Mapping Wilderness Character in Death Valley National Park

Technical Report and Methodology

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SUMMARY
This document provides the technical aspects and the methodology used to map the quality of wilderness character in Death Valley National Park (DEVA). It is written to support the parent document: Mapping Wilderness Character in Death Valley National Park (Tricker et al in press) which provides the background information and justification for the methods and approaches applied (the parent document is available at www.wilderness.net).

This document is designed to allow technical staff at DEVA to repeat the methodology allowing the maps of wilderness character quality to be updated as more accurate and complete datasets become available. Although reference to the parent document is preferable, the technical report provided is designed to be read as a stand-alone document. Each section begins with a general summary providing brief details of the map of wilderness character quality under investigation, the datasets used, and general considerations which need to be accounted for before analysis. The method was implemented in the ESRI ArcGIS Desktop Suite and in the voxel viewshed tool. Some GIS knowledge is assumed to allow for ease of reading but all tools, functions and map algebra expressions are clearly documented and the parameters applied also provided to allow for easy repetition of the method.

The maps are produced for all lands within the DEVA boundary (excluding the disjunct Devils Hole Unit), with additional buffer zones extending beyond park boundaries to 15km and 30km "respectively" for running the travel time and viewshed sub-models.

See accompanying folder on CD for data input files.

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1. NATURAL QUALITY

The natural quality is defined as wilderness ecological systems that are substantially free from the effects of modern civilization. This quality is degraded by the intended or unintended effects of modern people on the ecological systems inside the wilderness since it was designated (Landres et al. 2008).

1.1 Data Inputs

A wide variety of data were used to build the spatial model of this natural quality of wilderness character, including data on plants, animals, air and water quality, mining features, night sky, and artificial water features. These data sources are both vector and raster data, and exhibit high variation in scale, mostly high levels of accuracy, and differing levels of completeness (Table 1). Two additional data inputs, fire regime and climate change, were identified but because the data is inadequate or there is currently no information available, they were not included.

Table 1 Natural quality datasets

Dataset	**Source**	**Type**	**Scale**	**Accuracy**	**Completeness**
Landcover	Central Mojave Mapping Project/USGS NVC	Raster	5ha/ 30m	High	Medium
Exotic plants	NPS APCAM	Polygon	100m	High	Medium
Burros	DEVA	Polgon	100m	High	Low
AQ - Ozone & Wet desposited NO3 & NH4	Air Resources Division, NPS	Raster	12km	Medium	High
Mining sites	NPS AML/USGS/DEVA	Point	100m	High	Low
Open Pits	DEVA	Polygon	100m	High	High
Springs	DEVA	Point	10m	High	High
Nightsky - deviation from natural	Night Sky Team, NPS	Raster	1km	High	Medium
Grazing	DEVA	Polygon	100m	High	High
Guzzlers	DEVA	Polygon	100m	High	High
Fire regime*	FRCC	n/a	n/a	Unsuitable	n/a
Climate change*	n/a	n/a	n/a	n/a	n/a

*No data

<u>1.1.1 Land cover</u>

Sources

Raster datasets from Central Mojave Mapping Project (CMMP) (Thomas et al., 2004) & USGS National Vegetation Classification Standard (NVCS).

Processing

The CMMP data, which covers 95% of the park, is used as the primary land cover map. This map is used in combination with the USGS NVCS dataset to provide a complete land cover map for DEVA.

Step 1: Collate the land cover classes from the two data sources in an Excel sheet (retaining their land cover type codes) and rank each, according to their natural condition, on a scale of 1-5 (where 1 = low rankings and 5 = high rankings). Classes such as urban, agricultural and developed areas receive high rankings as they show high deviation from natural condition. Shrubland, high elevation woodland, and sparsely vegetated areas receive low rankings as they are close to their original natural state. For this project, the ranked condition classes are determined by the Park staff. A table with these rankings used for the analysis is in Appendix A.

Step 2: The CMMP data is converted to raster at 30m resolution using the SPATIAL ANALYST > CONVERT > FEATURES TO RASTER tool.

Step 3: A DEVA boundary mask is prepared for clipping the raster files to the park boundary. The park boundary shapefile is converted to a raster using the SPATIAL ANALYST > CONVERT > FEATURES TO RASTER tool. The SPATIAL ANALYSIST > RECLASSIFY tool is used to reclass the cell values within the park to 1, and all areas outside the park to NODATA[1]

Step 4: Both land cover rasters are multiplied by the mask in the RASTER CALCULATOR (found in the SPATIAL ANALYST toolbar) using the following equations:

OUTGRID1 = [CMMP] * [MASK]
OUTGRID2 = [USGS NVC] * [MASK]

Step 5: Combine the two rasters using the MERGE map algebra command in the RASTER CALCULATOR (the purpose of the merge is to retain the CMMP data as the primary land cover data and the USGS NVC data fills in the missing gaps); the following syntax applies:

OUTGRID = MERGE([CMMP], [USGS NVC])

Step 6: Open the excel sheet in ArcGIS. Right click the mosaic grid in the data frame and use the JOINS AND RELATES > JOIN tool to join the tables together using the common field (land cover type code) in both tables.

Step 7: Standardize the ranked condition classes using the SPATIAL ANALYST TOOLS > RECLASS > SLICE function set to equal interval standardization, 256 output zones and a base zone of 1.

Cautions: Of the two data sources, the CMMP provides the most recent and accurate land cover map for DEVA. Although data gaps occur in small areas to the north of the park and all lands located in Nevada, this map is considered most representative of current land cover by the park staff.

[1] NoData or null values in a raster grid contain no data and so are disregarded in most calculations unless the model explicitly references these.

1.1.2 Exotic species – plants

Sources
Vector dataset from the NPS Alien Plant Control and Monitoring Database (APCAM) based on GPS data collection and North American Weed Management Association data standards.

Processing
Step 1: Create a new field (e.g. Value) in the attribute table. Populate the field with the value "1" using the FIELD CALCULATOR tool.

Step 2: Convert the shapefile to a raster with the SPATIAL ANALYST > CONVERT > FEATURES TO RASTER tool, setting the field box to the "Value" field. Change the NoData values in the grid to 0 using the RECLASSIFY tool found in the SPATIAL ANALYST toolbar.

Step 3: Standardize the grid using the SPATIAL ANALYST TOOLS > RECLASS > SLICE function set to equal interval standardization, 256 output zones and a base zone of 1.

For steps 2 and 3, an automated processing (Conversion/Slice) tool can be configured in model builder using the following tools from the Arc toolbox: (1) CONVERSION TOOLS > TO RASTER > FEATURE TO RASTER, (2) SPATIAL ANALYST TOOLS > MAP ALGEBRA > SINGLE OUTPUT MAP ALGEBRA and (3) SPATIAL ANALYST TOOLS > RECLASS > SLICE. See Appendix B for variable settings and tool diagram.

Cautions
None.

1.1.3 Exotic species – animals

Sources
Vector dataset created by Linda Manning, DEVA wildlife biologist.

Processing
This dataset depicts known burro and feral horse ranges in DEVA.

Step 1: Create a new field (e.g. Value) in the attribute table. Populate the field with the value "1" using the FIELD CALCULATOR tool for areas where the animals are dispersed and a value of "2" for where the animals are more concentrated.

Step 2: Query the species type column in attribute field in create shapefiles for both species: use the SELECT BY ATTRIBUTES tool from the options tab in the attribute table. Use the following expression *"Species type" = 'Burros'* and export the selected records to a new shapefile. Repeat the same method for the horses.

Step 3: Convert the two shapefiles to a rasters with the SPATIAL ANALYST > CONVERT > FEATURES TO RASTER tool, setting the field box to the "Value" field. Change the NoData values in the grid to 0 using the RECLASSIFY tool found in the SPATIAL ANALYST toolbar.

Step 4: Add the two grids together in the RASTER CALCULATOR using the following equation:

OUTGRID = ([BURRO GRID] * 0.75) + ([HORSE GRID] * 0.25)

These weights are applied because burros are more prevalent and concentrated than feral horses in DEVA.

Step 5: Standardize the grid using the SPATIAL ANALYST TOOLS > RECLASS > SLICE function set to equal interval standardization, 256 output zones and a base zone of 1.

Cautions
The areas of high and low impact by exotic animal species are based on the experience and knowledge of the park wildlife biologist, whereas a different person may identify different areas and/or different impacts.

<u>1.1.4 Ozone & Wet deposited nitrate and ammonium (Air Quality)</u>

Sources
Raster datasets from NPS Air Resource Program. Data from the park's single air quality monitoring station was not used in the model because it was the opinion of the NPS Air Resource Program that data from this single station could not be used with other air quality monitoring stations in the region to extrapolate values for the rest of the park. Instead, the air quality rasters were obtained from the national dataset of modeled air quality values at a low resolution of 12km.

Processing
The air quality datasets are received in a text document as 2D arrays.

Step 1: Open text file array in Excel, and choose delimit with comma.

Step 2: Copy value, lat and long figures into separate worksheets using paste special/transpose.

Step 3: Run a macro program to stack the columns in each worksheet (code for "stacking" data can be found in Appendix 3). Add all the data alongside each other in a new worksheet.

Step 4: Open worksheet in ArcGIS and use TOOLS > ADD XY DATA to create a point shapefile for the data (using "North America Datum 1983" projection).

Step 5: Set data frame projection to "USA Contiguous Albers Equal Area Conic USGS". In Arc Tool Box, use the CONVERSION TOOLS > TO RASTER > POINT TO RASTER tool to create a grid from the shapefile with the cell size set to 12075.

Step 6: In Arc Tool Box, use the DATA MANAGEMENT TOOLS > PROJECTIONS AND TRANSFORMATIONS > RASTER > PROJECT RASTER tool to reproject the grid to NAD 1983 UTM Zone 11N choosing BILINEAR as the resampling technique.

Step 7: In the RASTER CALCULATOR, clip the air quality grid to the DEVA boundary mask using the following equation:

OUTGRID = [AIR QUALITY GRID] * [MASK]

Step 8: Standardize the grid using the SPATIAL ANALYST TOOLS > RECLASS > SLICE function set to equal interval standardization, 256 output zones and a base zone of 1.

Repeat processing for the second air quality raster

Cautions
Despite the low resolution of these grids, it was considered important to include these data to acknowledge how processes outside the park impact natural condition within the park.

1.1.5 Mining sites

Sources
NPS Abandoned Mineral Lands (AML) dataset, USGS mining dataset (the name and source of this data is unknown as it is no longer available for download), DEVA GIS dataset (open pits).

Processing
Three data sources and two vector types are combined into one input. The point data (depicting the many small mining features in DEVA) are assigned a value of 1 and the polygon data (depicting the large open pit mines) are assigned a value of 2. These values represent how the different mining features affect the natural quality in DEVA.

Step 1: Create a new field (e.g. Value) in the attribute table for all three datasets. Populate the field with the value “1” for the point data and “2” for the polygon data using the FIELD CALCULATOR tool.

Step 2: Convert the shapefiles to a rasters with the SPATIAL ANALYST > CONVERT > FEATURES TO RASTER tool, setting the field box to the “Value” field for each shapefile. Change the NoData values in the grid to 0 using the RECLASSIFY tool found in the SPATIAL ANALYST toolbar.

Step 3: The three grids need to be merged together in predetermined order so that where 2 or more features overlap the higher value is retained. In the RASTER CALCULATOR, the following syntax applies:

OUTGRID = MERGE([OPEN PITS], [AML GRID], [USGS GRID])

Step 4: Standardize the grid using the SPATIAL ANALYST TOOLS > RECLASS > SLICE function set to equal interval standardization, 256 output zones and a base zone of 1.

Cautions
Converting the mining point data to a grid at 100m resolution may misrepresent a number of small and inconspicuous mining features that have a negligible effect on the natural quality.

However, the majority of these mining features are clustered together and have a considerable local impact on the natural quality. Therefore, 100m resolution was considered appropriate in the context of the scale of the park. It must also be acknowledged that the AML dataset is a work in progress and represents only a quarter of all mining features in DEVA. The USGS mining dataset has no metadata or additional information supplied with the shapefiles. However, it was decided to use this dataset as it depicted mining sites accurately that weren't present in the incomplete AML dataset.

1.1.6 Springs

Sources
The DEVA springs database, created by the Mojave Network Inventory and Monitoring Program in 2007, is used to provide the locational data for the park's springs. However, the interpretation of spring manipulations or impacts was determined to be inadequate for use because of a lack of sufficient reporting about what data were collected and how they were collected. So the descriptions of spring manipulations or impacts was developed by Charlie Callagan, DEVA Wilderness Coordinator, based on his personal knowledge of the sites.

Processing
The DEVA springs database was queried by Charlie Callagan and exported to a new shapefile that depicts all springs with a known high deviation from natural condition.

Step 1: Create a new field (e.g. Value) in the attribute table. Populate the field with the value "1" using the FIELD CALCULATOR tool.

Use the Conversion/Slice tool to convert the shapefile to a data input, or perform the remaining steps.

Step 2: Convert the shapefile to a raster with the SPATIAL ANALYST > CONVERT > FEATURES TO RASTER tool, setting the field box to the "Value" field. Change the NoData values in the grid to 0 using the RECLASSIFY tool found in the SPATIAL ANALYST toolbar.

Step 3: Standardize the grid using the SPATIAL ANALYST TOOLS > RECLASS > SLICE function set to equal interval standardization, 256 output zones and a base zone of 1.

Cautions
The springs data only include sites that are known by park staff to have a very high deviation from their natural condition. Although park staff acknowledge that the majority of springs within DEVA have been manipulated to some extent from their natural condition, there is currently incomplete data to represent this.

1.1.7 Sky brightness above natural levels (Night sky)

Sources
Raster dataset created by Dan Duriscoe, NPS Night Sky Team. The grid is a spline surface model interpolated from 13 observation points.

Processing

Step 1: Re-project raster to NAD 1983 UTM Zone 11N coordinate system using the DATA MANAGEMENT TOOLS > PROJECTIONS AND TRANSFORMATIONS > RASTER > PROJECT RASTER tool in the Arc Toolbox.

Step 2: In the RASTER CALCULATOR, clip the night sky grid to the DEVA boundary mask using the following equation:

OUTGRID = [NIGHT SKY GRID] * [MASK]

Step 3: Standardize the grid using the SPATIAL ANALYST TOOLS > RECLASS > SLICE function set to equal interval standardization, 256 output zones and a base zone of 1.

Cautions

This data input represents temporal impacts to the natural quality which are only noticeable at night. In contrast to the night sky data inputs described under the solitude, this data input is all sky brightness above natural levels, as such deviations may impact various natural processes or activities of nocturnal species regardless of whether such unnatural brightness is detectable to the human eye.

<u>1.1.8 Grazing</u>

Sources

DEVA GIS dataset of allotment boundaries for Hunter Mountain Allotment.

Processing

Step 1: Create a new field (e.g. Value) in the attribute table. Populate the field with the value “1” using the FIELD CALCULATOR tool.

Use the Conversion/Slice tool to convert the shapefile to a data input, or perform the remaining steps.

Step 2: Convert the shapefile to a raster with the SPATIAL ANALYST > CONVERT > FEATURES TO RASTER tool, setting the field box to the “Value” field. Change the NoData values in the grid to 0 using the RECLASSIFY tool found in the SPATIAL ANALYST toolbar.

Step 3: Standardize the grid using the SPATIAL ANALYST TOOLS > RECLASS > SLICE function set to equal interval standardization, 256 output zones and a base zone of 1.

Cautions

This data input assumes every hectare of wilderness within the grazing allotment has been unnaturally grazed, trampled, etc. and therefore degraded. However, in reality the degree of degradation probably varies over space and time due to concentrations or dispersal of animals. But the working group lacks the data to articulate such intra-allotment variation into accurate geospatial data so the decision was made to assign the entire allotment the same value as there is probably at least some impact everywhere given the 140+ year grazing history of this allotment.

1.1.9 Guzzlers (artificial water sources previously installed for game species)

Sources
Point data based on communication with Linda Manning and a 2004 Sheep Guzzlers Condition and Use Assessment.

Processing
Five concentric 1km buffer zones are extended from the location of each guzzler, which are in turn assigned a decreasing range of values from the guzzler in the center (a value of 5 for the closest zone, and a value of 1 for the zone furthest from the center). These values represent the impact to the natural quality caused by animals being drawn unnaturally to this artificial water source. The different zones emphasize the greater impact, through unnatural grazing, droppings and trampling, nearer the guzzler, and less impact further away.

Step 1: In Arc Toolbox, select the ANALYSIS TOOLS > PROXIMITY > MULTIPLE RING BUFFER tool. Enter the 5 buffer distances (1 – 5km) into the distance box. Leave the dissolve option to "ALL".

Step 2: Create a new field (e.g. Value) in the attribute table. Populate the field with the value "5" for the 1km buffer zone, value "4" for the 2km buffer zone, etc.

Use the Conversion/Slice tool to convert the shapefile to a data input, or perform the remaining steps.

Step 3: Convert the shapefile to a raster with the SPATIAL ANALYST > CONVERT > FEATURES TO RASTER tool, setting the field box to the "Value" field. Change the NoData values in the grid to 0 using the RECLASSIFY tool found in the SPATIAL ANALYST toolbar.

Step 4: Standardize the grid using the SPATIAL ANALYST TOOLS > RECLASS > SLICE function set to equal interval standardization, 256 output zones and a base zone of 1.

Cautions
The different zones are created through consultation with park staff, who have seen the impacts the presence of guzzlers have on natural conditions. The concentric buffer zones are a coarse estimate of impacts and were not quantified on the ground.

1.2 Weights

The data inputs under each indicator are added together using a weighting regime decided by the DEVA staff (Table 2). These weights reflect the importance of a data input in relation to the others under a particular indicator. The “weighted” data inputs under each indicator total 100.

Although data for fire regime and climate change aren’t available, these “empty” data inputs are still assigned weights under the biophysical process indicator. This is to ensure that the other data inputs within this indicator don’t have a greater impact on the natural map due to these data gaps. In the future, as these missing data become available, they can be inputted seamlessly into the model.

In the Arc toolbox, use the SPATIAL ANALYST TOOLS > OVERLAY > WEIGHTED SUM tool to add the data inputs together for each indicator using the weights found in Table 2. For the biophysical processes indicator, the weights won’t total 100 as two of the data inputs aren’t available.

Standardize the indicator grids using the SPATIAL ANALYST TOOLS > RECLASS > SLICE function set to equal interval standardization, 256 output zones and a base zone of 1.

Table 2 Indicators and data inputs for the natural quality with weights and rationale

Indicator	Input	Weight	Rationale
Plant and animal species and communities	Land cover	50	Overriding descriptor of the landscape
	Exotic plants	25	Equal weighting because they are equally issues of concern in that exotic species degrade habitat quality
	Exotic animals	25	
Physical resources	Ozone (Air quality)	5	Minor issue in the desert due to relatively low concentrations and a lack of ozone sensitive species
	Wet deposited nitrate and ammonium (Air quality)	10	Important due to correlation with increased red brome invasion and altered fire regimes
	Mining sites	30	Pervasive impacts across park
	Springs	35	Very important resource for sustaining desert life
	Night sky – deviation from natural	20	Important issue to DEVA and degradation may impact nocturnal species, but time limited in that the impact is only felt during night time hours
Biophysical processes	Grazing	30	Important and long term issue that has known detrimental impacts to desert soils and plants
	Guzzlers	15	Localized impact
	Fire regime (FRCC)*	25	Important in the desert due to recent and widespread increases in fire frequency and fire size
	Climate change*	30	Very important in the desert due to effects of hotter temperatures and unresolved changes to timing and amount of precipitation
	* No data	300	

1.3 Natural quality map

To create the natural quality map (Figure 1), the 3 indicators are added together in RASTER CALCULATOR using the following equation:

OUTGRID = [INDICATOR1] + [INDICATOR2] + [INDICATOR3]

Standardize the grid using the SPATIAL ANALYST TOOLS > RECLASS > SLICE function set to equal interval standardization, 256 output zones and a base zone of 1.

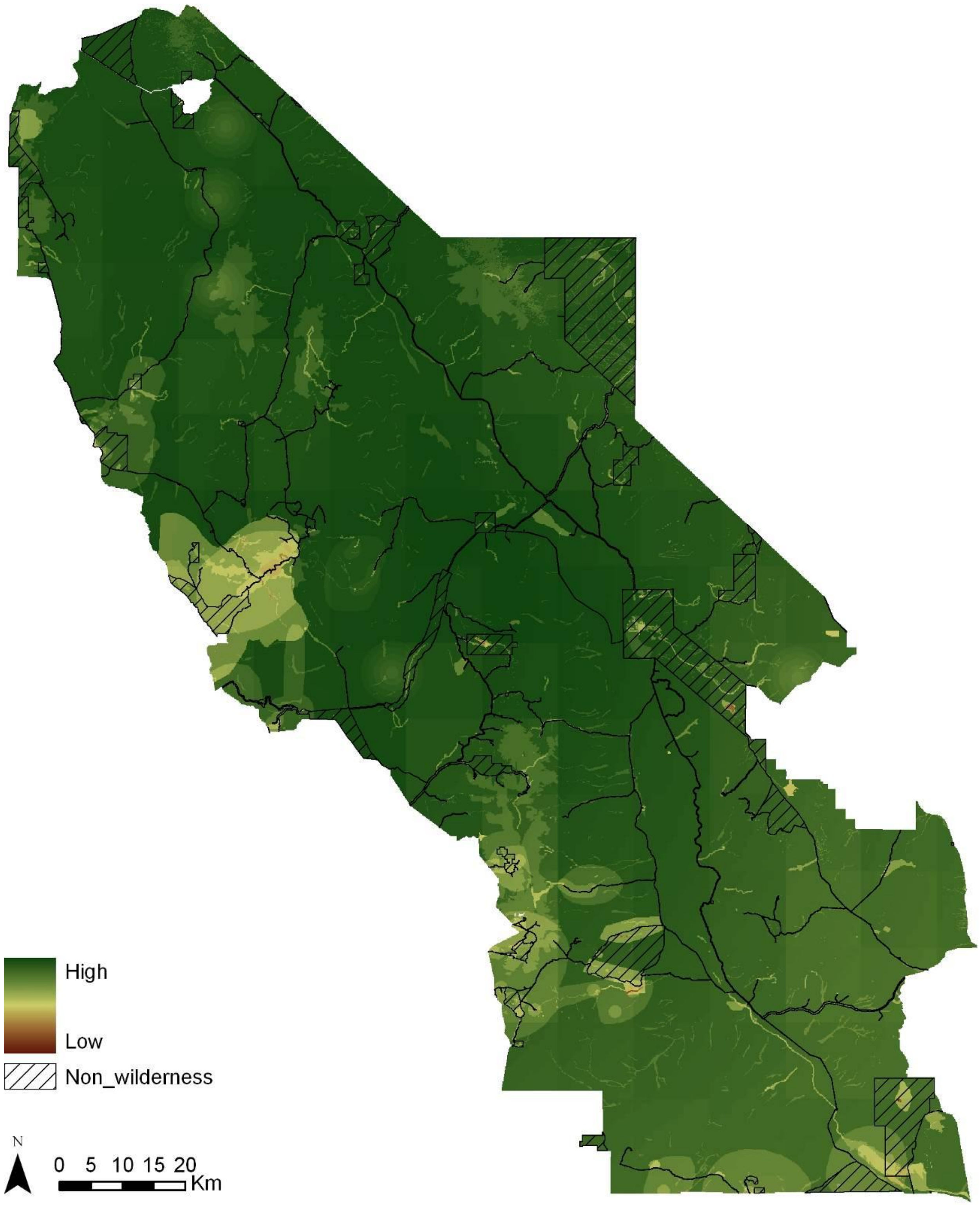

Figure 1 Natural quality of wilderness character

2. UNTRAMMELED QUALITY

The untrammeled quality is defined as wilderness areas that are essentially unhindered and free from modern human control or manipulation. The untrammeled quality is degraded by actions that intentionally manipulate or control ecological systems, whereas the natural quality is degraded by the intentional and unintentional effects from actions taken inside wilderness as well as from external forces on these systems (Landres et al., 2008).

2.1 Data Inputs

The untrammeled quality map is composed of four data inputs, reflecting the small number of modern human actions impacting the untrammeled quality of the DEVA wilderness (Table 3). Two additional data inputs, manipulation of water flows and poaching incidents, were identified but because there is currently no information available, they were not included.

Table 3 Untrammeled quality datasets

Dataset	Source	Type	Scale	Accuracy	Completeness
Supressed fires (natural ignitions)	DEVA	Polygon	100m	High	High
Weed treatments	NPS APCAM	Polygon	100m	High	High
Burro removals	DEVA	Point	100m	High	Low
Installation of mine closures/bat gates	DEVA	Point	100m	High	Moderate
Manipulation of landscape that alters water flow*	n/a	n/a	n/a	n/a	n/a
Poaching incidents*	n/a	n/a	n/a	n/a	n/a

* No data

2.1.1 Suppressed fires

Sources
GPS fire perimeters as recorded in the DEVA fire history database.

Processing
Step 1: Create a new field (e.g. Value) in the attribute table. Populate the field with the value “1” using the FIELD CALCULATOR tool.

Use the Conversion/Slice tool to convert the shapefile to a data input, or perform the remaining steps.

Step 2: Convert the shapefile to a raster with the SPATIAL ANALYST > CONVERT > FEATURES TO RASTER tool, setting the field box to the “Value” field. Change the NoData values in the grid to 0 using the RECLASSIFY tool found in the SPATIAL ANALYST toolbar.

Step 3: Standardize the grid using the SPATIAL ANALYST TOOLS > RECLASS > SLICE function set to equal interval standardization, 256 output zones and a base zone of 1.

Cautions
These actions are recorded for a period of one year as trammeling (as these management decisions are seen as a short term trade off for a long term benefit in the natural quality), although for this project all recorded trammeling events from 1999 onwards are included.

2.1.2 Weed treatments

Sources
Vector dataset from the NPS APCAM database.

Processing
Step 1: Create a new field (e.g. Value) in the attribute table. Populate the field with the value "1" using the FIELD CALCULATOR tool.

Use the Conversion/Slice tool to convert the shapefile to a data input, or perform the remaining steps.

Step 2: Convert the shapefile to a raster with the SPATIAL ANALYST > CONVERT > FEATURES TO RASTER tool, setting the field box to the "Value" field. Change the NoData values in the grid to 0 using the RECLASSIFY tool found in the SPATIAL ANALYST toolbar.

Step 3: Standardize the grid using the SPATIAL ANALYST TOOLS > RECLASS > SLICE function set to equal interval standardization, 256 output zones and a base zone of 1.

Cautions
None.

2.1.3 Burro removals

Sources
Point dataset providing approximate locations of burro removal sites as recorded in the 1999, 2000 and 2001 Burro Capture Summary Reports of DEVA.

Processing
Step 1: Create a new field (e.g. Value) in the attribute table. Populate the field with the value "1" using the FIELD CALCULATOR tool.

Use the Conversion/Slice tool to convert the shapefile to a data input, or perform the remaining steps.

Step 2: Convert the shapefile to a raster with the SPATIAL ANALYST > CONVERT > FEATURES TO RASTER tool, setting the field box to the "Value" field. Change the NoData values in the grid to 0 using the RECLASSIFY tool found in the SPATIAL ANALYST toolbar.

Step 3: Standardize the grid using the SPATIAL ANALYST TOOLS > RECLASS > SLICE function set to equal interval standardization, 256 output zones and a base zone of 1.

Cautions
Two locations are not known and so have not been placed.

2.1.4 Installation of mine closures/bat gates

Sources
DEVA GIS dataset.

Processing
Step 1: Create a new field (e.g. Value) in the attribute table. Populate the field with the value "1" using the FIELD CALCULATOR tool.

Use the Conversion/Slice tool to convert the shapefile to a data input, or perform the remaining steps.

Step 2: Convert the shapefile to a raster with the SPATIAL ANALYST > CONVERT > FEATURES TO RASTER tool, setting the field box to the "Value" field. Change the NoData values in the grid to 0 using the RECLASSIFY tool found in the SPATIAL ANALYST toolbar.

Step 3: Standardize the grid using the SPATIAL ANALYST TOOLS > RECLASS > SLICE function set to equal interval standardization, 256 output zones and a base zone of 1.

Cautions
None.

2.2 Weights

The data inputs under each indicator are added together using a weighting regime decided by the DEVA staff (Table 4). These weights reflect the importance of a data input in relation to the others under a particular indicator. The "weighted" data inputs under each indicator total 100.

Although data for manipulation of landscape that alters water flow and poaching incidents aren't available, these "empty" data inputs are still assigned weights under the two indicators for this quality. This is to ensure that the other data inputs within this indicator don't have a greater impact on the untrammled map due to these data gaps. In the future, as these missing data become available, they can be inputted seamlessly into the model.

In the Arc toolbox, use the SPATIAL ANALYST TOOLS > OVERLAY > WEIGHTED SUM tool to add the existing data inputs together for the authorized actions indicator using the weights found in Table 4. The weights won't total 100 for this indicator, as one of the data inputs is missing.

Standardize the indicator grid using the SPATIAL ANALYST TOOLS > RECLASS > SLICE function set to equal interval standardization, 256 output zones and a base zone of 1.

Table 4 Indicators and data inputs for the untrammeled quality with weights and rationale

Indicators	Input	Weight	Rationale
Authorized actions	Suppressed fires (natural ignitions)	20	Equal weights for all data inputs because all trammeling actions have the same effect on the untrammeled quality.
	Weed treatments	20	
	Burro removals	20	
	Installation of mine closures/bat gates	20	
	Manipulation of landscape that alters water flow*	20	
Unauthorized actions	Poaching incidents*	100	
	* No data	200	

2.3 Untrammeled quality map

To create the untrammeled quality map (Figure 2), the authorized indicator needs to be "diluted" to acknowledge the "empty" unauthorized actions indicator. In the RASTER CALCULATOR the following equation applies:

OUTGRID = [INDICATOR1] * 0.5

Standardize the grid using the SPATIAL ANALYST TOOLS > RECLASS > SLICE function set to equal interval standardization, 256 output zones and a base zone of 1.

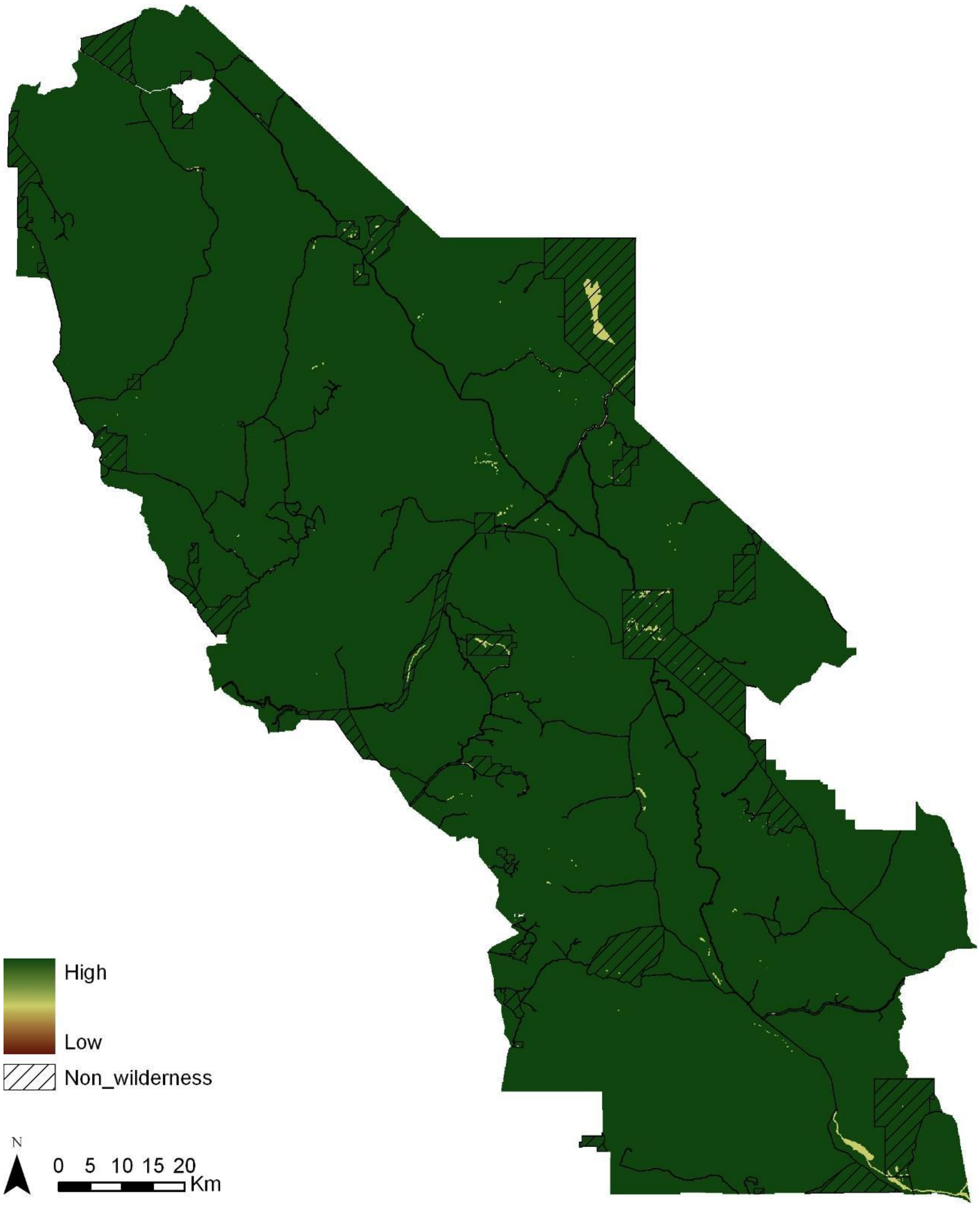

Figure 2 Untrammeled quality of wilderness character

3. UNDEVELOPED QUALITY

The undeveloped quality is defined as wilderness areas that are essentially without permanent improvements or modern human occupation. This quality is degraded by the presence of non-recreation structures and installations, habitations, and by the use of motor vehicles, motorized equipment, or mechanical transport that increases people's ability to occupy or modify the environment (Landres et al., 2008).

3.1 Data inputs

The undeveloped quality datasets are all vector data, are of high scale and are generally of moderate to high accuracy and completeness (Table 5).

Table 5 Undeveloped quality datasets

Dataset	Source	Type	Scale	Accuracy	Completeness
Installations	DEVA	Point	100m	Moderate	Low
Guzzlers	DEVA	Point	100m	High	High
Fences	NPS ASMIS	Polyline	100m	Moderate	Moderate
Unauthorized installations/debris	DEVA	Point	100m	Moderate	Low
Borrow pits	DEVA	Point	100m	High	Moderate
Inholdings	BLM GCDB	Polygon	100m	High	High
ORV trespass	DEVA	Polygon	100m	Moderate	Low
Administration uses	DEVA	Point	100m	Moderate	Moderate
Damaged or destroyed cabins	NPS ASMIS	Point	100m	High	High

<u>3.1.1 Installations (including guzzlers & fences)</u>

Sources

DEVA generated datasets. Installation point data created using topographic maps or aerial photographs. Guzzler point data is based on communication with Linda Manning and a 2004 Sheep Guzzlers Condition and Use Assessment. Fence line data from the NPS Archeological Sites Management Information System (ASMIS).

Processing

Step 1: For each shapefile, create a new field (e.g. Value) in the attribute table. Populate the field with the value "1" using the FIELD CALCULATOR tool.

Step 2: Convert the three shapefiles to rasters with the SPATIAL ANALYST > CONVERT > FEATURES TO RASTER tool, setting the field box to the "Value" field. Change the NoData values in the grid to 0 using the RECLASSIFY tool found in the SPATIAL ANALYST toolbar.

Step 3: Add the three rasters together using the merge command in the RASTER CALCULATER:

OUTGRID = MERGE([INSTALL], [GUZZLERS], [FENCES])

Step 4: Standardize the grid using the SPATIAL ANALYST TOOLS > RECLASS > SLICE function set to equal interval standardization, 256 output zones and a base zone of 1.

Cautions
The guzzler data input in the natural quality depicts the impact guzzlers have on the landscape through the unnatural grazing, trampling and droppings by animals attracted to the artificial water source. Here, for the undeveloped quality, the guzzler data input only records the location of the guzzler, which is considered a development or installation in wilderness.

3.1.2 Unauthorized installations/debris

Sources
Point dataset created by Charlie Callagan, Wilderness Coordinator.

Processing
Step 1: Create a new field (e.g. Value) in the attribute table. Populate the field with the value "1" using the FIELD CALCULATOR tool.

Use the Conversion/Slice tool to convert the shapefile to a data input, or perform the remaining steps.

Step 2: Convert the shapefile to a raster with the SPATIAL ANALYST > CONVERT > FEATURES TO RASTER tool, setting the field box to the "Value" field. Change the NoData values in the grid to 0 using the RECLASSIFY tool found in the SPATIAL ANALYST toolbar.

Step 3: Standardize the grid using the SPATIAL ANALYST TOOLS > RECLASS > SLICE function set to equal interval standardization, 256 output zones and a base zone of 1.

Cautions
The debris data input is acknowledged as being largely incomplete and only records particular objects that have been selected for removal by wilderness managers. Using points to represent debris which may be scattered over the land may also underestimate the impact of this dataset on the model, as the only pixel degraded is the one in which the point lies while in reality the debris may be spread over a few pixels. As this data source is updated, it will better inform the undeveloped quality.

3.1.3 Borrow pits

Sources
DEVA polygon dataset.

Processing
Step 1: Create a new field (e.g. Value) in the attribute table. Populate the field with the value "1" using the FIELD CALCULATOR tool.

Use the Conversion/Slice tool to convert the shapefile to a data input, or perform the remaining steps.

Step 2: Convert the shapefile to a raster with the SPATIAL ANALYST > CONVERT > FEATURES TO RASTER tool, setting the field box to the "Value" field. Change the NoData values in the grid to 0 using the RECLASSIFY tool found in the SPATIAL ANALYST toolbar.

Step 3: Standardize the grid using the SPATIAL ANALYST TOOLS > RECLASS > SLICE function set to equal interval standardization, 256 output zones and a base zone of 1.

Cautions
None.

3.1.4 Inholdings

Sources
Bureau of Land Management's Geographic Coordinate Data Base (GCDB).

Processing
The dataset was queried to create polygons for state, private and unpatented inholdings. The state inholdings and road data were analyzed (using the SELECT BY LOCATION tool in ArcGIS) to determine which polygons were accessible by roads.

Step 1: Query the inholdings shapefile using the SELECT BY ATTRIBUTES tool in the attribute table options menu to create individual shapefiles for state, private and unpatented inholdings.

Step 2: In the SELECTION drop-down menu, use the SELECT BY LOCATION tool to identify which state polygons INTERSECT with the roads shapefile. Save the selection to a new shapefile (State inholdings with road access). Then invert the selection using the SWITCH SELECTION tool in the attribute table options menu and save (as State inholdings without road access).

Step 3: For each shapefile, create a new field (e.g. Value) in the attribute table. Populate the field with the value "1" using the FIELD CALCULATOR tool.

Use the Conversion/Slice tool to convert the four shapefiles to data inputs, or perform the remaining steps.

Step 4: Convert the four shapefiles to rasters with the SPATIAL ANALYST > CONVERT > FEATURES TO RASTER tool, setting the field box to the "Value" field. Change the NoData values in the grid to 0 using the RECLASSIFY tool found in the SPATIAL ANALYST toolbar.

Step 5: Standardize the grid using the SPATIAL ANALYST TOOLS > RECLASS > SLICE function set to equal interval standardization, 256 output zones and a base zone of 1.

Cautions
This data delineates areas in the wilderness where development may occur. These inholdings typically pre-date the wilderness designation and have different likelihoods of development as

depicted in the weighting table. However, it is important to acknowledge that at present these parcels of land aren't developed and will appear no different than other parts of the wilderness.

3.1.5 ORV Trespass

Sources
Dataset heads-up digitized[2] by Charlie Callagan, DEVA Wilderness Coordinator, using National Agriculture Imagery Program (NAIP) imagery.

Processing
Step 1: Create a new field (e.g. Value) in the attribute table. Populate the field with the value "1" using the FIELD CALCULATOR tool.

Use the Conversion/Slice tool to convert the shapefile to a data input, or perform the remaining steps.

Step 2: Convert the shapefile to a raster with the SPATIAL ANALYST > CONVERT > FEATURES TO RASTER tool, setting the field box to the "Value" field. Change the NoData values in the grid to 0 using the RECLASSIFY tool found in the SPATIAL ANALYST toolbar.

Step 3: Standardize the grid using the SPATIAL ANALYST TOOLS > RECLASS > SLICE function set to equal interval standardization, 256 output zones and a base zone of 1.

Cautions
None.

3.1.6 Administrative uses

Sources
Point dataset created by Charlie Callagan, DEVA Wilderness Coordinator.

Processing
Step 1: Create a new field (e.g. Value) in the attribute table. Populate the field with the value "1" using the FIELD CALCULATOR tool.

Use the Conversion/Slice tool to convert the shapefile to a data input, or perform the remaining steps.

Step 2: Convert the shapefile to a raster with the SPATIAL ANALYST > CONVERT > FEATURES TO RASTER tool, setting the field box to the "Value" field. Change the NoData values in the grid to 0 using the RECLASSIFY tool found in the SPATIAL ANALYST toolbar.

Step 3: Standardize the grid using the SPATIAL ANALYST TOOLS > RECLASS > SLICE function set to equal interval standardization, 256 output zones and a base zone of 1.

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[2] Digitizing directly onto a map on the computer screen using the mouse cursor

Cautions
None.

3.1.7 Damaged or destroyed cabins

Sources
Point dataset created by Leah Bonstead, DEVA Archeologist using the ASMIS dataset.

Processing
Step 1: Create a new field (e.g. Value) in the attribute table. Populate the field with the value "1" for damaged cabins and "2" for destroyed cabins using the FIELD CALCULATOR tool.

Use the Conversion/Slice tool to convert the shapefile to a data input, or perform the remaining steps.

Step 2: Convert the shapefile to a raster with the SPATIAL ANALYST > CONVERT > FEATURES TO RASTER tool, setting the field box to the "Value" field. Change the NoData values in the grid to 0 using the RECLASSIFY tool found in the SPATIAL ANALYST toolbar.

Step 3: Standardize the grid using the SPATIAL ANALYST TOOLS > RECLASS > SLICE function set to equal interval standardization, 256 output zones and a base zone of 1.

Cautions
None.

3.2 Weights

The data inputs under each indicator are added together using a weighting regime decided by the DEVA staff (Table 6). These weights reflect the importance of a data input in relation to the others under a particular indicator. The "weighted" data inputs under each indicator total 100.

In the Arc toolbox, use the SPATIAL ANALYST TOOLS > OVERLAY > WEIGHTED SUM tool to add the data inputs together for each indicator using the weights found in Table 6.

Standardize the indicator grids using the SPATIAL ANALYST TOOLS > RECLASS > SLICE function set to equal interval standardization, 256 output zones and a base zone of 1.

Table 6 Indicators and data inputs for the undeveloped quality with weights and rationale

Indicator	Input	Weight	Rationale
Non-recreational structures, installations, and developments	Installations (including guzzlers & fences)	55	Big footprints and large areas of impact
	Unauthorized installations/debris	10	Small footprints, scattered
	Borrow pits	35	Big footprints, but few
Inholdings	State inholdings with road access	15	Limited potential for development
	State inholdings with no road access or held for wildlife	5	Least likely to be developed
	Private inholdings	60	Most likely to be developed
	Unpatented inholdings	20	Limited potential for development, but more than state inholdings with road access
Use of motor vehicles, motorized equipment, or mechanical transport	ORV trespass	60	Frequent occurrence with potential for long lasting impacts
	Administrative uses	40	Point data, limited in space, time and effect on land
Loss of statutorily protected cultural resources	Damaged or destroyed cabins	100	Important cultural resource and valued by park visitors. Destroyed ranked higher than damaged cabins
		400	

3.3 Undeveloped quality map

To create the undeveloped quality map (Figure 3), the 4 indicators are added together in RASTER CALCULATOR using the following equation:

OUTGRID = [INDICATOR1] + [INDICATOR2] + [INDICATOR3] + [INDICATOR4]

Standardize the grid using the SPATIAL ANALYST TOOLS > RECLASS > SLICE function set to equal interval standardization, 256 output zones and a base zone of 1.

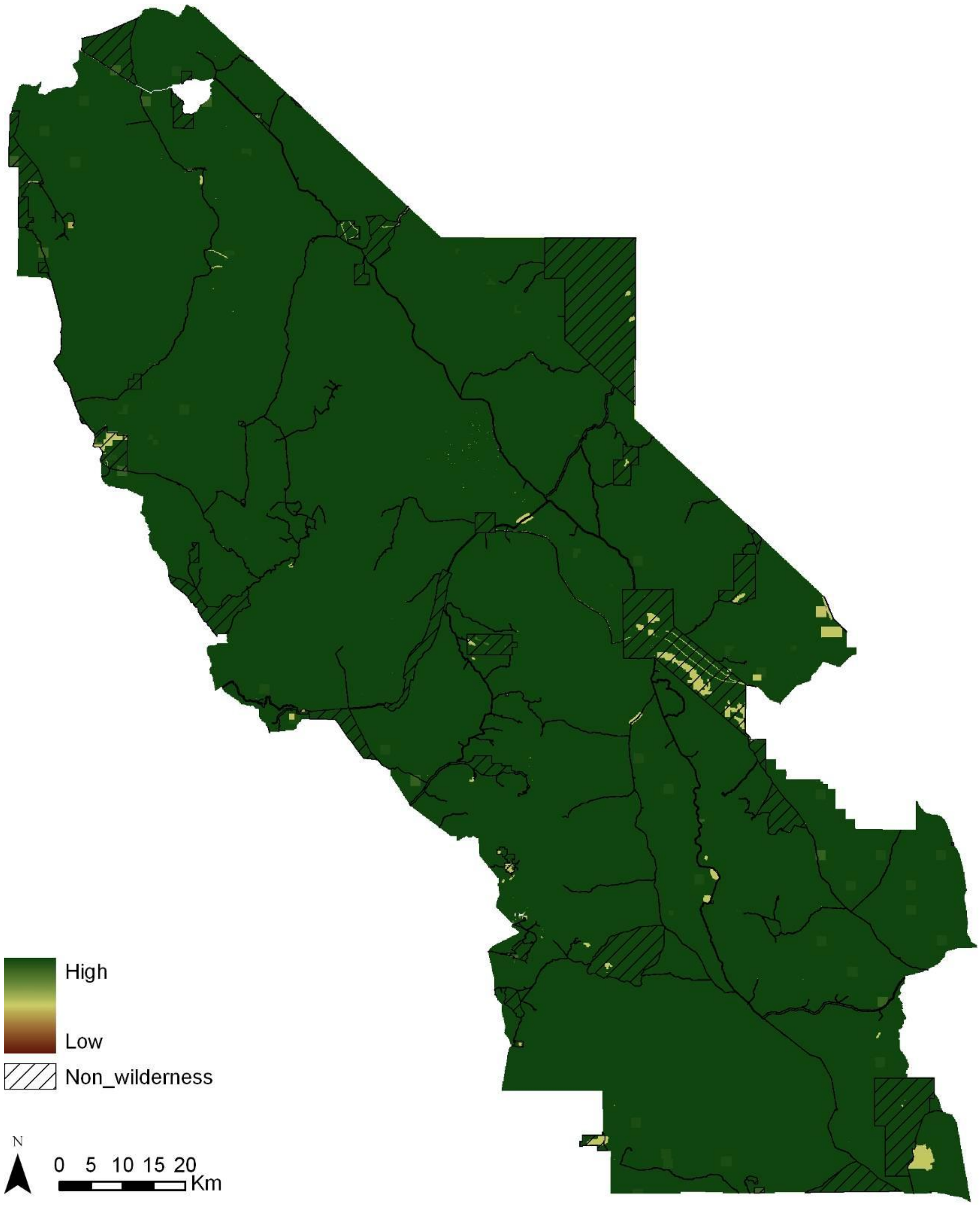

Figure 3 Undeveloped quality of wilderness character

4. SOLITUDE OR PRIMITIVE AND UNCONFINED QUALITY

The solitude or primitive and unconfined type of recreation quality is defined as visitors having outstanding opportunities to experience solitude and remoteness, which is free from the constraints of modern society. This quality is degraded by settings that reduce these opportunities, such as visitor encounters, signs of modern civilization, recreation facilities, and management restriction on visitor behavior (Landres et al., 2008).

4.1 Data inputs

A wide variety of data sources are used for the solitude or primitive and unconfined type of recreation map (Table 9), which encompass a range of different scales, variability in accuracy and completeness, and both vector and raster data.

Additionally, two sub models are employed for this quality to depict remoteness from the sights and sounds of people in wilderness. The travel time sub-model is used to delineate areas of DEVA that may be considered more remote than others due to the considerable time and distance required to reach these places. The viewshed sub-model is used to delineate the line of sight impacts of modern human features from inside and outside wilderness. Both sub-models use a variety of data at a higher resolution of 30m for more precise analysis. This analysis is extended into a buffer zone 15km outside the wilderness boundary for the travel time sub-model and up to 30km for the viewshed sub-model to allow for edge effects occurring outside the park. These sub-models analyze a variety of inputs, including road networks, vegetation and all modern human developments occurring in and around the park.

Table 7 Solitude and primitive and unconfined quality datasets

Dataset	Source	Type	Scale	Accuracy	Completeness
Travel time model	USGS, Central Mojave Mapping Project, DEVA	Raster/Polyline	30m	High	High
Viewshed model	See Table 8	Raster/Polygon	30m	Moderate	High
Over-flights	DEVA	Polygon	100m	High/Moderate	High/Moderate
Soundscape	NPS Natural Sounds Program	Raster		Moderate	Low
Nightsky - dark sky index	Night Sky Team, NPS	Raster	1km	High	Moderate
Air quality - visibilty	Air Resources Division, NPS	Raster	12km	High	High
Trails	DEVA	Polyline	100m	Moderate	Moderate
Visitor facilities	DEVA	Point	100m	High	High
Camping restrictions	DEVA	Polygon	100m	High	High
Closed to visitor use	DEVA	Polygon	100m	High	High

4.1.1 Travel time sub-model

Travel time is modeled in DEVA based on a GIS implementation of Naismith's Rule[3], with Langmuir's correction[4]. Terrain and land cover information are used to delineate the relative time taken to walk into a roadless area from the nearest point of legal motorized access taking the effects of distance, relative slope, ground cover and barrier features, such as very steep ground, into account. The travel time (or "remoteness") model, developed by Carver and Fritz (1999), assumes a person can walk at a speed of 5km/hr over flat terrain and adds a time penalty of 30mins for every 300m of ascent and 10mins for every 300m of descent for slopes greater than 12 degrees. When descending slopes between 5 and 12 degrees a time bonus of 10mins is subtracted for every 300meters of descent. Slopes between 0 and 5 degrees are assumed to be flat. Ancillary data layers are used to modify walking speeds according to ground cover (e.g. Naismith's 5 km per hour on the map can be reduced to 2 km per hour or less when walking across the Devil's golf course), and include barrier features as "null" values which force a detour[5].

Sources

Calculating travel time based on Naismith's rule requires a range of data including a detailed terrain model, land cover data and information on the location of barrier features, roads and other access features. The USGS 30m Digital Elevation Model (DEM) provide the terrain elevation data, the combined Mojave Vegetation Mapping Project and USGS National Vegetation Classification provide the land cover data, and a combination of the DEVA road dataset and heads-up digitized roads from the NAIP imagery is used to create the road classes. Additional inputs are derived from the trails, fences and closed to visitor use data sources and heads-up digitized data from ranger knowledge detailing unique land cover features such as the Devils golf course and Badwater basin.

Processing

A macro program implementing the PATHDISTANCE function in ArcGIS is used to model Naismith's rule. This estimates walking speeds based on relative horizontal and vertical moving angles across the terrain surface together with appropriate cost or weight factors incurred by crossing different land cover types and the effects of barrier features. The model is applied using the following conditions:

Source grid

This is taken to be the paved road network that provides vehicular access via private car.

Step 1: Create a mask: in Arc Toolbox, use the ANALYSIS TOOLS > PROXIMITY > BUFFER tool to buffer the DEVA park boundary by 15km.

[3] Naismith's Rule is a simple formula that helps to plan a hiking expedition by calculating how long it will take to walk the route, including ascents. Devised by William Naismith, a Scottish mountaineer, the basic rule states: "Allow … an hour for every three miles on the map, with an additional hour for every 2,000 feet of ascent" (1982).

[4] Langmuir's correction acknowledges the need to descend slowly in steep terrain as it is necessary to take shorter steps, or reduce slope angle and extend path length by zig-zagging.

[5] NoData or null values in a raster grid contain no data and so are disregarded in most calculations unless the model explicitly references these. NoData values are useful in building access models in that they can be used to describe the location of barrier features that cannot be crossed.

Step 2: In Arc Toolbox, use the ANALYSIS TOOLS > EXTRACT > CLIP tool to clip the roads shapefile with the mask set as the "Clip Features".

Step 3: Query the clipped roads shapefile for all paved roads using the SELECT BY ATTRIBUTES tool from the options tab in the attribute table with the following expression: *"Type" = 'Paved roads'*.

Step 4: Buffer the roads by 30m using the ANALYSIS TOOLS > PROXIMITY > BUFFER tool.

Step 5: Create a new field (e.g. Value) in the attribute table. Populate the field with the value "1" using the FIELD CALCULATOR tool.

Step 6: Convert the shapefile to a raster with the SPATIAL ANALYST > CONVERT > FEATURES TO RASTER tool, setting the field box to the "Value" field.

Cost surface

This is assumed to be 5km/hr for the majority of land cover types in DEVA. However, certain land cover types such as sagebrush are 4km/hr, high elevation pine woodlands are 3km/hr, chaparral are 2km/hr and sand dunes are 1km/hr (For a full list of vegetation impendence values see Appendix A). Footpath data are used to amend the cost surface as having the least resistance to movement (5km/hr). The unique land cover areas of the Devils golf course and Badwater supersede the land cover values at 2km/hr and 4km/hr respectively. Lastly, the backcountry roads are "hardwired" onto the cost surface to represent the different speeds a vehicle can travel in the back country. The roads are split into two categories: dirt roads suitable for low clearance, non-4x4 vehicles traveling at an average speed of 40km/hr and dirt roads only suitable for high clearance, 4x4 vehicles traveling at an average speed of 20km/hr.

Step 1: Collate the land cover classes from the two data sources in an Excel sheet (retaining their land cover type codes) and rank each, according to their perceived impedance, on a scale of 1-5. Classes such as chaparral, mesquite shrublands, and dunes receive high rankings as they are difficult landscape features to travel through. Wash systems, shrubland, and sparsely vegetated areas receive low rankings as they are easy landscape features to pass through. For this project, the ranked impedance classes are determined by the Park staff. A table with these rankings used for the analysis is in the Appendix A.

Step 2: The CMMP data is converted to raster at 30m resolution using the SPATIAL ANALYST > CONVERT > FEATURES TO RASTER tool.

Step 3: For the 15km buffered mask, create a new field (e.g. Value) in the attribute table. Populate the field with the value "1" using the FIELD CALCULATOR tool. Convert the shapefile to a raster with the SPATIAL ANALYST > CONVERT > FEATURES TO RASTER tool, setting the field box to the "Value" field.

Step 4: Both land cover rasters are multiplied by the mask in the RASTER CALCULATOR using the following equation:

OUTGRID1 = [CMMP] * [15KM_MASK]

OUTGRID2 = [USGS NVC] * [15KM_MASK]

Step 5: Combine the two rasters together using the MERGE map algebra command in the RASTER CALCULATOR (the purpose of the merge is to retain the CMMP data as the primary land cover data and the USGS NVC data fills in the missing gaps); the following syntax applies:

OUTGRID = MERGE([CMMP], [USGS NVC])

Step 6: Open the excel sheet in ArcGIS. Right click the mosaic grid in the data frame and use the JOINS AND RELATES > JOIN tool to join the tables together using the common field (land cover type code) in both tables. Using the SPATIAL ANALYST > RECLASSIFY tool, change the reclass field to the ranked impedance classes.

Step 7: Additional landscape features (not present in the two original vegetation datasets) are used to override the original values in the impedance grid:

i) The valley floor (impedance value of 2) and the Devil's Golf Course (impedance value of 4) – derived from a heads-up digitized shapefile provided by Charlie Callagan. Fences (impedance value of "5")
ii) Trails (impedance value of "1")
iii) Fences (impedance value of "5")
iv) Dirt roads suitable for low clearance, non-4x4 vehicles (nominal impedance value of "6") and dirt roads only suitable for high clearance, 4x4 vehicles (nominal impedance value of "7") - query the clipped roads shapefile for all unpaved roads using the SELECT BY ATTRIBUTES tool from the options tab in the attribute table with the following expression: *"Type" = 'Unpaved roads'*. Then use the DEVA visitor map to determine the road classification type for each road segment.

Step 8: Convert these modification shapefiles to raster with the SPATIAL ANALYST > CONVERT > FEATURES TO RASTER tool, setting the field box to the "Value" field (set the SPATIAL ANALYST > OPTIONS > EXTENT setting to that of the 15km buffered mask).

Step 9: Combine the modified features using the MERGE map algebra command in the RASTER CALCULATOR; the following syntax applies:

OUTGRID = MERGE([DIRT ROADS], [FENCES], [TRAILS], [VALLEY FLOOR], [VEG IMPEDANCE])

It is important to keep the correct order as specified in the syntax: the last grid listed has the lowest priority and the first the highest so valid values in [DIRTROADS] will replace the values in the other grids.

Step 10: Using the RASTER CLACULATOR, change the values to the m/s values using the following expression:

CON([COST GRID] = = 1, 0.72, [COST GRID] = = 2, 0.9, [COST GRID] = = 3, 1.2, [COST GRID] = = 4, 1.8, [COST GRID] = = 5, 3.6, [COST GRID] = = 6, 0.09, [COST GRID] = = 7. 0.18)

Barriers to movement
These include areas that are closed to visitor use and slope angles that are greater than 40 degrees.

Step 1: Clip the DEM to the15km buffered mask in the RASTER CALCULATOR using the following equation:

OUTGRID = [DEM] * [15KM_MASK]

Step 2: Derive a slope grid from the DEM using the SPATIAL ANALYST TOOLS > SURFACE > SLOPE command.

Step 3: Reclassify the slope grid using the RECLASSIFY function in the SPATIAL ANALYST toolbar so slopes ≥ 40° have a value of NoData and slopes < 40° have a value of 9999.

Step 4: For the closed to visitor use shapefile, create a new field (e.g. Value) in the attribute table. Populate the field with the value "9999" using the FIELD CALCULATOR tool.

Step 5: Convert the shapefile to a raster with the SPATIAL ANALYST > CONVERT > FEATURES TO RASTER tool, setting the field box to the "Value" field.

Step 6: Combine the modified features using the MERGE map algebra command in the RASTER CALCULATOR; the following syntax applies:

OUTGRID = MERGE([CLOSED TO VISITOR USE], [SLOPE], [COST GIRD])

Running the model
The final input required for the analysis is an aspect grid: derive an aspect grid from the DEM using the SPATIAL ANALYST TOOLS > SURFACE > ASPECT command.

Copy the AML code (for running the PATHDISTANCE function) and the vertical relative moving angles[6] table into the folder with the four grids (source grid, cost surface, DEM and aspect). Run the code in Arc GRID using the command "&Run Naismith".

Filling NoData gaps
The NoData gaps in the travel time outgrid are a result of the barrier features in the cost grid. Before the outgrid can be standardized for input into the indicator grid, use the SPATIAL ANALYST TOOLS > GENERALIZATION > NIBBLE function in the Arc Toolbox to fill in the NoData gaps. The NIBBLE function requires two input grids in integer format; one where the values will be nibbled and one which will act as a mask grid. As the travel time outgrid is in floating point format, it must be converted to integer format before using in the NIBBLE function.

[6] Vertical and horizontal factors determine the difficulty of moving from one cell to another while accounting for the vertical or horizontal elements that may effect the movement, these include slope and aspect as they determine the relative angle of the slope in the direction it is crossed and hence the height gained or lost.

Step 1: As the NIBBLE function will not nibble areas of NoData on the input grid, these must be assigned another value first. This can be done in the RASTER CALCULATOR using map algebra to assign an arbitrary value of 9999 to the NoData locations in order to generate the input grid to the NIBBLE tool:

OUTGRID = CON(ISNULL([GRID]), 9999, [GRID])

Step 2: Now, convert both grids (the travel time grid with NoData values changed to 9999 and the original travel time grid to be used as the mask) to integers using the following expression in Arc GRID:

OUTGRID = INT([GRID])

Step 3: Then run the NIBBLE function in Arc GRID using the following expression (INPUT1 is the travel time grid with NoData values changed to 9999 and INPUT2 is the mask):

OUTGRID = NIBBLE([INPUT1], [INPUT2], DATAONLY)

Step 4: Standardize the grid using the SPATIAL ANALYST TOOLS > RECLASS > SLICE function set to equal interval standardization, 256 output zones and a base zone of 1.

Step 5: The final task is to invert the values in the RASTER CALCULATOR using the following equation:

OUTGRID = ([GRID] – 256) * -1

Step 6: Re-perform the standardization in Step 2 as the value range in the grid after the inversion will be 0 – 255.

Cautions

Naismiths's Rule and the model used to implement it here assumes the person "travelling the landscape" to be a fit and healthy individual, and does not make allowances for load carried, weather conditions (such as extreme heat or strong head winds) and navigational skills. The model does, however, take barrier features and conditions underfoot into account. Steep slopes and areas closed to visitor use are considered impassable on foot and are included as barrier features by coding these as NoData (null values) in the model inputs. This forces the model to seek a solution that involves walking around the obstacle. The model also uses a cost or friction surface that controls the walking speed according to the land cover or conditions underfoot. A speed of 5km/hr (1.389m/s) is assumed for most land cover types, but some fall into a range of 4km/hr (1.112m/s) to 1km/hr (0.278m/s). The angle at which the terrain is crossed (i.e. the horizontal and vertical relative moving angles[7]) is used to determine the relative slope and height lost/gained. These values are input into the model using a simple lookup table as shown in Table 7. The paved road network, both within and outside the DEVA boundary, is used as the access

[7] Vertical and horizontal factors determine the difficulty of moving from one cell to another while accounting for the vertical or horizontal elements that affect the movement, these include slope and aspect as they determine the relative angle of the slope in the direction it is crossed and hence the height gained or lost.

points from which to calculate remoteness of non-road areas. The road network outside DEVA is included in the analysis to avoid any possible edge effects in the travel time calculation.

4.1.2 Viewshed sub-model

The visual impacts of modern human features in the DEVA wilderness are modeled using a custom-built software tool which has been designed to work directly with GIS data.
The presence of these artificial features, which may be located within or adjacent to the wilderness, are considered to be a detractor of a sense of solitude. Previous work on the effects of human features on perceptions of wilderness, carried out at national to global scales, has tended to focus on simple distance measures (Lesslie, 1993; Carver, 1996; Sanderson et al., 2002). More recent work has used measures of visibility of human features in 3D landscapes described using digital terrain models (Fritz et al., 2000; Carver and Wrightham, 2003). This is feasible at the landscape scale utilizing viewshed algorithms and land cover datasets to calculate the area from which a given feature can be seen[8].

Sources
Visibility analysis and viewshed calculations rely on the ability to calculate "line-of-sight" from one point on a terrain to another. It has been shown that the accuracy of viewshed produced in GIS is strongly dependant on the accuracy of the terrain model used and the inclusion of intervening features or "terrain clutter" in the analysis (Fisher, 1993). While previous studies have made use of a digital surface model (DSM) for obtaining "terrain clutter" (Carver et al., 2008), the extent of DEVA and relative lack of features allows feature information to be collated and formatted manually (Table 8). A resolution of 30m for the feature inputs was considered adequate for this analysis. The viewshed distance and height information were determined for each feature by the working group. The USGS 30m DEM was used to provide the terrain elevation data.

[8] Viewshed algorithms are used to calculate where a particular feature, say a building or radio antennae, can be seen from by a person standing anywhere in the landscape using digital terrain models. These algorithms calculate line-of-sight between the viewer and the feature being observed, and in particular those areas where line-of-sight is interrupted by intervening higher ground.

Table 8 Human features impacting viewshed

Feature	Source	Viewshed distance	Height	Accuracy	Completeness
Small installations	DEVA	1km	5m	Moderate	Moderate
Mines	NPS AML/ USGS/DEVA	1km	2m	High	Low
Utilities	DEVA	1km	5m	Moderate	High
Fences	NPS ASMIS	1km	1m	High	High
Dirtroads	DEVA	1km	2m	High	High
Debris	DEVA	1km	2m	Moderate	Low
Cabins	NPS ASMIS	10km	3m	High	High
Structures - isolated	DEVA	10km	5m	Moderate	Moderate
Structures - clustered	DEVA	10km	7m	High	High
Large mines	DEVA	10km	10m	High	High
Mormon Peak installation	DEVA	15km	10m	High	High
Paved roads	DEVA	15km	5m	High	High
Large clustered buildings	DEVA	30km	10m	Moderate	High
Open pits and Ryan, Briggs and Barrack Mines	DEVA	30km	5m	High	High
Rogers Peak installation	DEVA	30km	10m	High	High
Amargosa farming area	DEVA	30km	10m	Moderate	High

Processing

Viewshed analyses such as these are extremely costly in terms of computer processing time. Detailed analyses can take weeks, months or even years to process depending on the number of human features in the database. However, recent work by Washtell (2007) has shown that it is possible to both dramatically decrease the processing times required for GIS-based viewshed analyses and improve their overall accuracy, through judicious use of a voxel-based landscape model and a highly optimized ray-casting algorithm. The algorithm, which is similar to those used in real-time rendering applications and in some computer games, was designed to perform hundreds of traditional point viewshed operations per second. By incorporating this into a custom-built software tool which has been designed to work directly with GIS data (Figure 11), it is possible to estimate the visibility between every pair of cells in a high-resolution landscape model utilizing only moderate computing resources. This “viewshed transform” approach, which can be considered a maturation of traditional cumulative viewshed techniques (Carver et al., 2008), is used to:

- calculate the viewshed for every single feature,
- incorporate estimates of the proportional area of each feature that is visible; and
- run separate viewshed calculations for each of the different categories of features listed in Table 8 which can then be combined together to create the viewshed map.

An inverse square distance function is used in calculating the significance of visible cells. Put simply, the viewshed transform determines the relative viewshed value for each cell by calculating what proportion of the features can be seen and the distance between the cell and the particular features. Thus, the smaller the proportion of the feature in view and the further away it is, the lower the viewshed value for the particular cell. The greater the proportion of the feature in view and closer it is, the higher the viewshed value of the particular cell.

For this analysis certain compromises and customizations are necessary in order to make the task manageable. These include:

- The cell resolution in this instance was limited to 30m for all features;
- A "pessimistic" re-sampling was done to generate the 30m feature inputs in order to guarantee that features smaller than this area were included[9] with the result that the viewsheds produced may be viewed as a realistic representation of the visual impacts of the features present;
- The landscape was split into a number of overlapping tiles, such that they could be worked on in parallel by a cluster of desktop computers;
- The viewshed analysis was run for both 15km and 30km maximum viewshed distances. Features with a maximum viewshed distance listed as 15km or less in Table 8 are run in the 15km batch, with the 30km features in the latter batch. The smaller features with viewshed distance less than 15km are clipped to their respective pre-decided distances on completion of the analysis.

The two batched outputs are combined together using the MINIMUM function in ArcGIS to provide an overall viewshed grid for DEVA. The normalized viewshed data input needs to be inverted to reflect high degradation of solitude values near human features, and lower degradation further away from these features.

[9] Re-sampling of feature layers in GIS is normally carried out on a "majority class" basis wherein the value of a grid cell takes on the value of the largest feature by area that it contains. Using this rule, a 10x10m building in a 30x30m grid cell that was otherwise not classified as a feature, say shrubland, would not be recorded on re-sampling. The "pessimistic" re-sampling used here operates on presence/absence basis such that any grid cell containing a human feature will be classified as such even though the actual area or footprint of the feature may not cover the majority of the grid cell.

All human features identified for viewshed analysis (occurring both inside and outside the park boundary) are assigned viewshed distances and heights by the working group (Table 8). The heights for each feature type are entered into their respective attribute tables (create a new 'height' field in the attribute table for each feature and enter the assigned height values using the FIELD CALCULATOR tool). These features are then sorted into two categories, 15km and 30km, based on their maximum viewshed distance. The analysis is then run for these two distances separately. Within each run, up to four different categories of features can be analyzed. This allows specific features that have viewshed distances shorter than the maximum distance to be grouped together so that the output can be clipped to a shorter distance.

Prepping the 15km viewshed distance features

Clip the DEM to a mask of the park boundary buffered to 15km.

Step 1: Buffer the park boundary to 15km using the ANALYSIS TOOLS > PROXIMITY > BUFFER tool in the Arc Toolbox.

Step 2: Create a new field (e.g. Value) in the attribute table. Populate the field with the value "1" using the FIELD CALCULATOR tool.

Step 3: Convert the shapefile to a raster with the SPATIAL ANALYST > CONVERT > FEATURES TO RASTER tool, setting the field box to the "Value" field.

Step 4: In the RASTER CALCULATOR, multiply the DEM by the mask using the following equation:

OUTGRID = [DEM] * [15KM BOUNDARY MASK]

The height data for the 12 human features evaluated to the 15km viewshed distance need to be added to the DEM.

Step 5: Convert all the shapefiles to rasters with the SPATIAL ANALYST > CONVERT > FEATURES TO RASTER tool, setting the field box to the "Height" field.

Step 6: The human features need to be merged together in predetermined order so that where 2 or more features overlap the higher height value is retained. In the RASTER CALCULATOR, the following syntax applies:

OUTGRID = MERGE([LARGE MINES], [MORMON PEAK], [STRUCT CLUSTERED], [PAVED ROADS], [STRUCT ISOLATED], [SMALL INSTALL], [CABINS], [UTILITIES], [DIRT ROADS], [MINES], [DEBRIS], [FENCES])

Step 7: Add the above OUTGRID to the DEM in the RASTER CALCULATOR using the following equation:

OUTGRID = [DEM] + [ADDED FEATURES]

The features then need to sorted into four categories depending on their viewshed distances (as the majority of features need to be clipped down after the initial analysis to a viewshed distance of 1km and 10km respectively):

Category 1: Small installations, Mines, Utilities, Fences, Dirt roads, Debris
Category 2: Cabins, Structures – isolated & clustered, Large mines
Category 3: Mormon Peak installation
Category 4: Paved roads

Step 8: For categories 1 and 2, in the RASTER CALCULATOR, add the individual feature rasters together under the two categories with the following equations:

CAT1 = [SMALL INSTALL] + [MINES] + [UTILITIES] + [FENCES] + [DIRT ROADS] + [DEBRIS]
CAT2 = [CABINS] + [STRUCT ISOLATED] + [STRUCT CLUSTERED] + [LARGE MINES]

Step 9: Using the SPATIAL ANALYST > RECLASSIFY tool, change the reclass field of the added Category 1 raster to "Height", and reclass the values to 1. Repeat this process for the other three categories labeling them 2 through 4.

Prepping the 30km viewshed distance features
Clip the DEM to a mask of the park boundary buffered to 30km.

Step 1: Buffer the park boundary to 30km using the ANALYSIS TOOLS > PROXIMITY > BUFFER tool in the Arc Toolbox.

Step 2: Create a new field (e.g. Value) in the attribute table. Populate the field with the value "1" using the FIELD CALCULATOR tool.

Step 3: Convert the shapefile to a raster with the SPATIAL ANALYST > CONVERT > FEATURES TO RASTER tool, setting the field box to the "Value" field.

Step 4: In the RASTER CALCULATOR, multiply the DEM by the mask using the following equation:

OUTGRID = [DEM] * [30KM BOUNDARY MASK]

The height data for the four human features evaluated to the 30km viewshed distance need to be added to the DEM.

Step 5: Convert all the shapefiles to rasters with the SPATIAL ANALYST > CONVERT > FEATURES TO RASTER tool, setting the field box to the "Height" field.

Step 6: The human features need to be merged together in predetermined order so that where 2 or more features overlap the higher height value is retained. In the RASTER CALCULATOR, the following syntax applies:

OUTGRID = MERGE([LARGE CLUST BUILD], [OPEN PITS & MINES], [ROGERS PEAK], [AMARGOSA FARMS]

Step 7: Add the above outgrid to the DEM in the RASTER CALCULATOR using the following equation:

OUTGRID = [DEM] + [ADDED FEATURES]

As there are only four features for this viewshed distance analysis the features can be assigned to their own category:

Category 1: Large clustered buildings
Category 2: Open pits and Ryan, Briggs and Barrack Mines
Category 3: Rogers Peak installation
Category 4: Amargosa farming area

Step 8: Using the SPATIAL ANALYST > RECLASSIFY tool, change the reclass field of the added Category 1 raster to "Height", and reclass the values to 1. Repeat this process for the other three categories labeling them 2 through 4.

Running the viewshed analysis

Step 1: Convert the DEM and feature raster data into .flt using the CONVERSION TOOLS > FROM RASTER > RASTER TO FLOAT tool.

Step 2: Open the .hdr file for the DEM and remove the decimal place and numbers after it for the xllcorner and yllcorner values

Step 3: Load the feature data into the resample tool, enter the number of <u>columns</u> (this value is found in the .hdr file) into the ROW CELLS box. Click DISCRETIZE to generate the .int file.

Step 4: Load the DEM and feature data into the viewshed tool. The tiling tool screen will appear – set the desired number of horizontal and vertical tiles (use smaller tiles for PC's with lower amounts of memory and processing speed). For the 15km viewshed run, set the overlap slider to 500 cells (500 * 30m resolution of the raster equals 15km). Then in the main viewshed screen click 'Do Transform'.

Repeat the same steps for the 30km DEM and features but set the overlap for this run to 1000 cells (or a number slightly lower if 1000 isn't selectable on the slider).

Interpreting the output

The model generates .dat files for each feature layer assessed (i.e. 0 – 4), these need to be normalized against the 'no feature' layer (feature 0).

Step 1: Using the normalization tool, check the LOGARITHMIC OUTPUT box, click 'NORMALISE A VIEWSHED DATASET' and navigate to one of the viewshed output tiles. Repeat this step for the remaining tiles.

Note: As the invert box was left unchecked, low values = high visibility of features, high values = low visibility of features and NoData = non visibility.

Step 2: Each feature layer needs to be converted to raster format using the CONVERSION TOOLS > TO RASTER > FLOAT TO RASTER tool in the Arc Toolbox (batch runs can done for all the feature files by right clicking the tool).

Step 3: Use the MERGE map algebra command in the RASTER CALCULATOR to add the tiles together for each category of features using the following syntax:

OUTGRID1 = MERGE([CAT1 TILE1], [CAT1 TILE2], [CAT1 TILE3], etc.)
OUTGRID2 = MERGE([CAT2 TILE1], [CAT2 TILE2], [CAT2 TILE3], etc.)
OUTGRID3 = MERGE([CAT3 TILE1], [CAT3 TILE2], [CAT3 TILE3], etc.)
OUTGRID4 = MERGE([CAT4 TILE1], [CAT4 TILE2], [CAT4 TILE3], etc.)

Step 4: The viewshed output for the first two categories in the 15km analysis (see the "prepping the 15km viewshed distance features" section) needs to be clipped to their respective smaller viewed distances[10]. Buffer the features in category 1 and 2 by 1km and 10km respectively. Create a new field (e.g. Value) in the attribute table for both shapefiles and populate the field with the value "1" using the FIELD CALCULATOR tool. Convert the shapefiles to rasters with the SPATIAL ANALYST > CONVERT > FEATURES TO RASTER tool, setting the field box to the "Value" field. Then multiply categories 1 and 2 by their respective masks in the RASTER CALCULATOR using the following equations:

OUTGRID1 = [CAT1 FEATURES] * [1KM BUFF MASK]
OUTGRID2 = [CAT2 FEATURES] * [10KM BUFF MASK]

Based on the assumption of maximum visibility, a MIN calculation can be applied to combine the merged categories. To allow these categories to be combined, the NoData values in each raster category layer (indicating non visibility of that feature) need to be removed to prevent propagation of the NoData values into the final combined viewshed layer.

Step 5: An artificially high value of 9999 is assigned to NoData values in each merged raster category so any overlapping cells where another feature is visible are assigned this value over the 9999 data value when applying the MIN calculation. The following expression can be used in the RASTER CLACULATOR for each raster category layer (1-4) as follows:

OUTGRID = CON(ISNULL([CAT1]), 9999, [CAT1])

Step 6: The MIN calculation can then be applied in the RASTER CALCULATOR using the outputs generated from the expression above:

OUTGRID = MIN([CAT1],[CAT2],[CAT3],[CAT4])

Step 7: After applying the MIN calculation, any remaining areas of 9999 represent areas where none of the input features are visible. These can then be set back to NoData to allow the

[10] This action is only necessary for the 15km features

extent of these areas to assessed in relation to the rest of the park. The following expression in the RASTER CLACULATOR applies:

OUTGRID = SETNULL([MINCALC] = = 9999, [MINCALC])

Step 8: In order for the visibility layer to be standardized on a 1-256 scale, any areas of NoData must be assigned a valid value within the range of existing values. As the high values represent low visibility of features, the current maximum value can be established from the output using the SETNULL expression. A new maximum value (x)[11] can then be assigned to the NoData areas to represent non visibility as follows:

OUTGRID = CON(ISNULL[GRID], x, [GRID])

The final step is to clip the visibility raster to the park boundary

Step 9: For the park boundary polygon, create a new field (e.g. Value) in the attribute table. Populate the field with the value "1" using the FIELD CALCULATOR tool.

Step 10: Convert the shapefile to a raster with the SPATIAL ANALYST > CONVERT > FEATURES TO RASTER tool, setting the field box to the "Value" field.

Step 11: In the RASTER CALCULATOR, multiply the visibility raster by the mask using the following equation:

OUTGRID = [15KM VIS] * [BOUNDARY MASK]

After completing the 15km run, repeat the same steps for the 30km features, but setting the DEM mask to 30km.

Combining the two viewshed grids together

Step 1: The two viewshed outputs are then combined together using the MIN calculation, expressed in the following equation:

OUTGRID = MIN([15KM GRID], [30KM GRID])

Step 2: Standardize the grid using the SPATIAL ANALYST TOOLS > RECLASS > SLICE function set to equal interval standardization, 256 output zones and a base zone of 1.

Step 3: The final task is to invert the values in the RASTER CALCULATOR using the following equation:

OUTGRID = ([GRID] – 256) * -1

Step 4: Re-perform the standardization in Step 2 as the value range in the grid after the inversion will be 0 – 255.

[11] In the current study the maximum value was 21.5 so a new maximum value of 22 was used

Cautions
Categorizing the human features in DEVA into specific viewshed distances requires careful consideration to how well each type of feature blends into the desert background. For example, the majority of utility lines in DEVA are largely unnoticeable from close distances, because they are difficult to pick out against a desert backdrop, and are assigned a maximum viewshed distance of 1km. Isolated and clustered structures, which have larger surface areas, stand out when viewed against a desert backdrop and are assigned a maximum viewshed distance of 10km.

Depending on the angle of view, an unpaved road in the backcountry can be largely unnoticeable from a distance as close as 50m. However, if a vehicle is on the road and is creating a dust plume, the road quickly becomes apparent. Thus, this particular feature is calibrated negatively at a height of 2m in anticipation of traffic on the road.

Another issue that exists in a modeling context is the realistic representation of re-sampled feature inputs in the viewshed analysis. The utility lines in the model are represented as a solid 5m high “wall”, where in reality these features are only consist of poles and powerlines. These are limitations of the model and should be considered when analyzing the viewshed results.

<u>4.1.3 Over-flights</u>

Sources
This data input is a composite of three data sources. The first is polyline data depicting proposed air tour routes from the draft Air Tour Management Plan – heads-up digitized by Charlie Callagan using the DEVA road data (the proposed routes will follow the road network on the eastern side of the park). The second is polygon data depicting several existing airstrips inside of DEVA – heads-up digitized using NAIP imagery. The final data source depicts the impact of military over-flights occurring over DEVA (the park is near several major military installations). The Air Force and Navy both use the airspace above and near the park for training exercises. However, the airspace to the west of the old monument boundary has a significantly lower legal “flight floor”; therefore, the western side of the current park boundary experiences a greater impact on solitude from military over-flights, due to the aircraft flying at lower altitudes over this area. The western side of the park, which falls outside the old monument boundary, is used as the area to depict the impact of this lower, more audible and visible air traffic.

Processing
The proposed air tour routes are buffered by 2km to represent the visual and noise impact of this air traffic. The airstrips are buffered in the style of commercial runway noise maps to represent the visual and noise impacts of aircraft landing and taking off. The military over-flights polygon is buffered twice, by 1km and 4km respectively, to represent less impact further away from this area. The proposed air tour routes are given a value of 1 as the routes are correlated to the road network in DEVA, which makes their noise and visual impact less noticeable. The impact of the airstrips is more localized and flights landing and taking off are less frequent, so this data is given a value of 3. Military over-flights are given a value of 10 because they have the highest noise impact and are most frequent. The buffer zones of reduced values (9 for the 1km buffer and 6 for the 4km buffer) signify less impact further away from the over-flight area. These three datasets are then added together to create the over-flights data input.

Step 1: The proposed air tour routes are buffered by 2km using the ANALYSIS TOOLS > PROXIMITY > BUFFER tool in the Arc Toolbox. Then, create a new field (e.g. Value) in the attribute table and populate the field with the value "1" using the FIELD CALCULATOR tool.

Step 2: The airstrips are buffered manually in the style of commercial runway noise maps using the EDITOR toolbar. Then, create a new field (e.g. Value) in the attribute table and populate the field with the value "3" using the FIELD CALCULATOR tool.

Step 3: The lower military flights only occur in the western side of the park. Use the EDITOR tools to align the eastern monument boundary with the existing DEVA boundary. Using a copy of a DEVA boundary shapefile, use the ANALYSIS > OVERLAY > ERASE tool in the Arc Toolbox to erase the edited old park boundary from the current boundary. Then, buffer the remaining area by 1km using the ANALYSIS TOOLS > PROXIMITY > BUFFER tool in the Arc Toolbox. Buffer the 1km buffer 4km using the same tool. Then, create a new field (e.g. Value) in the attribute table and populate the field with the value "10" for initial area, "9" for the 1km buffer and "6" for the 4km buffer using the FIELD CALCULATOR tool.

Step 4: Convert the three shapefiles to rasters with the SPATIAL ANALYST > CONVERT > FEATURES TO RASTER tool, setting the field box to the "Value" field.

Step 5: Combine the three rasters together using the MERGE map algebra command in the RASTER CALCULATOR; the following syntax applies:

OUTGRID = MERGE([OVERFLIGHTS], [AIRSTRIPS], [AIRTOURS])

Step 6: Change the NoData values in the grid to 0 using the RECLASSIFY tool found in the SPATIAL ANALYST toolbar.

Step 7: Standardize the grid using the SPATIAL ANALYST TOOLS > RECLASS > SLICE function set to equal interval standardization, 256 output zones and a base zone of 1.

C*autions*

This data input represents temporal impacts to solitude and assumes a worst case scenario.

4.1.4 Soundscape

Sources

Raster datasets provided by the NPS Natural Sounds Program. These data are collected through strategically selected measurement sites to collect acoustic data to maximize generalizing that data for the entire park. Computer modeling is used to estimate and then logarithmically add the contributing effects of other mechanical sound sources, such as roads, to the measured ambient sound to create "combined" ambient sound. Road sound sources are estimated based on data gathered from Federal Highway Administration (FHWA) sources and represent traffic that would occur on an average day during the peak summer visitation month.

Processing
The "natural measured sound" raster was subtracted from the "existing combined sound" raster to produce a raster depicting non-natural sound.

Step 1: In the RASTER CALCULATOR, subtract the Nat_L50(measured layer) from the Exist_L50(combined layer) using the following equation:

OUTGRID = [EXIST_L50] – [NAT_L50]

Step 2: Standardize the grid using the SPATIAL ANALYST TOOLS > RECLASS > SLICE function set to equal interval standardization, 256 output zones and a base zone of 1.

Cautions
The Natural Sounds Program data is produced for the entire park using certain estimations for natural measured (ambient) sound based on a small number of sampling points and a very limited sampling period. This data input represents temporal impacts to solitude and assumes a worst case scenario.

4.1.5 Dark sky index (Night sky)

Sources
Raster dataset created by Dan Duriscoe, NPS Night Sky Team. The grid is a spline surface model interpolated from 13 observation points.

Processing
Step 1: Re-project raster to NAD 1983 UTM Zone 11N coordinate system using the DATA MANAGEMENT TOOLS > PROJECTIONS AND TRANSFORMATIONS > RASTER > PROJECT RASTER tool in the Arc Toolbox.

Step 2: In the RASTER CALCULATOR, clip the night sky grid to the DEVA boundary mask using the following equation:

OUTGRID = [NIGHT SKY GRID] * [MASK]

Step 3: Standardize the grid using the SPATIAL ANALYST TOOLS > RECLASS > SLICE function set to equal interval standardization, 256 output zones and a base zone of 1.

Cautions
This data input represents temporal impacts to solitude which are only noticeable at night.

4.1.6 Visibility (Air quality)

Sources
Raster dataset from NPS Air Resource Program.

Processing
The air quality datasets are received in a text document as 2D arrays.

Step 1: Open text file array in Excel, and choose delimit with comma.

Step 2: Copy value, lat and long figures into separate worksheets using paste special/transpose.

Step 3: Run a macro program to stack the columns in each worksheet (code for "stacking" data can be found in Appendix C). Add all the data alongside each other in a new worksheet.

Step 4: Open worksheet in ArcGIS and use TOOLS > ADD XY DATA to create a point shapefile for the data (using "North America Datum 1983" projection).

Step 5: Set data frame projection to "USA Contiguous Albers Equal Area Conic USGS". In Arc Tool Box, use the CONVERSION TOOLS > TO RASTER > POINT TO RASTER tool to create a grid from the shapefile with the cell size set to 12075.

Step 6: In Arc Tool Box, use the DATA MANAGEMENT TOOLS > PROJECTIONS AND TRANSFORMATIONS > RASTER > PROJECT RASTER tool to reproject the grid to NAD 1983 UTM Zone 11N choosing BILINEAR as the resampling technique.

Step 7: In the RASTER CALCULATOR, clip the air quality grid to the DEVA boundary mask using the following equation:

OUTGRID = [AIR QUALITY GRID] * [MASK]

Step 8: Standardize the grid using the SPATIAL ANALYST TOOLS > RECLASS > SLICE function set to equal interval standardization, 256 output zones and a base zone of 1.

Cautions
None.

4.1.7 Trails

Sources
Polyline dataset created by Leah Bonstead, DEVA Archaeologist, from topographic maps, aerial photographs and GPS tracks. Three types of trails were recorded: route – a cross country path with no signage, informal trail – a use-worn path but not designated as a trail by park management, and formal trail – a managed trail with interpretation. Each trail type will experience different levels of impacts on opportunities for a wilderness experience through visitor encounters and the degradation of self-sufficiency in wilderness.

Processing
The different trails types are processed according to their perceived impact by park staff on visitors seeking opportunities for a wilderness experience (through potential visitor encounters and the trails themselves degrading a true wilderness experience). Routes are given a value of 1, informal trails a value of 2 and formal trails a value of 4.

Step 1: Create a new field (e.g. Value) in the attribute table. Select all routes under the "Type" column using the SELECT BY ATTRIBUTES tool from the options tab in the attribute table with the following expression: *"Type" = 'Route'*. Use the FIELD CALCULATOR to set the value for this selection to "1". Repeat for the "informal trails" and "formal trails" using the values "2" and "4" respectively.

Use the Conversion/Slice tool to convert the shapefile to a data input, or perform the remaining steps.

Step 2: Convert the shapefile to a raster with the SPATIAL ANALYST > CONVERT > FEATURES TO RASTER tool, setting the field box to the "Value" field. Change the NoData values in the grid to 0 using the RECLASSIFY tool found in the SPATIAL ANALYST toolbar.

Step 3: Standardize the grid using the SPATIAL ANALYST TOOLS > RECLASS > SLICE function set to equal interval standardization, 256 output zones and a base zone of 1.

Cautions
None.

4.1.8 Visitor facilities

Sources
Polygon datasets created by Leah Bonstead, DEVA Archaeologist, from aerial photographs. Three types of existing visitor facilities were recorded: designated campsites, backcountry campsites, and campsites in wilderness. Each type of visitor facility will experience different levels of use and associated impacts to surrounding area (presence of litter and human feces, evidence of fire collection).

Processing
The different types of visitor facilities are processed according to their perceived impact by park staff on visitors seeking opportunities for a wilderness experience (through other visitor impacts and potential encounters, and the facilities themselves degrading a true wilderness experience). Designated and backcountry campsites were buffered by 500m and wilderness campsites by 100m. All sites are given a value of 1.

Step 1: Two shapefiles were provided: designated campsites and backcountry/wilderness campsites. Query the latter layer using the SELECT BY ATTRIBUTES tool from the options tab in the attribute table with the following expression: *"Type" = 'Backcountry campsites'*. Save the selection to a new shapefile. Then use SWITCH SELECTION in the options tab of the attribute table and save selection to a new shapefile.

Step 2: In Arc Toolbox, use the ANALYSIS TOOLS > PROXIMITY > BUFFER tool to buffer the designated and backcountry campsites by 500m and the wilderness campsites by 100m.

Step 3: Create a new field (e.g. Value) in the attribute table for each shapefile. Populate the fields with the value "1" using the FIELD CALCULATOR tool.

Step 4: Convert the shapefiles to a raster with the SPATIAL ANALYST > CONVERT > FEATURES TO RASTER tool, setting the field box to the "Value" field. Change the NoData values in the grid to 0 using the RECLASSIFY tool found in the SPATIAL ANALYST toolbar.

Step 5: In the RASTER CALCULATOR, add the three campsite rasters together using the following equation:

OUTGRID = [DESIGNATED] + [BACKCOUNTRY] + [WILDERNESS]

Step 6: Standardize the grid using the SPATIAL ANALYST TOOLS > RECLASS > SLICE function set to equal interval standardization, 256 output zones and a base zone of 1.

Cautions
All designated and backcountry campsites in DEVA are placed in the frontcountry or backcountry lands, not in wilderness. However, their proximity to wilderness may affect a visitor seeking a wilderness experience.

<u>4.1.9 Camping restrictions</u>

Sources
A polygon dataset derived from the DEVA road network and information from Charlie Callagan, DEVA Wilderness Coordinator. Camping is restricted in areas within 2 miles of all paved roads in DEVA. Additionally, specific areas such as the Valley floor, the Racetrack and Saratoga Spring are included as no camping zones. These specific areas were heads-up digitized using NAIP imagery.

Processing
Step 1: Query the roads shapefile for all paved roads using the SELECT BY ATTRIBUTES tool from the options tab in the attribute table with the following expression: *"Type" = 'Paved roads'*. Add the following road segments to the selection using the SELECT FEATURES tool:

i) Titus Canyon road
ii) Teakettle Junction to bottom of racetrack road
iii) West Side road
iv) Skidoo (townsite) road
v) Aguereberry point road
vi) Keane Wonder Mine road
vii) Marble Canyon/Cottonwood Canyon access road

Step 2: In Arc Toolbox, use the ANALYSIS TOOLS > PROXIMITY > BUFFER tool to buffer the selected roads 2 miles.

Step 3: Copy/paste the additional digitized zones identified by Charlie Callagan (Valley floor, Racetrack playa and Saratoga Spring) to the buffered roads layer.

Step 4: Create a new field (e.g. Value) in the attribute table. Populate the field with the value "1" using the FIELD CALCULATOR tool.

Use the Conversion/Slice tool to convert the shapefile to a data input, or perform the remaining steps.

Step 5: Convert the shapefile to a raster with the SPATIAL ANALYST > CONVERT > FEATURES TO RASTER tool, setting the field box to the "Value" field. Change the NoData values in the grid to 0 using the RECLASSIFY tool found in the SPATIAL ANALYST toolbar.

Step 6: Standardize the grid using the SPATIAL ANALYST TOOLS > RECLASS > SLICE function set to equal interval standardization, 256 output zones and a base zone of 1.

Cautions
The camping restrictions won't impact on a visitor seeking a wilderness during the day, but the knowledge that these areas can't be camped in during the night represents a loss of unconfined recreation.

4.1.10 Closed to visitor use

Sources
Polygon data created by Charlie Callagan, DEVA Wilderness Coordinator.

Processing
Step 1: Create a new field (e.g. Value) in the attribute table. Populate the field with the value "1" using the FIELD CALCULATOR tool.

Use the Conversion/Slice tool to convert the shapefile to a data input, or perform the remaining steps.

Step 2: Convert the shapefile to a raster with the SPATIAL ANALYST > CONVERT > FEATURES TO RASTER tool, setting the field box to the "Value" field. Change the NoData values in the grid to 0 using the RECLASSIFY tool found in the SPATIAL ANALYST toolbar.

Step 3: Standardize the grid using the SPATIAL ANALYST TOOLS > RECLASS > SLICE function set to equal interval standardization, 256 output zones and a base zone of 1.

Cautions
None.

4.2 Weights

The data inputs under each indicator are added together using a weighting regime decided by the DEVA staff (Table 9). These weights reflect the importance of a data input in relation to the others under a particular indicator. The "weighted" data inputs under each indicator total 100.

In the Arc toolbox, use the SPATIAL ANALYST TOOLS > OVERLAY > WEIGHTED SUM tool to add the data inputs together for each indicator using the weights found in Table 9.

Standardize the indicator grids using the SPATIAL ANALYST TOOLS > RECLASS > SLICE function set to equal interval standardization, 256 output zones and a base zone of 1.

Table 9 Indicators and data inputs for the solitude or primitive and unconfined quality with weights and rationale

Indicator	Input	Weight	Rationale
Remoteness from sights and sounds of people inside the wilderness	Travel time sub-model	70	Remoteness is highlighted in the General Management Plan as a park value to be preserved
	Viewshed sub-model	30	Scenic quality is mentioned in General Management Plan as a park value to be preserved
Remoteness from occupied and modified areas outside the wilderness	Over-flights	25	Issue of concern identified by the public during public scoping for the DEVA Wilderness Plan
	Soundscape	20	Issue of concern identified by the public during public scoping for the DEVA Wilderness Plan
	Night sky – dark sky index	35	Important resource identified in the GMP as a park value to be preserved
	Visibility (Air quality)	20	As a component of scenic vistas, this is a park value identified in the GMP to be preserved
Facilities that decrease self-reliant recreation	Trails	20	Less influential on self-reliance
	Visitor facilities	80	More influential on self-reliance
Management restrictions on visitor behavior	Camping restrictions	20	Less impact on visitor use
	Closed to visitor use	80	High impact on visitor use
		400	

4.3 Solitude or primitive and unconfined quality map

To create the solitude or primitive and unconfined quality map (Figure 4), the 4 indicators are added together in the RASTER CALCULATOR using the following equation:

OUTGRID = [INDICATOR1] + [INDICATOR2] + [INDICATOR3] + [INDICATOR4]

Standardize the grid using the SPATIAL ANALYST TOOLS > RECLASS > SLICE function set to equal interval standardization, 256 output zones and a base zone of 1.

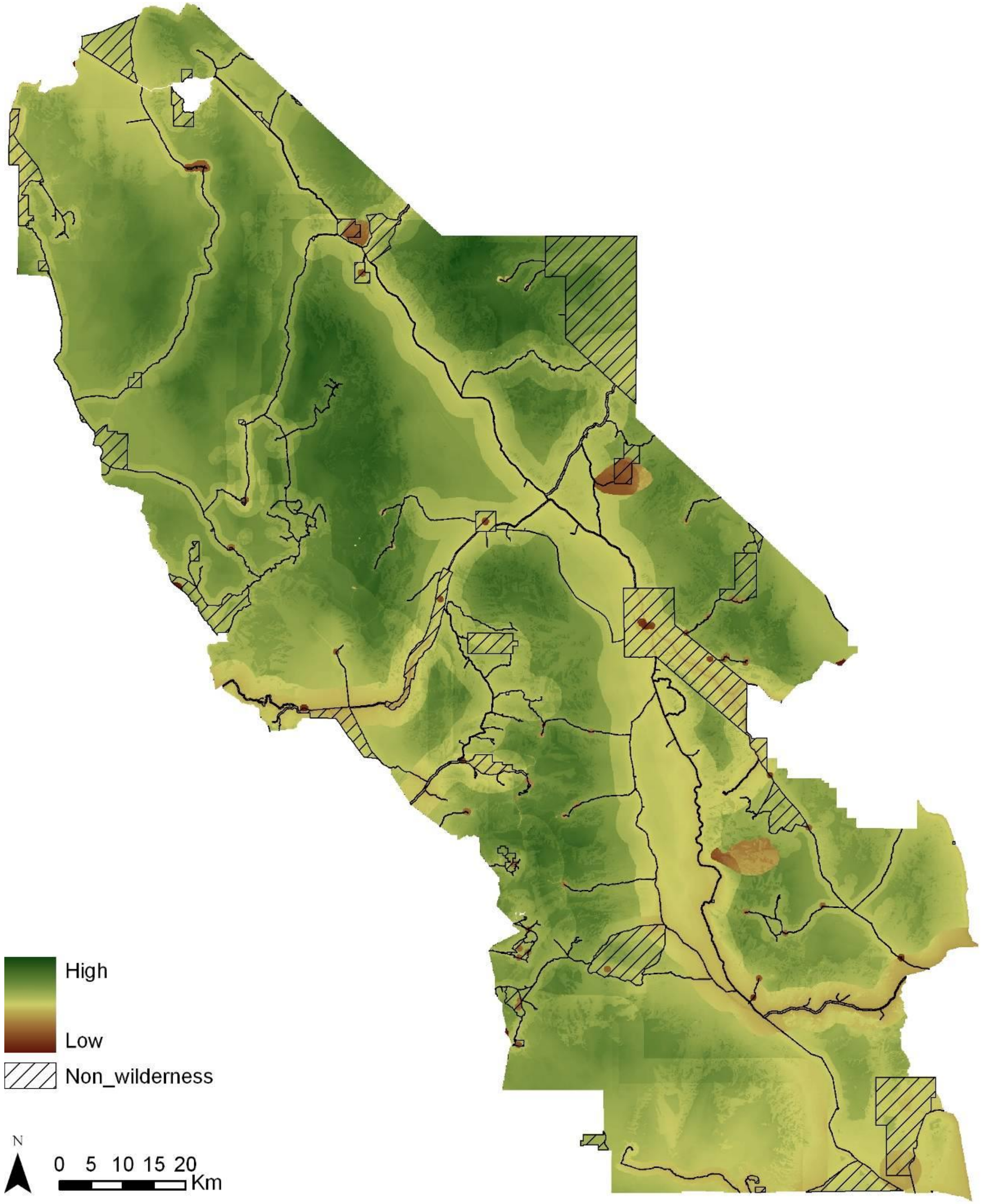

Figure 4 Solitude or primitive and unconfined quality of wilderness character

5. THE WILDERNESS QUALITY MAP

The methodology described in the previous four sections produces four maps, one for each of the qualities of wilderness character. In order to combine these four maps into a single map of wilderness character, each of the individual quality maps have been standardized to common scale, whereby their values differentiate between areas of high and low wilderness character (Figure 5). These maps are then combined to provide a single map of overall wilderness character quality in DEVA. Because all four qualities are equally important and none is held in higher or lower regard than others, the four qualities are added together equally. It is then necessary to clip out the non-wilderness areas of DEVA (as the analysis was run for the entire park) when presenting the maps (Figure 6).

Step 1: Add the four quality maps together in the RASTER CALCULATOR using the following equation:

OUTGRID = [NAT] + [UNTRAM] + [UNDEV] + [SOL]

Step 2: Create a new field (e.g. Value) in the attribute table of the wilderness boundary shapefile. Populate the field with the value "1" using the FIELD CALCULATOR tool.

Step 3: Convert the shapefile to a raster with the SPATIAL ANALYST > CONVERT > FEATURES TO RASTER tool, setting the field box to the "Value" field.

Step 4: Multiply the wilderness map by the boundary mask in the RASTER CALCULATOR using the following equation:

OUTGRID = [WILD MAP] * [WILD MASK]

Step 5: Standardize the grid using the SPATIAL ANALYST TOOLS > RECLASS > SLICE function set to equal interval standardization, 256 output zones and a base zone of 1.

To display the values of this map in ten equal categories (Figure 7), click the CLASSIFY option using the SPATIAL ANALYST toolbar > RECLASSIFY tool, and in the classification box set method to "equal interval" and classes to "10".

Lastly, to achieve a true visual reflection of the values in the quality and wilderness grids when using a color ramp, it is advisable to display the grids using the MINIMUM – MAXIMUM stretch in LAYER PROPERTIES > SYMBOLOGY.

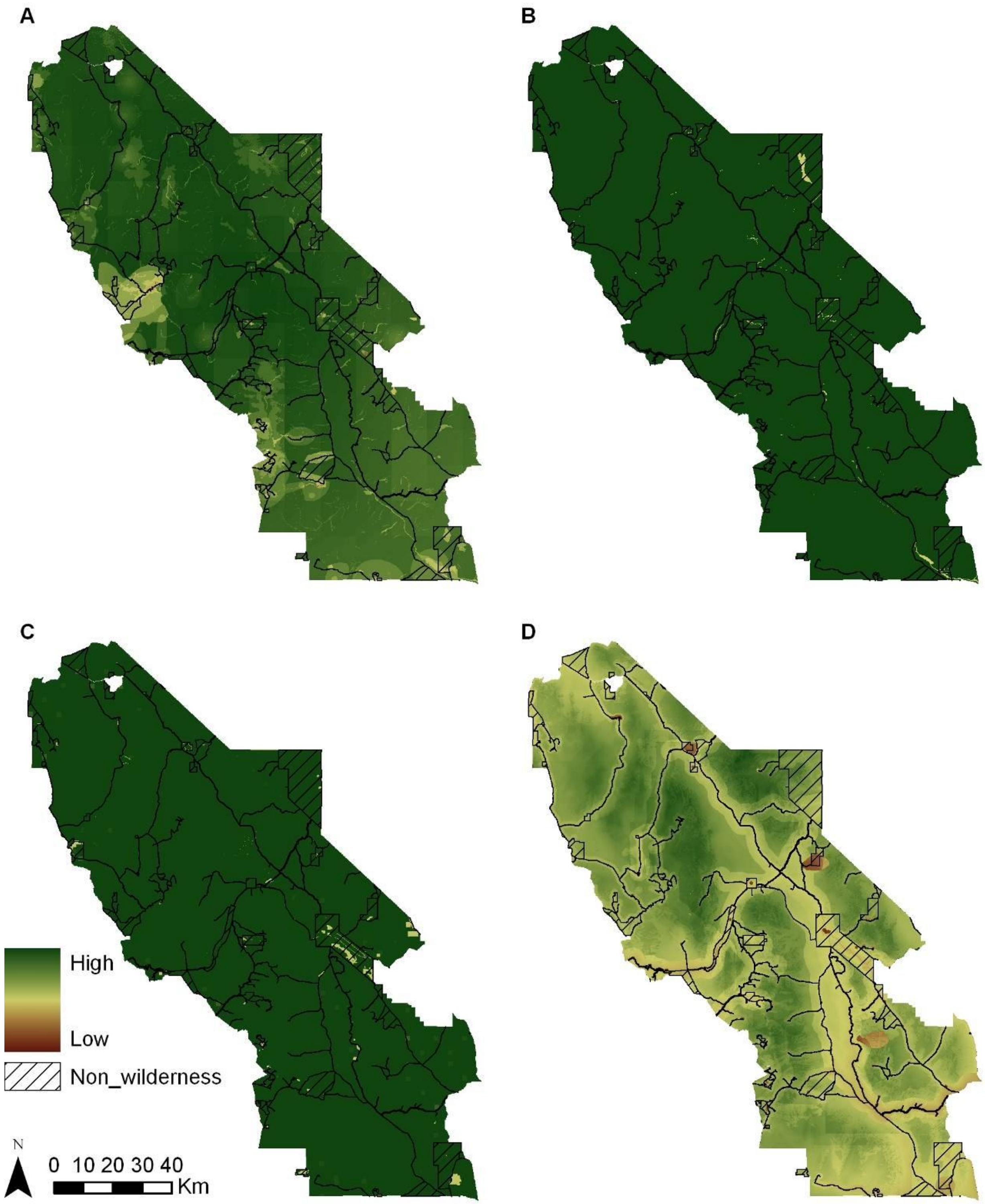

Figure 5 Four qualities of wilderness character (A) natural, (B) untrammeled, (C) undeveloped, and (D) solitude or primitive and unconfined

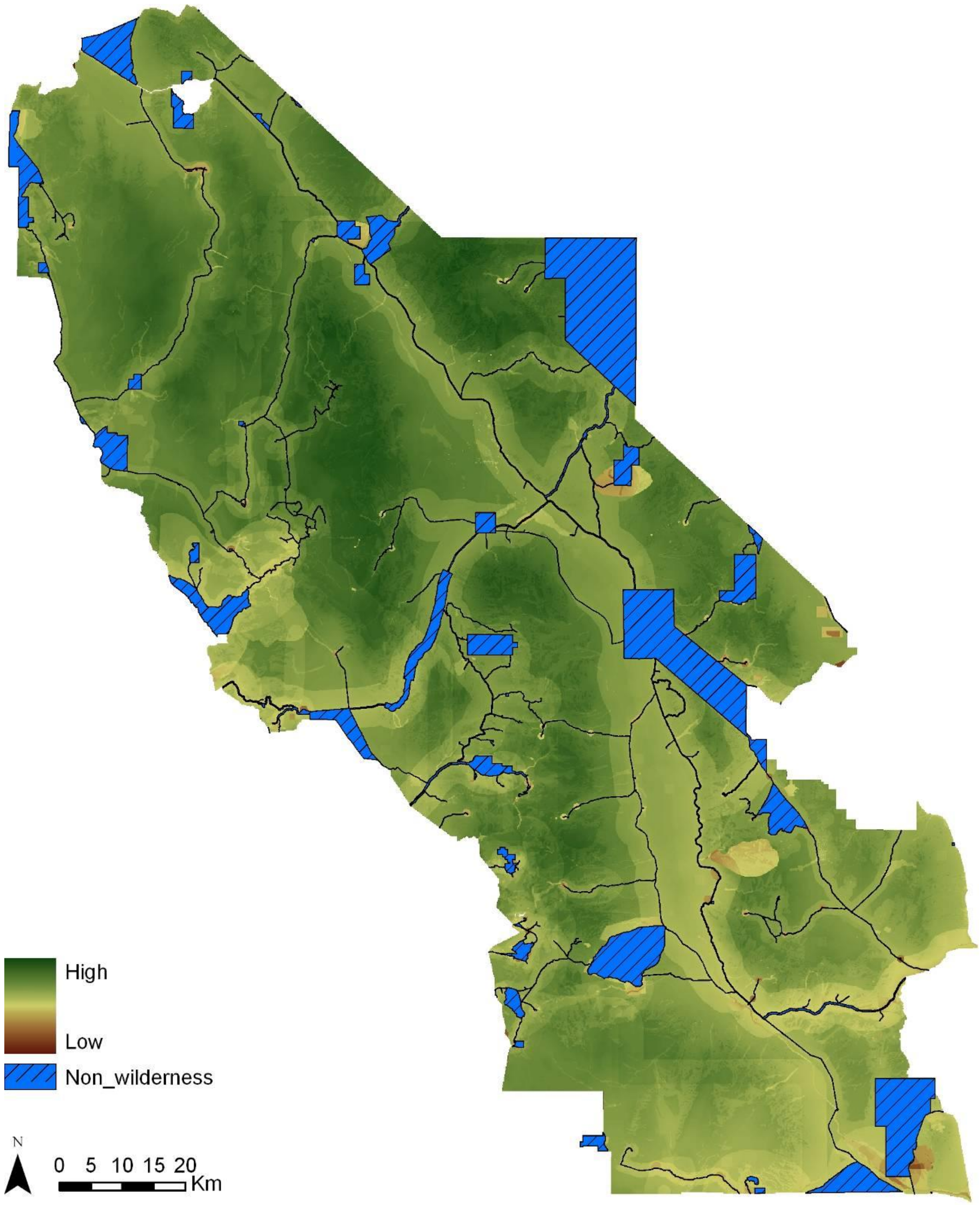

Figure 6 Map of wilderness character in DEVA

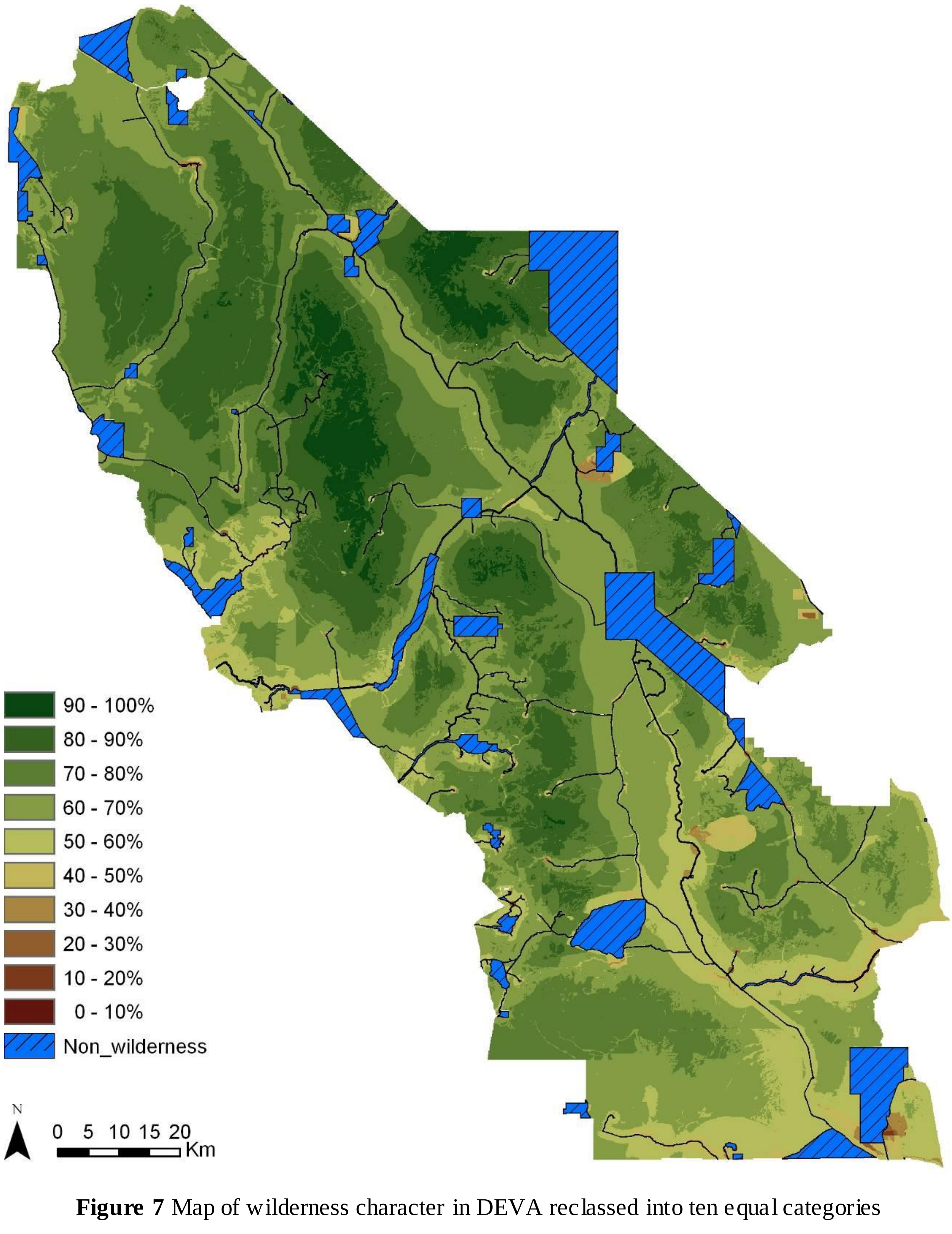

Figure 7 Map of wilderness character in DEVA reclassed into ten equal categories

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APPENDIX A – Deviation from natural condition and travel impedance for vegetation classes

The condition column ranks the vegetation classes on a scale of 1-5 according to their deviation from natural condition (1 = least natural, 5 = natural). The impedance column ranks the vegetation classes on a scale of 1-5 according to their perceived impedance when "walking" through the landscape (1 = easy, 5 = difficult).

Habitat - Central Mojave Mapping Project	**Condition**	**Justification**	**Impedance**
Mining	1	Highly altered landscape	4
Rural Development	1	Highly altered landscape	1
Urban	1	Highly altered landscape	1
Agricultural Land Use	2	Altered landscape	2
Mesquite Shrublands	4	Manipulated by traditional use	4
Pinyon Woodlands and Shrublands	4	Manipulated by traditional use	3
Big Sagebrush Shrubland	5	Unmanipulated and unaltered	1
Blackbrush Shrubland	5	Unmanipulated and unaltered	2
Creosote Bush Shrubland	5	Unmanipulated and unaltered	2
Creosote Bush/Brittlebush Mosaic	5	Unmanipulated and unaltered	2
Desert Holly Shrubland	5	Unmanipulated and unaltered	1
Dunes	5	Unmanipulated and unaltered	5
Galleta Grasslands	5	Unmanipulated and unaltered	1
High Elevation Pine Woodlands	5	Unmanipulated and unaltered	3
High Elevation Wash System	4	Corridor frequently used for human foot travel, some impacts	1
Hopsage Shrubland	5	Unmanipulated and unaltered	1
Iodine Bush-Bush Seepweed Complex	5	Unmanipulated and unaltered	2
Joshua Tree Wooded Shrubland	5	Unmanipulated and unaltered	2
Juniper Wooded Shrubland	5	Unmanipulated and unaltered	3
Lava Beds and Cinder Cones	5	Unmanipulated and unaltered	5
Low Elevation Wash System	4	Corridor frequently used for human foot travel, some impacts	1
Menodora Shrubland	5	Unmanipulated and unaltered	1
Mid Elevation Wash System	4	Corridor frequently used for human foot travel, some impacts	1
Mojave Yucca Shrubland	5	Unmanipulated and unaltered	1
Nevada Joint-fir Shrubland	5	Unmanipulated and unaltered	2
Playa	5	Unmanipulated and unaltered	1
Shadscale Shrubland	5	Unmanipulated and unaltered	1
Saltgrass	5	Unmanipulated and unaltered	1
Shadscale Shrubland	5	Unmanipulated and unaltered	1
Sparsely Vegetated	5	Unmanipulated and unaltered	1
White Burrobush Shrubland	5	Unmanipulated and unaltered	1
Habitat - USGS NVCS			
Developed-Open Space	2	Altered landscape	1
Developed-High Intensity	1	Highly altered landscape	2
Developed-Medium Intensity	1	Highly altered landscape	1
Agriculture-Cultivated Crops and Irrigated Agriculture	2	Altered landscape	3
Developed-Low Intensity	2	Altered landscape	1
Agriculture - Pasture/Hay	2	Altered landscape	2
Sierra Nevada Subalpine Lodgepole Pine Forest and Woodland	5	Unmanipulated and unaltered	2
Introduced Riparian Vegetation	3	Unnatural veg type, but still has	2

		some natural habitat value	
Introduced Upland Vegetation-Annual Grassland	3	Unnatural veg type, but still has some natural habitat value	1
Introduced Upland Vegetation-Perennial Grassland and Forbland	3	Unnatural veg type, but still has some natural habitat value	1
Introduced Upland Vegetation-Annual and Biennial Forbland	3	Unnatural veg type, but still has some natural habitat value	1
Rocky Mountain Aspen Forest and Woodland	5	Unmanipulated and unaltered	2
Great Basin Pinyon-Juniper Woodland	4	Manipulated by traditional use	2
Inter-Mountain Basins Subalpine Limber-Bristlecone Pine Woodland	5	Unmanipulated and unaltered	2
California montane Jeffery Pine (Ponderosa Pine) woodland	5	Unmanipulated and unaltered	2
Southern Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest and Woodland	5	Unmanipulated and unaltered	2
Southern Rocky Mountain Mesic Montane Mixed Conifer Forest and Woodland	5	Unmanipulated and unaltered	2
Southern Rocky Mountain Ponderosa Pine Woodland	5	Unmanipulated and unaltered	2
Rocky Mountain Subalpine-Montane Limber-Bristlecone Pine Woodland	5	Unmanipulated and unaltered	2
Inter-Mountain Basins Curl-leaf Mountain Mahogany Woodland and Shrubland	5	Unmanipulated and unaltered	2
Inter-Mountain Basins Greasewood Flat	5	Unmanipulated and unaltered	2
Inter-Mountain Basins Montane Riparian Systems	4	Corridor frequently used for human foot travel, some impacts	3
North American Warm Desert Riparian Systems	4	Corridor frequently used for human foot travel, some impacts	3
Rocky Mountain Montane Riparian Systems	4	Corridor frequently used for human foot travel, some impacts	3
Open Water	5	Unmanipulated and unaltered	barrier
Barren	5	Unmanipulated and unaltered	1
Inter-Mountain Basins Sparsely Vegetated Systems	5	Unmanipulated and unaltered	1
North American Warm Desert Sparsely Vegetated Systems	5	Unmanipulated and unaltered	1
Rocky Mountain Alpine/Montane Sparsely Vegetated Systems	5	Unmanipulated and unaltered	1
Great Basin Xeric Mixed Sagebrush Shrubland	5	Unmanipulated and unaltered	1
Inter-Mountain Basins Big Sagebrush Shrubland	5	Unmanipulated and unaltered	2
Inter-Mountain Basins Mixed Salt Desert Scrub	5	Unmanipulated and unaltered	1
Mojave Mid-Elevation Mixed Desert Scrub	5	Unmanipulated and unaltered	1
Sonora-Mojave Creosotebush-White Bursage Desert Scrub	5	Unmanipulated and unaltered	2
Sonora-Mojave Mixed Salt Desert Scrub	5	Unmanipulated and unaltered	1
Great Basin Semi-Desert Chaparral	5	Unmanipulated and unaltered	4
Mogollon Chaparral	5	Unmanipulated and unaltered	4
Rocky Mountain Gambel Oak-Mixed Montane Shrubland	5	Unmanipulated and unaltered	2
Sonora-Mojave Semi-Desert Chaparral	5	Unmanipulated and unaltered	4
Southern Rocky Mountain Ponderosa Pine Savanna	5	Unmanipulated and unaltered	2

Columbia Plateau Low Sagebrush Steppe	5	Unmanipulated and unaltered	1
Inter-Mountain Basins Big Sagebrush Steppe	5	Unmanipulated and unaltered	2
Inter-Mountain Basins Montane Sagebrush Steppe	5	Unmanipulated and unaltered	2
Inter-Mountain Basins Semi-Desert Shrub-steppe	5	Unmanipulated and unaltered	2
Inter-Mountain Basins Semi-Desert Grassland	5	Unmanipulated and unaltered	1
Rocky Mountain Subalpine-Montane Mesic Meadow	5	Unmanipulated and unaltered	2
Coleogyne ramosissima Shrubland Alliance	5	Unmanipulated and unaltered	2
Grayia spinosa Shrubland Alliance	5	Unmanipulated and unaltered	1
Artemisia tridentata ssp. vaseyana Shrubland Alliance	5	Unmanipulated and unaltered	2

APPENDIX B – Conversion/Slice tool

The settings for the variables from the three tools used in the Conversion/Slice tool (Figure 1) are as follows:

1. CONVERSION TOOLS > TO RASTER > FEATURE TO RASTER

   i) "Input features" set as the first model parameter
   ii) "Field" set as the second model parameter
   iii) "Output cell size" set to 100m
   iv) "Extent" set to the boundary mask
   v) Rename "Output raster (1)" to Raster1

2. SPATIAL ANALYST TOOLS > MAP ALGEBRA > SINGLE OUTPUT MAP ALGEBRA

   i) Join "Raster1" to the "Single Output Map Algebra" tool
   ii) Input the following expression in the "Map Algebra expression" box:

      con(isnull(Raster1) = = 0, (Raster1), 0)

3. SPATIAL ANALYST TOOLS > RECLASS > SLICE

   i) Join "SingleOutput2" to the "Slice" tool
   ii) "Number of output zones" set to 256
   iii) "Slice method" set to EQUAL_INTERVAL
   iv) "Base zone for output" set to 1
   v) "Mask" is set to the boundary mask
   vi) "Output raster (3)" set as the third model parameter

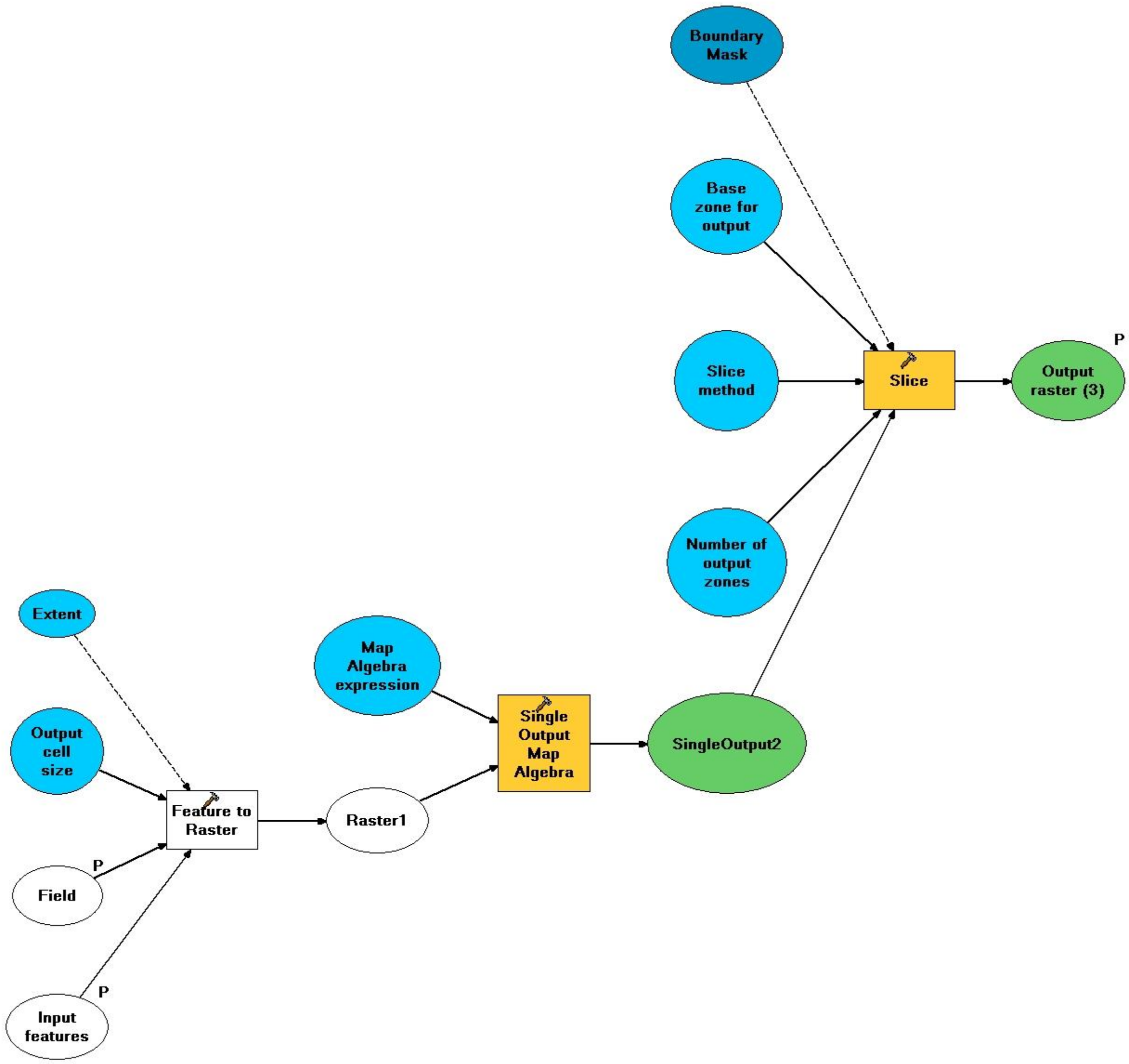

Figure 1 Layout for the Conversion/Slice tool

APPENDIX C – Macro code for stacking columns in Microsoft Excel

```
Sub Stack_cols()

On Error GoTo Stack_cols_Error

Dim lNoofRows As Long, lNoofCols As Long
Dim lLoopCounter As Long, lCountRows As Long
Dim sNewShtName As String
Dim shtOrg As Worksheet, shtNew As Worksheet

'Turn off the screen update to make macro run faster
Application.ScreenUpdating = False
'Ask for a new sheet name, if not provided use newsht
sNewShtName = InputBox("Enter the new worksheet name", "Enter name", "newsht")
'Set a sheet variable for the sheet where the data resides
Set shtOrg = ActiveSheet
'Add a new worksheet, rename it and set it to a variable
If Not SheetExists(sNewShtName) Then
Worksheets.Add(After:=Worksheets(Worksheets.Count)).Name = sNewShtName
Set shtNew = Worksheets(sNewShtName)
Else
MsgBox "Worksheet name exists. Try again", vbInformation, "Sheet Exists"
Exit Sub
End If

With shtOrg
'Get the last column number
'Replace .Range("IV1") with .Range("XFD1") for Excel 2007
lNoofCols = .Range("IV1").End(xlToLeft).Column
'Start a loop to copy and paste data from the first column to the last column
For lLoopCounter = 1 To lNoofCols
'Count the number of rows in the looping column
'Replace .Cells(65536, lLoopCounter) with .Cells(1048576, lLoopCounter) for Excel 2007
lNoofRows = .Cells(65536, lLoopCounter).End(xlUp).Row
.Range(.Cells(1, lLoopCounter), .Cells(lNoofRows, lLoopCounter)).Copy
Destination:=shtNew.Range(shtNew.Cells(lCountRows + 1, 1), shtNew.Cells(lCountRows +
lNoofRows, 1))
'count the number of rows in the new worksheet
lCountRows = lCountRows + lNoofRows
Next lLoopCounter
End With

On Error GoTo 0
SmoothExit_Stack_cols:
Application.ScreenUpdating = True
```

```
Exit Sub

Stack_cols_Error:
MsgBox "Error " & Err.Number & " (" & Err.Description & ") in Sub:Stack_cols"
Resume SmoothExit_Stack_cols
End Sub
'Check if a worksheet exists or not
Public Function SheetExists(sShtName As String) As Boolean
On Error Resume Next

Dim wsSheet As Worksheet, bResult As Boolean
bResult = False
Set wsSheet = Sheets(sShtName)

On Error GoTo 0
If Not wsSheet Is Nothing Then
bResult = True
End If
SheetExists = bResult
End Function
```