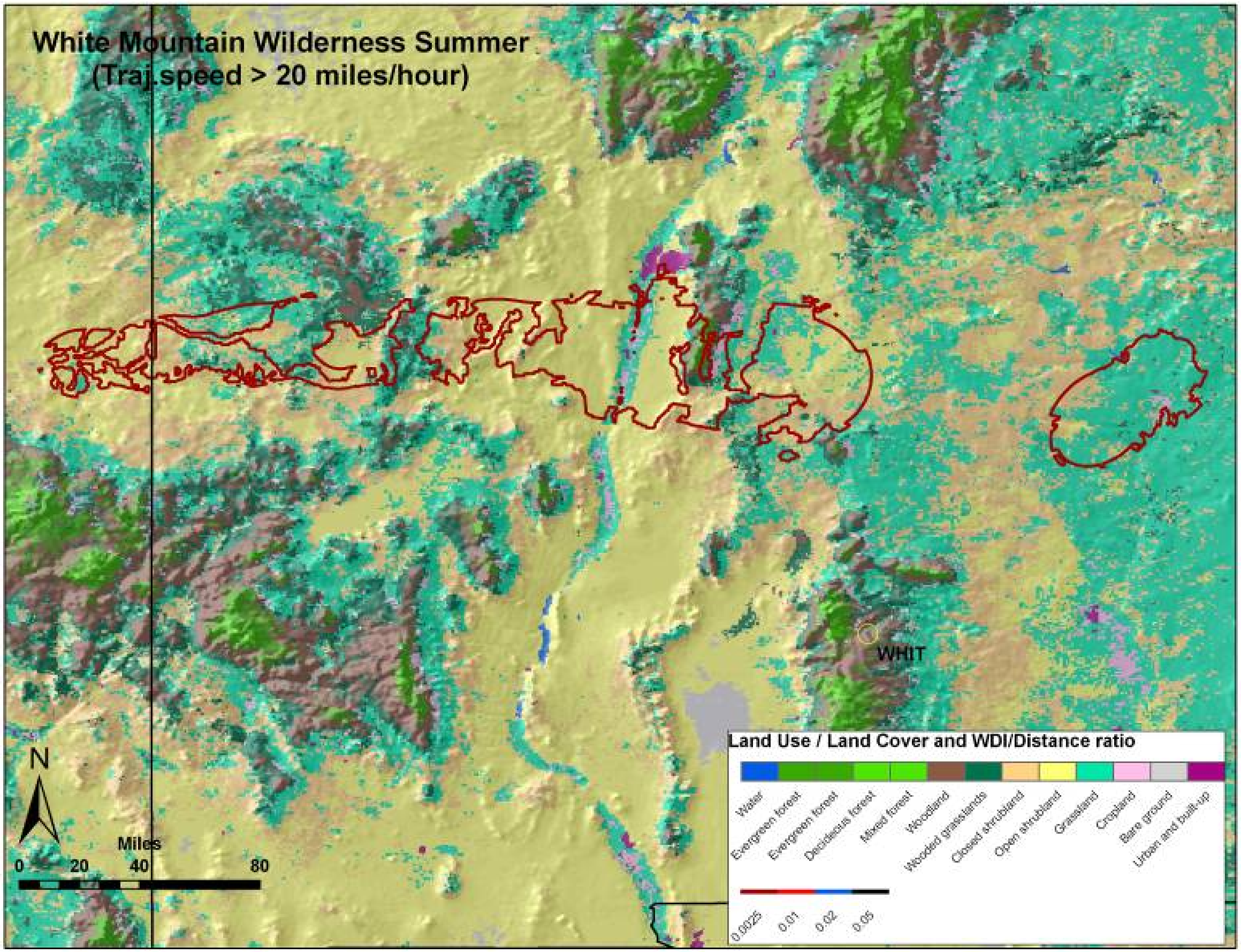


Figure 6-66 Contour plot of WDI/distance for White Mountain Wilderness (2001-2003, Summer, Traj. speed > 20 miles/hour)



7. Conclusions

7.1 Salt Creek Wilderness area

Elevated dust concentrations, during worst dust days of 2001-2003 period, are strongly associated (WDI > 0.3, WDI/distance> 0.02) with:

- Local sources (up to 40 miles) from the site including the urban area of Roswell;
- Regional sources (up to 150 miles from the site) from the southwest (areas in Otero, Dona Ana, Sierra and Lincoln counties, including the White Sands Missile Range), southeast (areas in Lee and Eddy counties in NM and Andrews, Loving and Winkler Counties in TX) and northeast (Roosevelt and De Baca Counties in NM and Cochran, Yoacum, Bailey, Hoakley and Lamb Counties in TX);
- Upwind transport (up to 450 miles) from the northeast (Briscoe, Motley, Hall, Donley, Collingsworth, Wheeler, Gray and Hemphill Counties in TX).

Other areas located in southwest and central NM, southeast and northeast AZ, north TX and Mexico are characterized by more moderate WDI values (0.15-0.30).

Spatial patterns of WDI and WDI/distance do not change substantially between the two threshold trajectory speeds (20 and 26 miles/hour) and from year to year, providing evidence that the same major source areas affected dust concentrations in Salt Creek throughout the 2001-2003 period. However, seasonal differences in WDI and WDI/distance values are observed. Specifically, WDI/distance analysis highlighted source areas located within 60 miles from Salt Creek during winter, spring and summer, whereas no nearby source areas are highlighted in the fall. Source areas southwest of the site, and to a lesser extent to the northwest and northeast, exhibit moderate-to-high WDI values during the winter. In the spring, source areas southwest, northeast, and southeast of the site show high WDI index values. This pattern changes substantially during the summer and fall, where only regions located North and northeast of the site are associated with high WDI values.

Areas with high WDI values are mostly associated with specific types of land use such as

- Open and closed shrublands, Urban development and agricultural areas near the site (> 50 miles)
- Bare ground and open shrubland in White Sands Missile Range area located southwest of the site
- Closed shrublands, grasslands and croplands in Texas
- Open shrubland and bare grounds in northern Mexico

7.2 White Mountain Wilderness area

Elevated dust concentrations during worst dust days during the 2001-2003 period are strongly related (WDI > 0.3, WDI/distance> 0.02) to:

- Local sources (up to 40 miles) southwest of the site including the White Sands Missile Range area
- Regional sources (up to 150 miles from the site) from the southwest (areas in Dona Ana, Sierra and Luna counties), and northeast (Roosevelt, De Baca, Carry and Quay Counties) sectors in NM

Upwind transport (up to 450 miles) from Mexico and, the northeast (Parmer, Oldham and Deaf Smith Counties in TX), northwest (Socorro, Valencia and Cibola Counties in NM and Apache and Navajo Counties in AZ) and southwest (Grant and Hidalgo Counties in NM and Cochise County in AZ) sectors were moderate (WDI values (0.15-0.30)).

The WDI and WDI/distance patterns do not change substantially between the two threshold trajectory speeds (20 and 26 miles/hour). Inter-annual variation is observed for WDI and WDI/distance values. Specifically, during 2002, regions in central/west New Mexico and east Arizona together with regions along the southwest/northeast corridor are highlighted as likely source areas, while only the latter is identified during 2003. WDI/distance analysis highlights areas located within 60 miles northeast and southwest of the site, while no areas located near the site are highlighted for summer. In addition, areas located in the southwest and northeast sectors exhibit moderate-to-high WDI values during the winter and spring. This pattern changes substantially during the summer, where only regions located north/northeast of the site show high WDI values

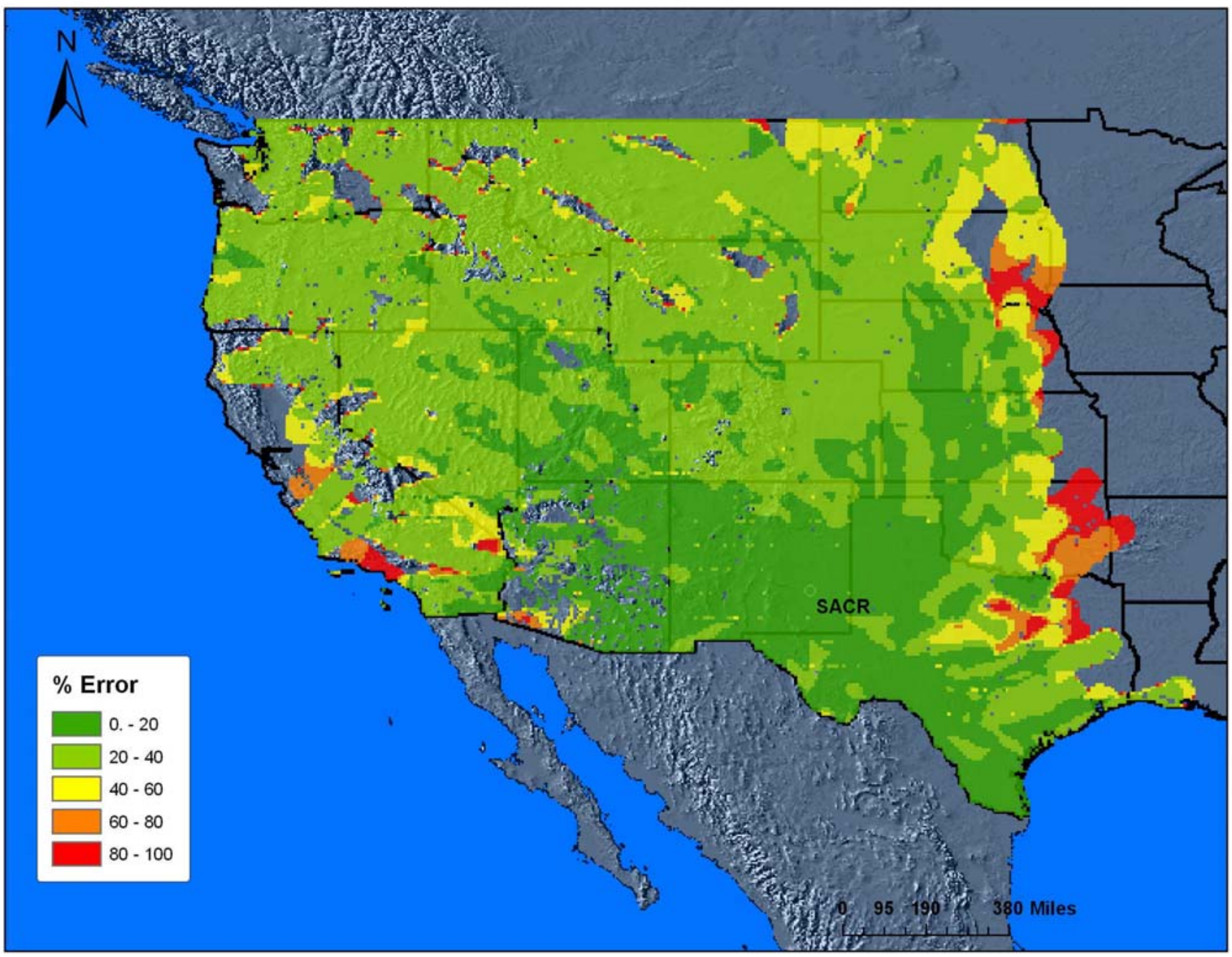
Areas with high WDI values were mostly associated with specific types of land use such as

- Bare gound and open shrubland in White Sands Missile Range area located southwest of the site (> 50 miles)
- Closed shrublands, grasslands and croplands in east NM and TX areas
- Open shrublands in AZ
- Open shrubland and bare grounds in northern Mexico.

Appendix A

The estimation of Windblown Dust Index (WDI) is site-, period- and trajectory speed-specific. Because trajectory speed is included in the calculation as a surrogate measure of surface wind velocity, it is obvious that changes in trajectory speed thresholds may result in over and/or underestimation of WDI for specific regions. For this reason, a sensitivity analysis to evaluate the effect of trajectory speed on WDI values is done. Specifically, WDI is calculated for five trajectory speeds (a) 14 miles/hour; (b) 18 miles/hour; (c) 20 miles/hour; (d) 26 miles/hour and; (e) 30 miles/hour. The percentage ratio of the standard error of the mean WDI to the mean WDI for each cell is estimated to evaluate the robustness of WDI estimations. Figure 1 shows the values of the percentage error for U.S.

Figure 1: Percentage of the standard error of the mean WDI to the mean WDI



This analysis showed that for the vast majority of western U.S. region (even regions located more than 300 miles away), the estimated WDI did not change significantly for trajectory speeds from 14 up to 30 miles/hour. More specifically, for areas identified as potential sources of windblown dust at a threshold trajectory speed of 20 miles/hour, the estimated percentage error was lower than 20%. Overall, no substantial miscalculation of WDI is observed for different trajectory speed thresholds and thus misclassification of potential dust sources. As a result, a trajectory speed threshold of 20 miles/hour is chosen for the detailed analysis. Other reasons include that trajectory speeds higher than 20 miles/hour will ensure that surface wind velocity (which normally will be lo can facilitate wind erosion of the soil.