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Procedure to update transportation map of the Bedell Flat, Nevada, quadrangle from high resolution satellite imagery.

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By

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Abstract

This thesis develops and documents a technique to update the transportation data layer for the area covered by the U.S. Geological Survey Bedell Flat, Nevada, 1:24,000 scale map. This is a rural area located 25 kilometers north of Reno, Nevada. Recent high resolution satellite imagery is utilized to identify and map 27.7 kilometers of new road segments related to low density urban development and a 9.7 kilometer section of a major gas line. Procedures are developed that utilize convolution masking to extract new road alignments from satellite imagery utilizing desktop computer hardware and software. New road segments are then vectorized for use in Geographic Information Systems and desktop publishing packages. This data is then verified by examination of aerial photography, statistical analysis, and field investigation.

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Introduction

As development spreads into the rural areas surrounding existing urban concentrations, it is becoming more costly and time consuming to monitor new road development and update transportation maps in rural areas. Current procedures that utilize aerial photography and stereo compilation or digital orthophoto quad (DOQ) production and manual update procedures are slow, costly, and usually have only a low resource priority. Currently in Nevada, of 1,986 topographic quadrangles published by the U.S. Geological Survey to complete coverage of the State, 735 or 37 percent date from 1980 or earlier. With the development of new high resolution, 5 meter and better, satellite data, available in a timely manner and relatively inexpensive, it is now possible to update rural transportation maps in a cost effective manner using desktop computers and PC software. This thesis develops the procedures to do that, and suggests that while the U.S. Geological Survey is not currently using this method, it is useful and can be relatively easily accomplished by state and local agencies and other individuals that are concerned with creating and maintaining up-to-date transportation maps.

Study Area

Bedell Flat Quadrangle, the selected study area, is located 25 kilometers north of Reno, Nevada (Figure 1). The southern and central parts of the study area are undergoing low-density urban development, interspersed with sections of open public land, while the northern part of the study area remains as open range for livestock operations (Figure 2).

The area has seen development of more than 27 kilometers of new graded and maintained roads, constructed for access to the developing areas. A new major natural gas intertie line, constructed during 1995, slices across 9 plus kilometers of the northern part of the quadrangle and is not shown on current maps. The area has seen a scattering of small scale historic mining activity and occasional modern exploration activity. Much of the open range is utilized for cattle grazing.

The area is semi-arid and contains parts of Hungry, Freds, Dogskin, and Warm Springs Mountains, and Antelope and Bedell Flat valleys. Antelope Valley is a bolson with active playas and Pleistocene lake deposits. Study area elevation ranges from valley floors at 1500 meters to mountainous areas reaching almost 2200 meters. Some of the area's vegetation includes Big Sagebrush (*Artemisia tridentata),* Rabbit Brush (*Chrysothamnus* spp.), and Mormon Tea (*Ephedra nevadensis*) all intermixed with various understory grasses. Burned sites are covered with Cheat grass (*Bromus tectorum*). The prominent

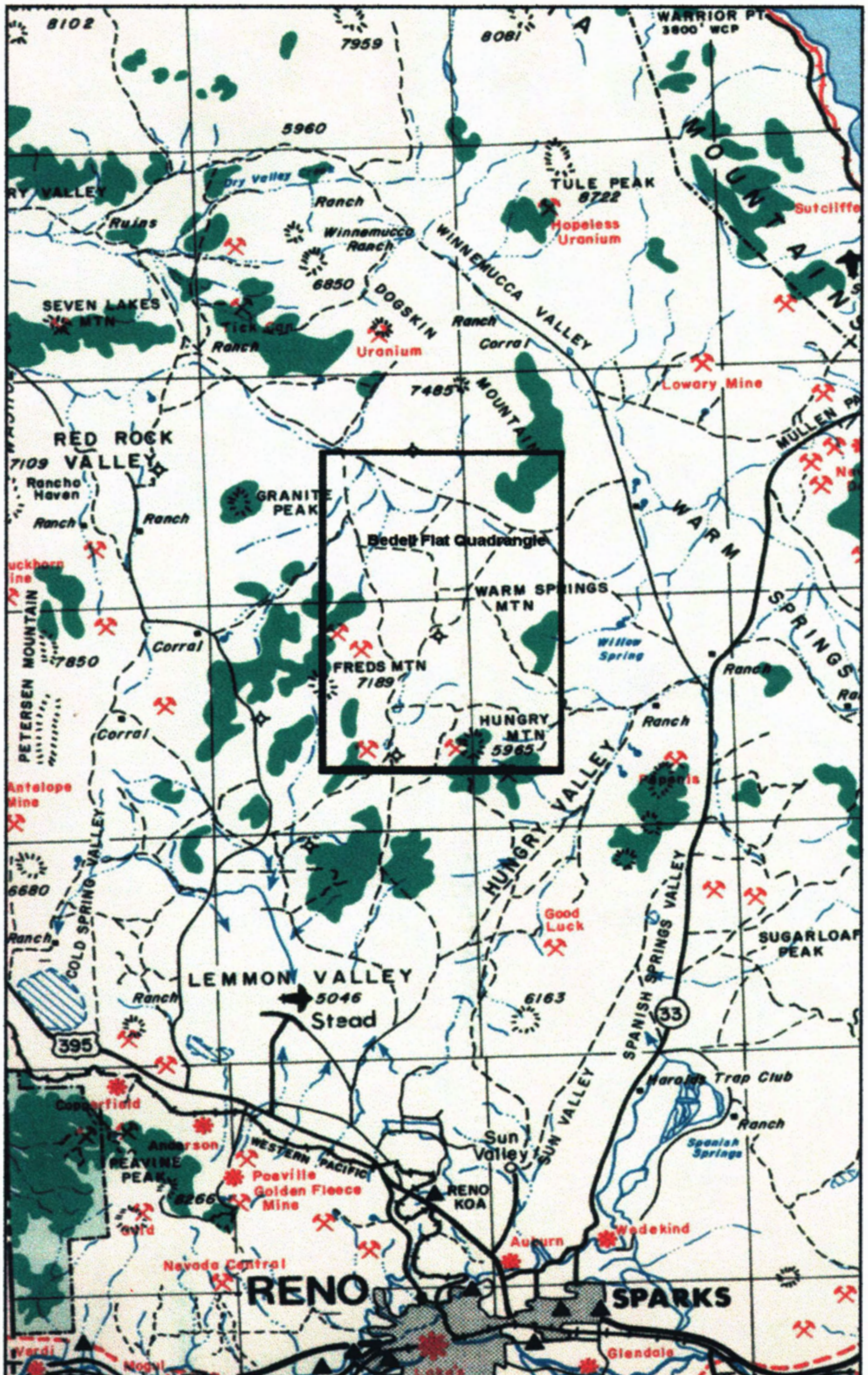

Figure 1
Location map of study area with Bedell Flat quadrangle outlined. Map from "The Map: Washoe and Storey Counties" by J. Hunt, 1973.

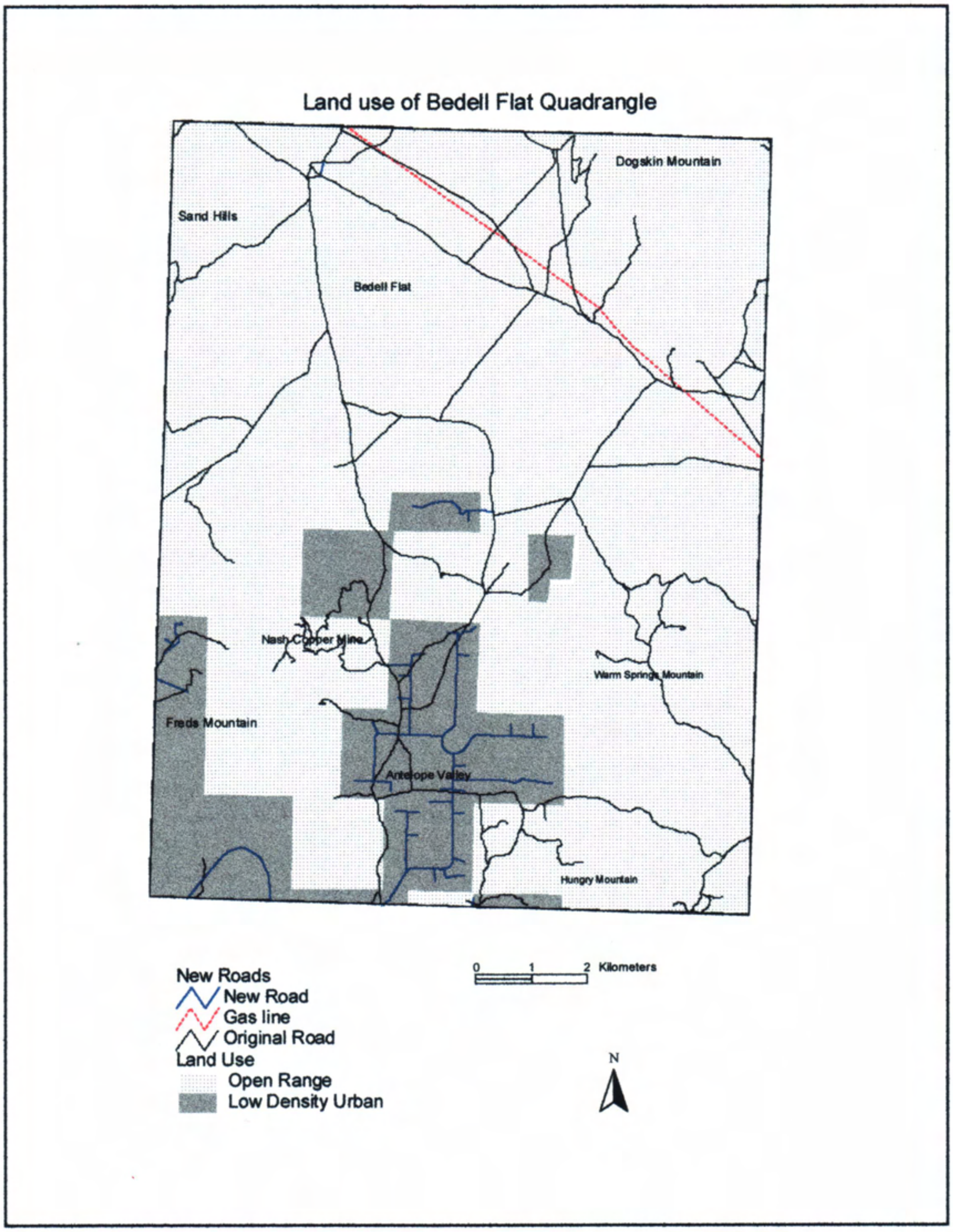

Figure 2
Land use data from Washoe County Department of Comprehensive Planning, original road data from U.S. Geological Survey Bedell Flat DLG, and new roads and gas line data developed from satellite imagery.

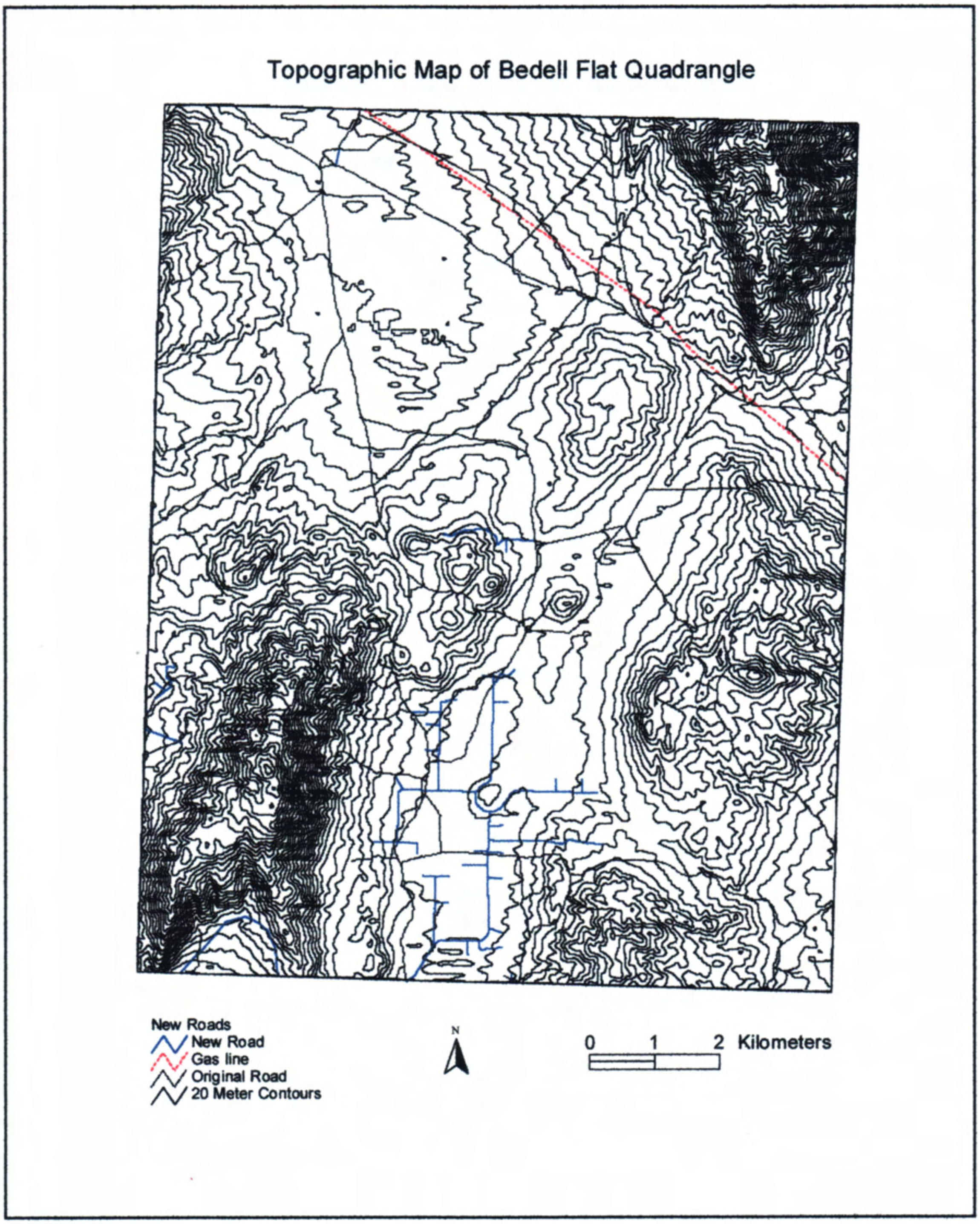

Figure 3
Topographic contours from U.S. Geological Survey Bedell Flat 1:24,000 scale digital elevation model (DEM) data, original roads from U.S. Geological Survey Bedell Flat 1:24,000 scale digital line graph (DLG) data, and new roads and gas line data from 1997 satellite imagery.

tree species in the area is Utah Juniper (*Juniperus osteosperma*) with forests on some hillsides and summits (Grayson 1993).

The updated "Topographic Map of Bedell Flat Quadrangle" (Figure 3) shows the relief of the area with 20 meter topographic contours, roads in black from the original U.S. Geological Survey 1:24,000 scale quadrangle map, with new road segments in blue and the new natural gas intertie line in red. The last two were developed from this thesis.

Physiography

Antelope Valley is a bolson with active playas during periods of heavy runoff, and Pleistocene lake deposits prominent on the valley floor (Peterson 1981 and Garside 1993). Stream courses are intermittent carrying water only during periods of heavy snow melt or after the occasional heavy summer convective precipitation event. Average annual precipitation ranges from 11" in the valleys to 18" in the higher mountains. The southeast part of Bedell Flat valley, located in the northwest part of the study area, drains to the northwest beyond the study area. During field work no intermittent streams were flowing.

The oldest rocks in this area are of Jurassic (130-200 million years) age and found towards the northeastern end of Freds Mountain, on the west side of Antelope Valley.

The Nash copper property, a currently inactive mining area consisting of a series of pits, adits, cuts, and roads, is located on this older mete-andesite unit. The rest of the high elevation areas of Freds Mountain are made up of Cretaceous (67-130 million years) age quartz diorite (southern part) and quartz monzonite and granodiorite (northern part). These units form older, well rounded surfaces with occasional prominent outcrops. There are several small areas of Oligocene (37 million years) age tuffs located at the northern end of Freds Mountain between some granodiorite and monzonite units to the south and early Pleistocene pediment deposits to the north. The pediment deposits overlay tertiary sedimentary rocks (Miocene to Pliocene, approximately 7.5 million years in age). This unit is made up of sandstone, siltstone, and shale and forms the dominate rock type in the Sand Hills located in the northwest part of the quadrangle (Garside 1993).

A very prominent geomorphic feature that cuts through the study area is the Freds Mountain Fault. Located on the east side of Freds Mountain, it has created well defined faceted spurs. This fault can be traced from Lemmon Valley in the south to its terminus in Bedell Flat with the Honey Lake Fault Zone. It is 30 kilometers in length. Just south of the quadrangle, and continuing northward on to the quadrangle, the fault is splayed into two parallel strands separated by about 1 kilometer, creating a pedimented surface (resembling a large bench) cut into weathered granite on the eastern side of Freds Mountain. Its eastern edge consists of Mesozoic (approximately 200 million years) age foliated granodiorite. In areas along the range front the fault is defined by over steepened

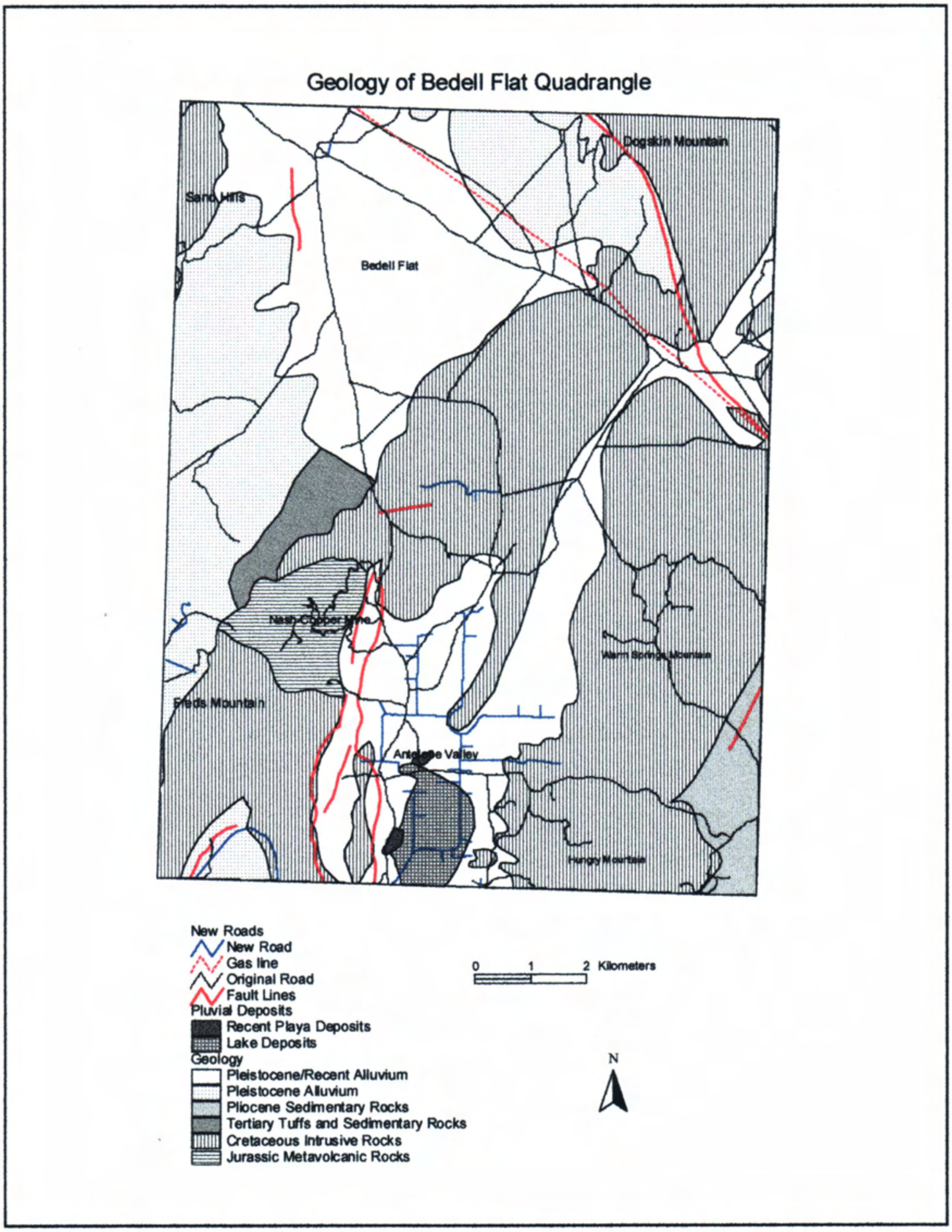

Figure 4
Physiographic map compiled from Bonham 1969, Garside 1993, and Hess 1996.

bedrock slopes and steep linear escarpments, faceted spurs are clearly evident. In Pleistocene alluvium it forms scarps and fault traces. To the north of Freds Mountain the fault steps west to the Sand Hills on the southwest side of Bedell Flat. The most recent event on this fault is estimated to have had one meter of displacement sometime in the early to mid-Holocene (Nitchman and Ramelli 1991 and Garside 1993).

The dominant rock unit of the southern end of Dogskin Mountain, located on the northeast part of the quadrangle, is Cretaceous-age quartz monzonite. A range front fault, on the west side of Dogskin Mountain, forms the approximate contact between this unit and alluvial-fan deposits of Bedell Flat.

Bedell Flat and much of Antelope Valley is Quaternary alluvial plains and fans. A series of small hills at the northern end of Antelope Valley are composed of Cretaceous-age granodiorite and Oligocene-age tuffs. Part of Antelope Valley is covered with playa deposits consisting of silt and clay and a much larger area of lake deposits consisting of silt, clay, and fine to coarse sand (Garside 1993). These deposits along with beach and beach bar deposits were formed by a late Pleistocene lake in Antelope Valley (Figure 4).

Warm Springs Mountain and Hungry Mountain, on the east side of the quadrangle, are primarily made up of Cretaceous (67-130 million years) age quartz monzonite and granodiorite. Both mountains have a series of north trending aplite and pegmatite dikes that are 1 to 2 meters wide and stand out from the surrounding material (Garside 1993).

Most new road development is taking place in the valleys on alluvial fill and on lower slopes. It is associated with ongoing low density urban development in the area. Most of the new road segments are also located in the valleys with some cutting across hillsides and through lower passes. The natural gas intertie line goes through a low pass and then enters Bedell Flat and continues off of the quadrangle.

The Problem

The current published U.S. Geological Survey 1:24,000 scale map of the Bedell Flat Quadrangle dates from 1980. Although issued in 1980, its information is based on aerial photography flown during 1975 and field checked in 1976. This published map also served as the source for the georeferenced digital line graph (DLG) roads data that the U.S. Geological Survey now distributes via the Internet. The same published map in a digitally scanned georeferenced format known as digital raster graphic (DRG), which is also available from the U.S. Geological Survey and other vendors in a world TIFF file format (TFW). However, all of these products are based on the original 1980 published map that only shows the transportation network as it existed on the 1975 aerial photography now almost a quarter-century old.

Late in the 1970s a large part of the central and southern portion of the Bedell Flat Quadrangle was subdivided into parcels ranging in size from 10 to 40 acres. Part of the subdivision process included development of a new, well-maintained, graded road network that would allow owners or new residents access to the parcels. This road network was constructed late in the 1970s, before the publication date of the Bedell Flat Quadrangle but several years after the aerial photography was flown from which the map was constructed. In essence, a major new road network was in place when the map was published but had yet to be built five years earlier when the actual photography that the map is based on was flown. The published map lacks almost all of the regularly maintained active road network in many areas. Since the initial subdivision road network has been constructed, other wide graded roads, usually shorter road segments connecting to the new network, have been added for direct access to the smaller parcels. These shorter road segments have appeared at various times during the 1980s and 1990s.

During 1995 a major natural gas intertie line was constructed through the northern part of the Bedell Flat Quadrangle. It follows a route through the pass between Warm Springs Mountain and Dogskin Mountain, continuing northwest through Bedell Flat.

For regional planning purposes the problem is best defined as how to obtain, in a digital format and cost effective manner, the additions to the transportation network of the Bedell Flat quadrangle that have been constructed since 1976. This is a relevant concern in Nevada were 37 percent of currently available U.S. Geological Survey 1:24,000 scale topographic maps have been published prior to 1981.

This problem will be solved by utilization of new high resolution panchromatic satellite data, digitally filtered to highlight the maintained road network, and converted to vector format for use in Geographic Information Systems (GIS) and desktop publishing packages.

Digital Data

At the time this thesis was under taken a new digital satellite image product had just become available. It is obtained from a 5 meter resolution panchromatic instrument flown on an Indian Remote Sensing Satellite (IRS) and distributed in the United States by EOSAT, Inc. This new, low cost, panchromatic product is now available on a request basis for many parts of the world. The image ordered for this project came from archives (this cost less than requesting a new acquisition) and covered the entire study area. The image was ordered with the specification that it be cloud free and taken between May 1, 1997 and October 31, 1997. The image is dated 6/21/97 and cost $250.00. It was delivered as a georeferenced TIFF format file on CDROM. This became the basic digital coverage for updating the Bedell Flat road network.

In addition to the satellite image data, Digital Line Graph (DLG) data layers for Transportation, Boundaries, Public Land Survey, and digital elevation model (DEM) data were obtained from the U.S. Geological Survey, at no cost, via their web site at "http://edcwww.cr.usgs.gov/doc/edchome/ndcdb/ndcdb.html". The Digital Raster Graphic (DRG) data for Bedell Flat was ordered from the U.S. Geological Survey at a cost of $36.00. It arrived on CDROM as part of a set of 64 DRGs. A digital version of the parcel/ownership map was obtained from the Washoe County office of Comprehensive Planning. The latter digital products were used for comparison and base map generation for this project. Non-digital vertical aerial photography was obtained for field checking and data clarification. The photography utilized was the National Aerial Photography Program (NAPP) 1:40,000 scale black and white photography flown on June 18 and 21, 1994 and National High Altitude Photography (NHAP) 1:58,000 scale color infrared photography flown on July 30, 1980. Both NHAP and NAPP are nation-wide aerial photography programs that are managed by the U.S. Geological Survey. Negatives, positives, and prints from these missions can be ordered from EROS Data Center, which is the U.S. Geological Survey's image depository. Complete coverage of older NHAP and newer NAPP photography is available for all of the lower 48 states.

Software

A variety of software packages were examined for use during this project with the primary goal being to allow completion of the project within a desktop computer environment. This was somewhat of a challenge because no one product appeared to have the optimum package of capabilities that would produce the best results combined with ease of use, low cost, and availability on lower-end desktop computers. All of the raster based modeling, filtering, and analysis was performed using the PC based Idrisi GIS software package. This is a full featured raster-based GIS mapping and modeling program that has been produced by Clark Labs at Clark University. It has many image processing, cartographic algebra, import/export, projection, and plotting utilities that make it most useful for this type of project (Eastman 1997a and b). It is also relatively inexpensive, meaning that it may be affordable for the many rural public agencies that may wish to make use of this type of analysis (Foresman 1993). Idrisi, however, lacks a robust raster-to-vector line generator. This disadvantage sent me scurrying forth until I found one. For some data presentation, editing, and attributing line work, I utilized Arcview 3.0a, a desktop GIS software package from Environmental Systems Research Institute (ESRI 1996).

I examined and used (for comparison purposes) four different software packages with raster-to-vector line conversion capability. These were Arc/Info, the basic unix workstation version 7.0.3 and 7.1, which utilized the “gridline” command. The Arc/Info Arcscan package under Version 7.0.3 and 7.1 which is an additional add-on package to Arc/Info that includes a sophisticated raster line generator and editing environment. Both these packages are products of Environmental Systems Research Institute (ESRI) and are considered high-end products.

The Arc/Info gridline command is very fast, and converts a clean raster image to vector in short order. However, it has few options and produces a line coverage in Arc/Info, which then has to be edited in a different Arc/Info package or exported into still different software for editing. The advantages of this raster-to-vector conversion program are speed, accessability (part of the basic unix/nt Arc/Info installation), a command option that specifies type of line intersection required (square or rounded) and the ability to rapidly bring the product into Arcview (an ESRI desktop product) where it can be converted to a shape file, edited, and attributed (ESRI 1994a and Kreis 1995). A shape file is a public digital file structure and format designed for digital map data storage and analysis. It was originally developed and made public by ESRI and has gained wide acceptance throughout the GIS industry.

The Arcscan conversion process utilizes an add-on product to Arc/Info which is called Arcscan. This provides a very powerful raster-to-vector conversion and editing capability. It has a longer learning curve and is only available on higher end nt and unix machines. But this procedure develops a clean, high quality line product that can then be exported in several different formats.

The big difference in the functioning of these two raster-to-vector conversion programs is that gridline is executed from the Arc/Info command line with options selected that are dependant on the quality and purpose of the original raster data and vector output, while Arcscan provides a graphical editing interface where you actually select various routes and groups of cells to be vectorized by pointing to them with the mouse. The gridline option has to be edited after it is converted while, with Arcscan editing and vectorization are part of the same process. In both options attributing is done after the vectorization process (ESRI 1994b).

The third package, again, within the realm of low cost desktop products, was R2V for Windows, available from Able Software Company. This product produced a good quality line from raster data and has a built in, on screen, editing environment that allows for selected or layer-wide edits. There is a large collection of both raster and vector editing, filtering, smoothing, and enhancement tools available within this package. It has a long list of image formats that it will read as well as a long list of vector output formats that it supports. This package is similar in function as Arcscan, but with a graphical interface that is much more intuitive to use, and a much shorter learning curve.

The fourth package, a lowcost shareware software, called KVEC, and available from KK Software in Wieden Germany (the software is available via the Internet), was also examined. This package is also command-line driven, much like the gridline command in Arc/Info. However, KVEC has a multitude of command-line options available that allow for refinement of the output vector data set based on shape, size, and pixel continuity of the input data. It handles most common raster and vector line file formats. The registered version includes a series of advanced filters and line output coding. I found this a useful package for converting raster images into line files. The disadvantage is that, like gridline, without any interactive editing capability, you still have to clean up the output file in a different software package. With both KVEC and the Arc/Info gridline vector files I converted the output to shape file format for use in Arcview, where I edited and removed the unnecessary vectors, and attributed the remaining ones.

These four are but a small sampling of raster-to-vector line generators available on the market today. There are many add-on and standalone products available for almost any platform and designed to support computer aided drafting and drawing (CADD), GIS, and computerized publishing software packages. Cost ranges from shareware to several thousand dollars per software site license.

Image Processing Methodology

The main goal of this project is the digital isolation of new road segments from a 5 meter resolution panchromatic satellite image. These new road segments will then be used to update the existing, but outdated, digital roads coverage of the Bedell Flat quadrangle.

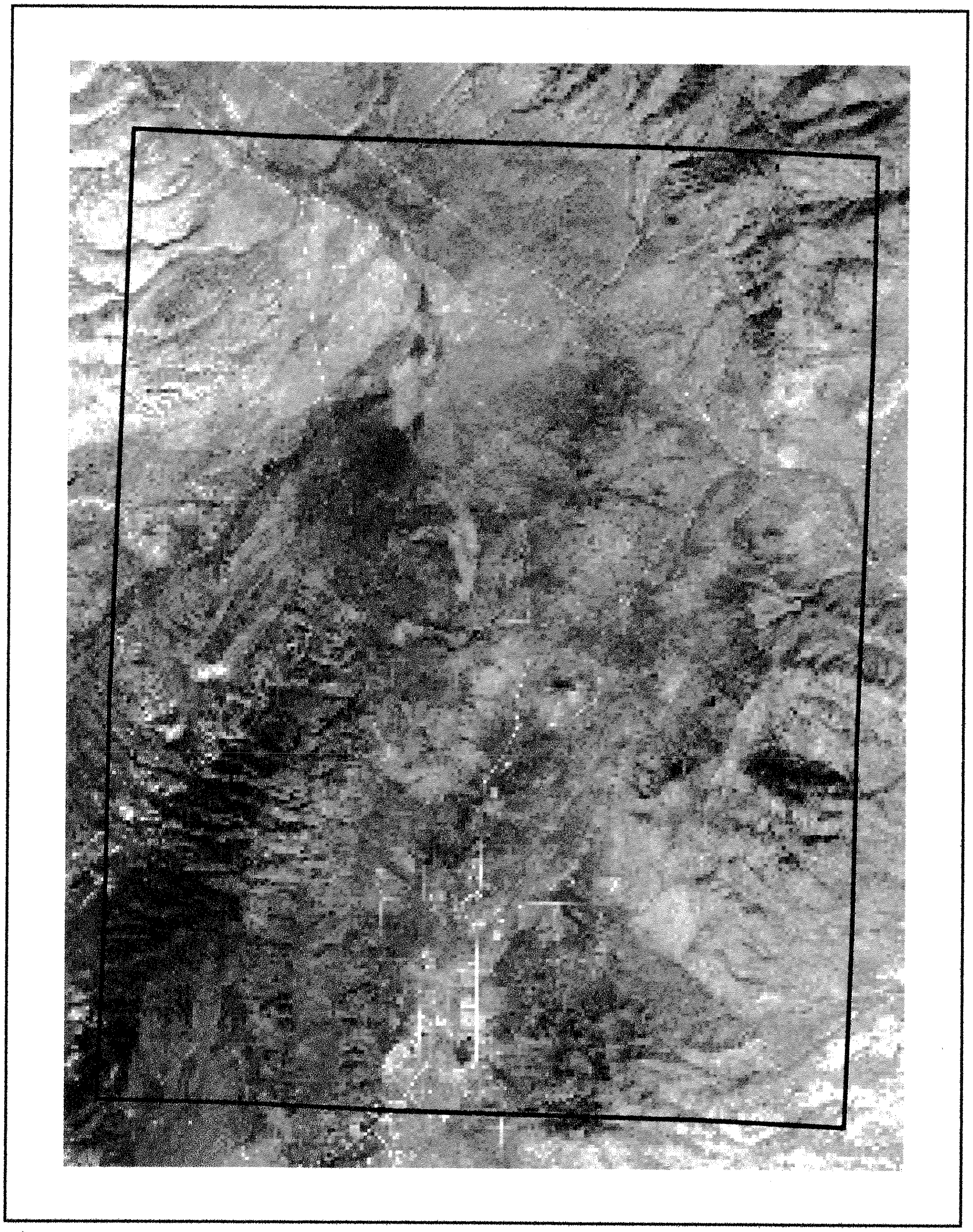

Figure 5
PAN1 satellite image of study area. Boundary of Bedell Flat quadrangle shown on image.

Discussion Leading up to development of Methodology

The panchromatic satellite image (referred to hereafter as PAN1) can be described as having good contrast (Figure 5) and the image histogram shows well distributed DN values ranging from 16 through 255 (Figure 6). The new road network is easily identified on the image with just visual inspection, as is most of the older road network and the new natural gas intertie line. New homes and home sites that dot much of the southern part of the study area are also visible. The image is cloud free (Figure 5).

In initial planning of this project, I gave considerable forethought to the limitations associated with using a single panchromatic image. Limitations include lack of the ability to ratio various bands to highlight features of interest, no vegetation indexes for highlighting high or low biomass areas, and no multiband unsupervised or supervised classifications. But in order to keep cost, processing time, learning curve, and computer software/hardware requirements to a minimum this limitation was acceptable. More and higher resolution panchromatic satellite data will be publicly available in the near future. There will be continued production of conventional digital orthophoto quads, and the procedures developed here ought to be readily translatable to these other products.

Careful examination of PAN1 (Figure 5) and its associated histogram (Figure 6) revealed that the spectral response of the new roads ranged anywhere from a digital number (DN)

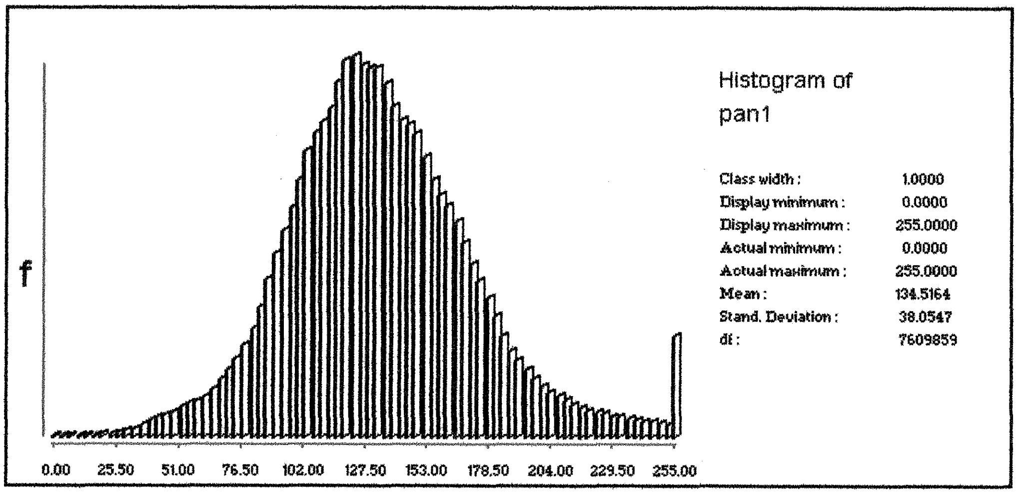

Figure 6
Histogram of DN values of the original panchromatic satellite data, named "PAN1" during processing.

value of 130 all the way to a DN value of 255. Because of the roads wide spectral variation the key to success was finding an appropriate convolution filter (or mask) able to highlight the specific spectral responses associated with the linear shapes of the new road network. It was hoped that one filter could be developed to satisfy all requirements.

A particular problem faced was the general width of the new roads and the physical dimension of their associated spectral response as measured at the instrument. The well-used (defined as driven portion, gutter to gutter) road bed measures between 9 and 15 meters in width. In addition to this, grading for road material make-up, fire prevention, and above/below ground utilities have created a disturbed area that in some locations adds an additional 10 meters in width of disturbed area to the driven portion of the road bed. Many of these shoulders, although seldom driven upon, are regularly graded to remove vegetation and maintain a fire break, obtain additional road bed material, and clear gutter drainage obstructions. Shoulders on the low-use roads that are not graded regularly are generally maintained at least once per year.

In addition to shoulder-road distinctions, for most of the study area, the basic road material is just a hard-packed version of the surrounding natural material. Those few sections of road that have imported gravel, a crushed andesite, also show a high DN spectral response much like the roads formed of native material. Most of the native material appears to be variations of a sandy loam, with a large sand component made up of decomposed granite.

New road segment disturbed areas include driven and non-driven portions of roadway that are characterized by high DN reflectance values in the visible spectrum, and the roadway ranges in width from 9 to 25 meters. Most of the road targets are characterized as wide linear features with strong DN pixel responses, usually saturating 3 to 5 pixels in width for the length of the road feature. In contrast to this, many of the older roads and the somewhat passable trails in the area that are shown on the U.S. Geological Survey roads DLG for Bedell Flat have a width of 3-4 meters. However, some of the heavily used original roads, such as the main road through Bedell Flat, have widths similar to the new road segments described.

The second target, a new large natural gas intertie line put in several years ago, with a construction effected and reclaimed area 30 meters wide for its entire length. This feature runs generally northwest-to-southeast across the northern portion of the study area and shows up as a visible feature on the image. But due to new vegetation growth on the pipeline corridor (mainly reseeded grasses) its DN spectral response is much lower then the DN values associated with the new road segments and in many places merges into the same spectral response associated with surrounding natural vegetation.

Convolution Filtering (Masks)

A mask or convolution filter can best be thought of as a box that contains a series of numeric values or coefficients, having a specified height and width, that is systematically moved across a raster image. Every time the box is placed over a portion of the image the coefficients within the box mathematically function upon the image values located directly below them and when summed form the new filtered pixel output value assigned to the pixel located at the center of the convolution or filter box.

Applying convolution or mask filters, a neighborhood function, to an image is utilized to modify the centroid pixel of a mask based on the calculated effects of a set of chosen coefficients operating on the values of the image in the immediate neighborhood of the center cell of the mask (Tomlin, 1990). Both the shape and size of the neighborhood as well as the coefficient values and any additional weighting or bias factors are selected by the individual doing the processing. Convolution filters are used for a variety of purposes such as sharpening, edge enhancement, averaging, blurring, noise removal or addition, etc.

A good definition of convolution filtering is given by Faust 1998 in *Introductory Digital Image Processing, Volume 3:*

> Convolution involves the passing of a moving window over an image and creating a new image where each pixel in the new image is a function of the original pixel values within the moving window and the coefficients of the moving window as specified by the user. The window, a convolution operator, may be considered as a matrix (or mask) of coefficients that are to be multiplied by image pixel values to derive a new pixel value for a resultant enhanced image. This matrix may be of any size in pixels and does not necessarily have to be square.

Filters that emphasize or highlight rough areas or areas with frequently changing DN values are called high-pass filters. The term "high-pass" is used because in frequency domain terminology, they pass high frequency components of the input signal, while reducing or eliminating the low frequency components. High frequency components are edges and other features that tend to show detail on the image (Gonzalez and Woods, 1993). These filters are utilized to enhance subtle differences that indicate a change in DN value from one location on the image to another.

An example of a high pass filter is one with negative coefficients in the top row of the mask with positive coefficients in the bottom row of the mask. When utilized, if a significant difference occurs between the sum of both the top and bottom rows as compared to the original DN value of the centroid pixel, it indicates that the filter is sitting on a horizontal edge based on the images original DN values. High-pass filters can help identify such features as geologic contacts, faults, roads, vegetation differences, water bodies, and features with distinct differences.

A smoothing or averaging filter is called a low-pass filter. An example of a low-pass filter would be an averaging filter that calculates and sums the image cell values within the mask, divides it by the number of cells contained in the mask, and replaces the DN value in the image with this new value (the average). This type of process is used to smooth or blur an image (Avery and Berlin, 1992). Another application is averaging the values associated with digital elevation model data to remove unnatural spikes within the data set. The term low-pass is used because in frequency domain terminology they pass low frequency components of the input signal while reducing or eliminating the high frequency components. Low-pass filters tend to remove or reduce the effects of high frequency components within the image (Gonzalez and Woods, 1993). Low-pass filters tend to reduce image noise.

3x3 Examples of Masks Described Above

	1	1	1			-1	-1	-1
1/9 x	1	1	1		Sum	0	0	0
	1	1	1			1	1	1
Low-pass averaging filter					High-pass horizontal edge detector			

Filters of various sizes and shapes with various coefficients effect images in various ways. In the high-pass filter example with negative coefficients along the top row and positive coefficients along the bottom row, horizontal edges are easily located. Conversely a filter with negative coefficients along the left side and positive coefficients alone the right side is well designed to locate vertical edges. These high-pass edge detectors are also known as Prewitt operators (Gonzalez and Woods, 1993). The size and strength of the convolution mask directly affects the size and shape of the image features that it will detect. In evaluating high-pass filters, Avery and Berlin note that "In general, a high-pass spatial filter enhances features that are less than half the size of the window being used while de-emphasizing features that are more than half the window size" (1992, page 426).

An important component of this project is determining the appropriate size and strength of high-pass convolution filter. To select one to best highlight new road segments while reducing other non-essential image features, and allow appropriate raster-to-vector conversion.

Determining the size and appropriate placement of coefficients became a long process. It basically revolved around the following procedure: decide on a size, i.e. 3x3 or 5x5 or larger, enter the series of coefficients to be used, run the filter, and observe the output. I started with the smaller filters, many of which are described in various texts (Schowengerdt 1983 and Gonzalez and Woods 1992). I observed in the output the density of information in regions away from the roads of interest, the values associated with the road pixels, the values of the pixels adjacent to the road pixels, watched for continuity of pixel values along the position of the road, and tracked how many of the road segments of interest stood out on the image with either positive or negative values. I also tried variations of the process such as running multiple filters on an image, thresholding, binary conversion and then filtering, and filtering then thresholding then filtering again. (Schowengerdt 1983 and Schneider and Robbins 1995). The process was long and tedious, started with 3x3 filters and ended up with 11x11 filters. Field checking and comparison to recent conventional aerial photography were utilized to identify linear features that were appearing as output from the various filters tested. This process was utilized to confirm or deny the existence of new road segments during the filter testing stage of the project..

In general, because of the width of the road segments that I was targeting, the smaller filters tended to develop multiple edges, with opposite values for the pixels that represented the middle of the road feature and the outlying boundaries of the feature.

Most of the smaller filters and many of the larger ones that utilized coefficients in all or most of the interior cells of the mask left too much detail, in addition to the road features. Thresholding the initial image before processing did remove many of the pixels that were cluttering the background of the filtered images. However, it also introduced an extensive series of strong artificial edges that were spread throughout the image. Running multiple filters eroded pixel connectivity along road segments while having only a small effect on the outlying background pixels that were left from the initial filter run.

Many of the mask combinations that were run were unique, meaning that I had not found them in literature beforehand. However, it does not mean that they have never been tried before. Many tended to sharpen all features in general, such as some Laplacian masks, but many were based on enlarged versions of directional edge enhancement masks that were put together by enlarging the distribution of coefficients from the smaller masks. This latter idea tended to improve the quality of the output as the mask size increased.

As the mask size increased, to the range of 7x7 and 9x9 pixels in size, and moved to a model where all of the coefficients were located on the outside edge of the mask, the wide road segments started becoming more visible. These images displayed good pixel-to-pixel connectivity along road segments, well defined in most directions, with a large difference between road segment pixel values and background pixel values. A large difference in the value of the pixels of interest versus background pixels is important because it allows for a more accurate reclassification to a binary image. This process is best accomplished by examining the various pixel values of the filtered image and determining a cutoff value where all pixels below a certain value are assigned the value of 1 (features of interest: new roads, gas line) and all other pixels are assigned a value of 0 (features not of interest). After this step the image is vectorized, selecting the appropriate options for a center line down all groups of pixels valued 1.

The filter that eventually proved most effective for delineating new road segments on this project is the following 9x9 filter:

1	1	1	0	0	0	1	1	1
1	0	0	0	0	0	0	0	1
1	0	0	0	0	0	0	0	1
0	0	0	0	0	0	0	0	0
0	0	0	0	-20	0	0	0	0
0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	1
1	0	0	0	0	0	0	0	1
1	1	1	0	0	0	1	1	1

The function of this convolution mask is such that cells with a one in them multiply the original image pixel value, lying underneath that particular cell, by the coefficient 1. The original pixel value located at the centroid or center of the mask is then multiplied by a negative 20. All of the products of the outlying coefficients are then summed and added to the product of the centroid pixel. This becomes the output value for that pixel in the filtered image. Pixels located under zero values in the mask do not effect the convolution. Output values will range between high positive and low negative real numbers. Values close to zero are non-edges; positive values are areas of change or pixels approaching edges; negative values indicate edges. In the study area, road centers were typically identified by values of -350 or less, bounded by high positive values, and these high positive values went out to background (non-edge related features) values near zero. This filter and the other experimental filters were run in the Idrisi, Version 2 for Windows, GIS software package.

This filter had the best results of the many run. One of its characteristics, which makes this filter appropriate for this project, is the edge enhancement that is created by focusing on features that are more then three pixels wide in the horizontal and vertical directions. This is accomplished by only assigning coefficients of 1 to the vertical and horizontal cells of the outside corners of the mask and leaving sections 3 pixels wide along the center of the outside vertical and horizontal cells assigned 0. This mask also tends to reduce the effects of smaller nonlinear and/or isolated features by not calculating cell values that lie under zero values inside the mask itself.

At this point in the process a binary reclassification of the filtered output image is created. Idrisi software can calculate and display real number images, so conversion to an 8 bit image is unnecessary before binary reclassification. A binary image of an area along part of Antelope Valley Road was generated in the southern part of the study area (Figure

7). Long heavy lines running through the image are new roads that are not on the existing U.S. Geological Survey map of the area. The small patches in the outlying areas are unwanted background data that came through the mask. Some of these areas will be eliminated in the vectorization process automatically, because they are not large enough to meet a minimum cutoff value for vector length. Those remaining will either be

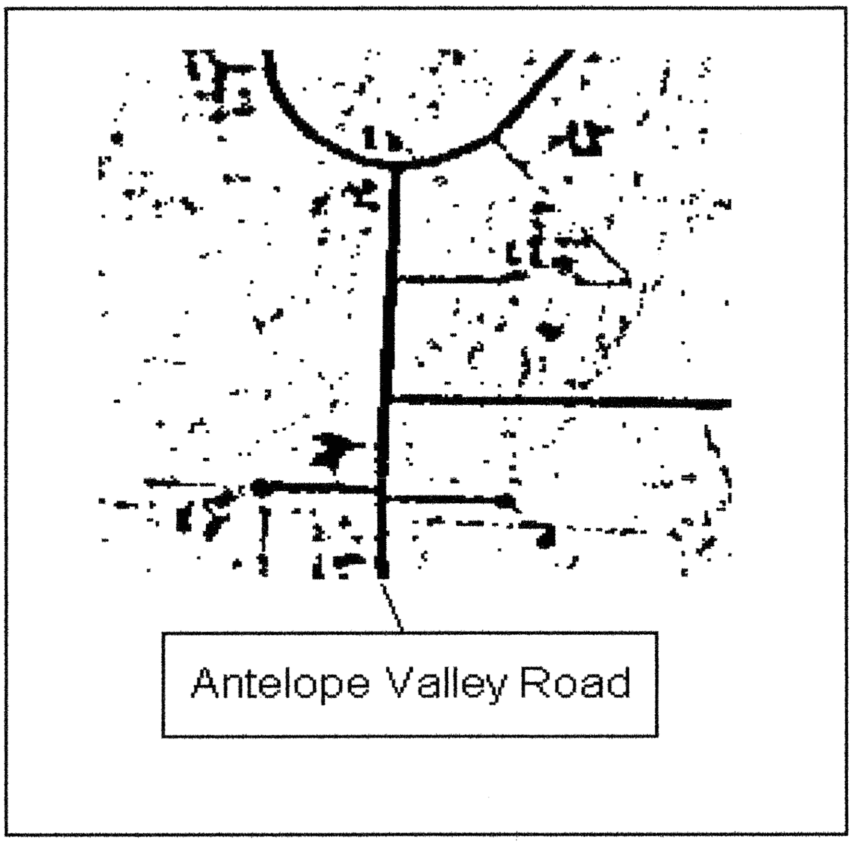

Figure 7
Binary version of part of the filtered image after thresholding.

removed after the vectorization process is complete or during the vectorization process, depending on which vector conversion software package is used. In the image generated there is strong pixel continuity and well-defined routes for both vertical and horizontal new road segments as well; and curved road segments appear clearly along the top edge (Figure 7). This type of pixel continuity, and few breaks, combined with a several pixel width, vectorizes well with few errors. This type of file is not difficult to vectorize in any of the software packages tested.

Some problem areas do appear in a different part of the study area. On Freds Mountain Road, on the southwest corner of the study area, much of the road surface is composed of the same material as the well-exposed slopes on both sides of the road, and this combined with the road being cut more narrowly, because of the hillside, has the effect of reducing the size of the spectral target and lowering the typical DN value of the disturbed road segments (Figure 8, box labeled A). Notice the narrow width in some areas, and the poor pixel-to-pixel continuity. Also shown is an area of Freds Mountain Road (Figure 8, box labeled B) which is built wider and has denser vegetation cover on both sides of the road. This increases the spectral variation between the disturbed road area and the surrounding natural vegetation cover. Notice how this segment shows a good pixel width and strong pixel-to-pixel continuity. However, even in areas with multiple breaks between pixels there were still sufficient remaining pixels to connect to and complete the vectorization of the road segments, although it took more direct operator involvement than if pixel continuity had been maintained.

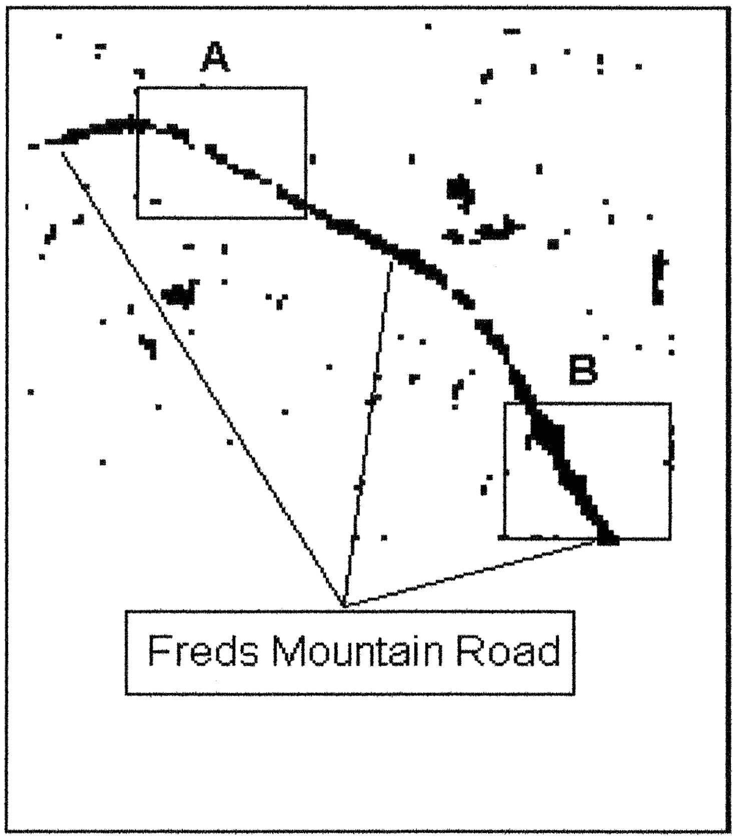

Figure 8
Binary version of part of the filtered image after thresholding.

Another problem area was the new gas intertie line. The gas line route consists of a 30 meter wide construction-disturbed corridor that has been reclaimed by surface leveling and reseeded with grasses and forbs during 1995. Because of reseeding, the associated DN values of the gas line corridor in many areas was interspersed with values close to those of the surrounding vegetated areas. This created areas along the gas line corridor that showed poor pixel connectivity; they were, in effect, simply too close spectrally to the native vegetation to produce a well connected set of pixels. However there were still sufficient sections of pixels along the corridor to allow vectorization, but additional editing was required to connect several vectors.

Because some software packages can only utilize 8 bit data I ran a test to observe the affects of conversion to 8 bit data. It compressed the image values down to between 0 and 255. This produced an image histogram that looked like the Sears Tower in Chicago near the middle with very long almost non-existent tails to the upper and lower end of the graph (Figure 9). This complicated finding an appropriate cutoff value for the binary conversion, compressing many of the real number values into a very few DNs. The original filtered, real number, image histogram also showed a narrow distribution toward the center with long narrow tails but because of the additional range of values available to select the cutoff value from, there were cleaner results.

After the binary reclassification is accomplished, the next step is conversion of the binary raster image to a vector file. This was accomplished utilizing the raster-to-vector software discussed earlier. After experimenting with these vectorization packages, it was obvious that all of them would work effectively for this project. For final project compilation I utilized the Arc/Info gridline command, converted the output to a shapefile format; then edited, and attributed the road segments.

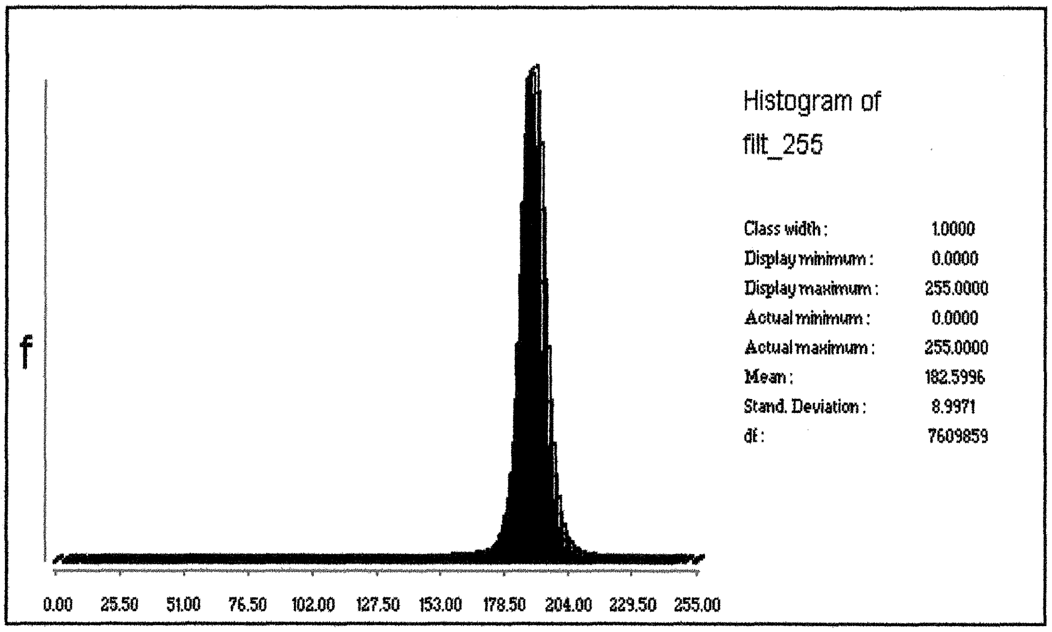

Figure 9
Image histogram of filtered image after conversion to 8 bit data.

New Roads

The original road network was relatively evenly distributed across the Bedell Flat quadrangle (Figure 10). The new road segments are primarily located on the southern part of the quadrangle (Figure 11) while the gas intertie line cuts across the northern part of the quadrangle (Figure 12). Location of new roads and the gas intertie line were developed and plotted as part of this thesis. A combination of all three coverages clearly shows the intrusion of a sizable (27.7 kilometer) network of new roads (Figure 13). This adds 20 percent to the length of the road network shown on the current U.S. Geological Survey topographic quadrangle of the area. The original roads DLG for Bedell Flat listed 141.2 kilometers of roads and passable trails. This project identified 27.7 kilometers of new graded development roads plus 9.7 kilometers associated with the gas line right-a-way. The final combined coverage shows 168.9 kilometers of roads plus 9.7 kilometers associated with the gas line that crosses the northern part of the quadrangle.

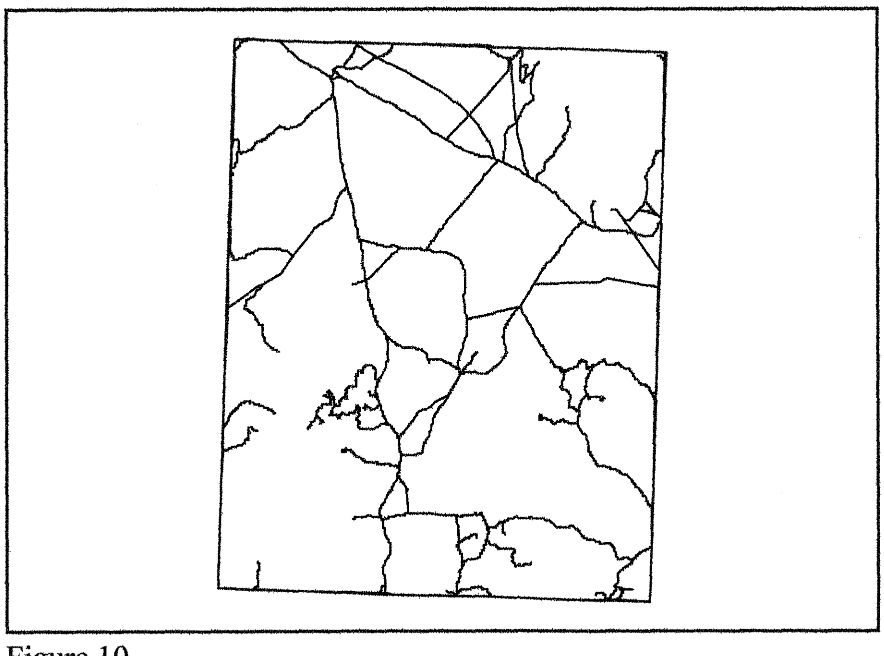

Figure 10
141.2 Kilometers of roads shown on original Bedell Flat roads DLG. This DLG was originally developed from the Bedell Flat quadrangle published in 1980 which was created from aerial photography dated 1975.

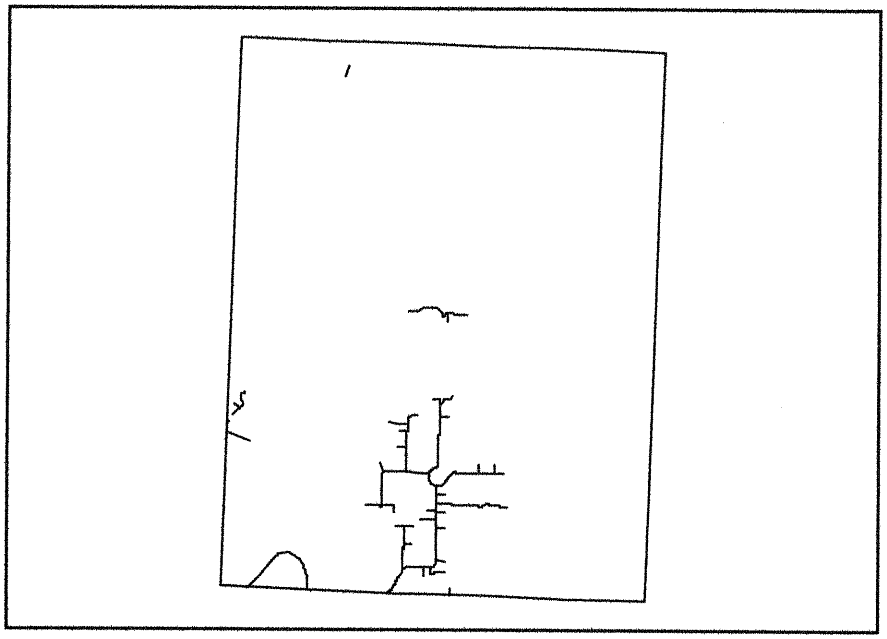

Figure 11
27.7 Kilometers of maintained graded roads newly mapped as part of this project.

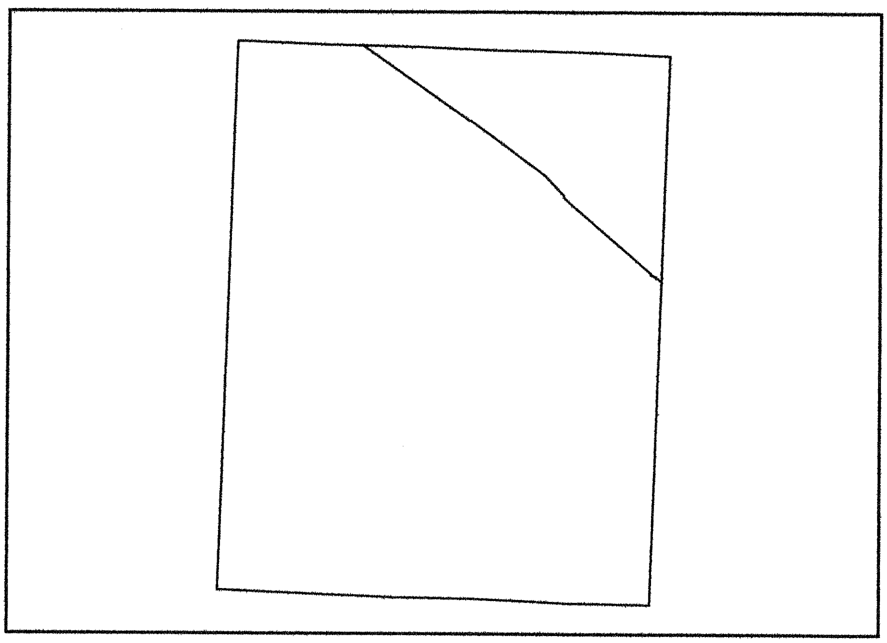

Figure 12
9.7 Kilometers of gas line newly mapped as part of this project.

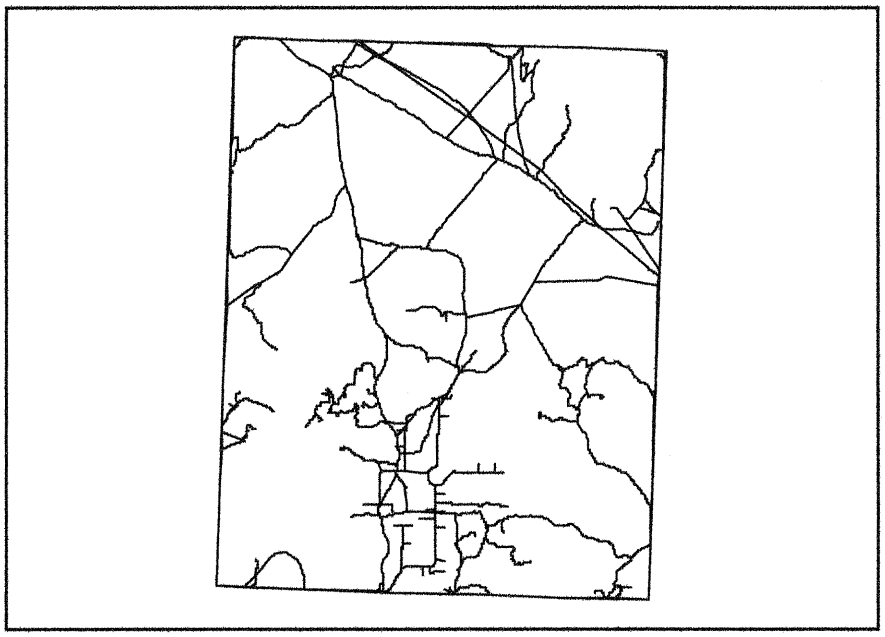

Figure 13
Combined original roads, new graded roads, and gas line. Total length of roads is 168.9 kilometers and 9.7 kilometers of gas line.

Accuracy Assessment

For a new road coverage to be of maximum value, its output vector files must fall within the U.S. Geological Survey horizontal map accuracy standards for 1:24,000 scale mapping. This is the same accuracy standard that governed publication of the original 1:24,000 scale Bedell Flat map, and the standard for the original Bedell Flat roads DLG, which was created from the published map. The U.S. Geological Survey national map standard for horizontal accuracy states:

> Horizontal accuracy. For maps on publication scales larger than 1:20,000, not more than 10 percent of the points tested shall be in error by more than 1/30 inch, measured on the publication scale; for maps on publication scales of 1:20,000 or smaller, 1/50 inch. These limits of accuracy shall apply in all cases to positions of well-defined points only. Well-defined points are those that are easily visible or recoverable on the ground, such as the following: monuments or markers, such as bench marks, property boundary monuments; intersections of roads, railroads, etc.; corners of large buildings or structures (or center points of small buildings);etc. In general what is well defined will also be determined by what is plottable on the scale of the map within 1/100 inch. Thus while the intersection of two road or property lines meeting at right angles would come within a sensible interpretation, identification of the intersection of such lines meeting at an acute angle would obviously not be practicable within 1/100 inch. Similarly, features not identifiable upon the ground within close limits are not to be considered as test points within the limits quoted, even though their positions may be scaled closely upon the map. In this class would come timber lines, soil boundaries, etc. (Muehrcke 1986, page 307).

For 1:24,000 scale maps this standard translates to 90 percent of all identifiable, well-defined points, which must be mapped to within ±12.2 meters (±40 feet) of actual location (Thompson 1981).

To establish the locational accuracy of the new vectorized road coverage, road segments that were on the original Bedell Flat roads DLG were selected that were identifiable on the vectorized new roads coverage. The location of these road segments from the new vector coverage, created from filtered PAN1 5 meter imagery, were compared to the location of the same road segments found on the original Bedell Flat roads DLG. These road segments, with a total length of 4.5 kilometers, were a mix of well-used existing graded roads and roads that had been improved and incorporated into the new maintained road network.

A series of samples was taken. The distance between the original road segments, identified from the DLG, and the new vectorized road segments were measured in meters. Values were recorded as positive if the new line segments were north or west, and negative if the new line segments were south or east of the original DLG road segments. This produced a data set that showed a normal distribution with the following descriptive statistics:

Number of Samples	50.000
Sample Mean	0.760
Minimum	-10.660
Maximum	16.580
Variance	31.256
Standard Deviation	5.591

As described in the U.S. Geological Survey map accuracy standard, 90 percent of all well-defined points on a 1:24,000 scale map must be within ±12.2 meters of actual position. This comparison looks at the variation of location as measured from the original Bedell Flat roads DLG.

A t-test was run on the sample, with a null hypothesis that the population mean equals zero and an alternate hypothesis meaning it does not equal zero. The result was a calculated t-value of 0.96 with 49 degrees of freedom, significantly below the t-table value of 2.01 (for a 95 percent confidence level) meaning that I accept the null hypothesis that the value zero is the mean of the error population and reject the alternate hypothesis (Black 1994). Furthermore, the above test shows a standard deviation of 5.591. That can be interpreted, based on the empirical rule of statistics, to indicate that 68 percent of all sample points fall within ±5.59 meters of the mean and that 95 percent of all sample points fall within ±11.18 meters of the mean (Black 1994). This indicates that, based on the sample standard deviation, at least 95 percent of the new road segments are 11.18 meters or less from the original DLG road segments.

Furthermore, using the following Z value equation to determine the percentage of the distribution equal to and less then ±12.2 meters from the original roads DLG produces a value of 95.9 percent. This is well above the required 90 percent accuracy standard (Thomas 1980).

$$\pm Z = \text{X-Mean} / \text{Standard Dev.} = 12.2 - 0.760 / 5.591 = 2.046$$

On the Z table, for areas of the standard normal distribution, 2.046 translates to 47.98 percent of the upper half of the distribution. This shows that almost 48 percent of the upper half of the error distribution is contained within the distance from the mean to +12.2 meters. Since we are measuring both above and below the mean, this figure is doubled to include the area from -12.2 meters to the mean for a total of 95.96 percent. This indicates that almost 96 percent of the new road segments fall within 12.2 meters of the original road segments that were included within the test (Black 1994).

A further accuracy test, based on a root-mean-square error (RMSE) acceptance test as defined by Thompson in 1981, is defined as follows:

RMSE = Square Root (Sum of error values squared / number of samples)

Allowable RMSE at 1:24,000 scale = 12.2 / 1.66 = 7.3494

The value 1.66 in the above equation is the Z table for 90 percent.

RMSE = Square Root (1560.4294 / 50) = 5.5865

The 5.5865 value of the sample data is approximately 24 percent below the RMSE cutoff value of 7.3494 indicating that the new roads coverage is within the allowable tolerances of the national map accuracy standards.

Procedures

The following is the catalogue of procedures used to obtain a vector line file of new road segments and new gas intertie line located on the Bedell Flat, Nevada, quadrangle..

1. Obtain digital versions of required and base data layers, i.e., current 5 meter panchromatic satellite imagery or other current digital orthophoto quadrangle (DOQ) type product to be used for roads update, roads and boundary digital line

graphs (DLGs), and digital raster graphic (DRGs) from existing published map source available from U.S. Geological Survey.

2. Convert or resample all digital data sets to raster images in same projection, in this case UTM zone 11, and check for proper overlay. A certain amount of this time will also be spent on data familiarization.

3. Confirm by visual inspection that the road network is visible and overlay the out-of-date road network on imagery to become familiar with differences between the two. This type of exploratory data analysis also serves to acquaint the operator with the quality of the imagery and the lay of the land. Some familiarity with the area is beneficial in spotting potential errors.

4. Apply the following 9x9 convolution filter to your image data.

1	1	1	0	0	0	1	1	1
1	0	0	0	0	0	0	0	1
1	0	0	0	0	0	0	0	1
0	0	0	0	0	0	0	0	0
0	0	0	0	-20	0	0	0	0
0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	1
1	0	0	0	0	0	0	0	1
1	1	1	0	0	0	1	1	1

Examine the output for delineation of roads. Examine the histogram of output values. I actually used a query by cursor command to get an idea of the values associated with the items of interest, mainly the new road segments. Note the cutoff value or the value that contains the majority of the pixels that make up the class of features that you are trying to isolate.

5. Reclassify your image to a binary format. Do this by reclassifying the range of values, up to your cutoff value from the last step, to the value 1. All other values are then assigned 0.

6. Examine the binary output. Look for continuity of pixels along road systems. Look at the amount of background pixels and the size of the groups they form. This is an important step. Too much background will develop too many unnecessary background vectors during the vectorization process. Lack of pixel continuity will lead to the need for additional editing of line work either during or after the vectorization process depending on which software package is used. If the binary output has too much background, go back and run the reclassification again with a lower cutoff value. If you lack pixel connectivity along linear features, run the reclassification again with a higher cutoff value.

7. At this point, vectorize the binary file using whichever raster-to-vector software package you have available.

8. Compare the vector output by overlaying it upon the original image data. Look for roads that fall outside of the visible roadway on the image. Look for missing road segments and meaningless vectors that are caused by background features from the binary coverage. These items will have to be edited.

9. In areas where there is overlap between roads on the original DLG and the new roads vector coverage develop a set of samples of the distance between the two and apply your choice of the statistical tests described in the accuracy assessment section of this text. The one of choice would be the RMSE test which would identify if your data is within the acceptable range as stated by the national map accuracy standards. When sampling for this test make sure that the road segments that you are measuring are in fact the same roadways on both data sets and not different roads that have come into use at different times. You should sample no fewer than 30 sites; more is better.

10. Attribute new road segments and other features of interest.

11. The final step is a Q&A examination of the final project. Include in examination a comparison between final road network, original road network, original image, and filtered image. Check for attributing errors. If no errors are found your project is complete.

Summary

This project identified and mapped 27.7 kilometers of new graded roads on the Bedell Flat quadrangle that are associated with low density rural development. Utilizing the same imagery a new major gas intertie line, 9.7 kilometers long, that crosses the northern part of the quadrangle was also mapped.

The methodology and procedures presented allow for the successful updating of rural road networks by utilizing low-cost, high-resolution panchromatic satellite imagery through the application of convolution masking techniques that isolate the parts of the imagery that are associated with well maintained graded roads. This output is then vectorized for use in Geographic Information Systems and desktop Publishing packages. The final output product is well within the accuracy tolerances stated in the U.S. Geological Surveys national map accuracy standards.

This technique will prove useful well into the future as existing missions and future planned launches of 3 to 6 meter resolution imaging satellites continues. As imagery at even higher resolution becomes available this same technique and filter design, but with an enlarged mask area, should function just as effectively.

As the availability of high resolution satellite imagery continues to increases and the cost decrease more agencies will be able to make use of this technique. It is a useful, timely, accurate, and cost effective method of updating rural transportation networks.

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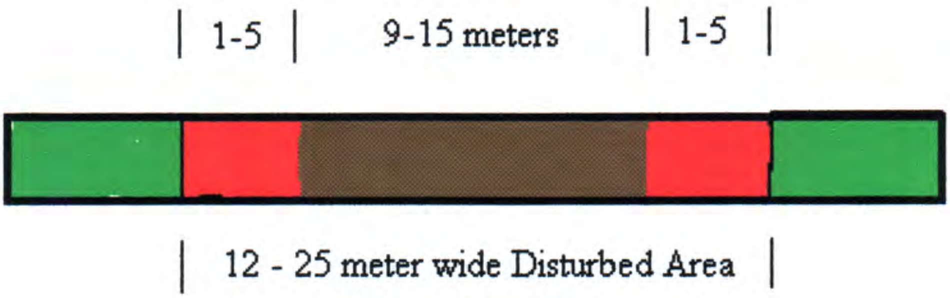
Typical New Road Segment Cross Section

Graded imported gravel or local native material road base.



Graded, Driven Portion of Roadway, edged by Drainage way on each side

Utilities, Drainage, Road Bed Make-up Material, Disturbed and/or Removed Vegetation Area

Natural Vegetation - Undisturbed Area