A GEOGRAPHIC INFORMATION SYSTEM FOR RESOURCE MANAGERS BASED ON MULTI-LEVEL REMOTE SENSING DATA

Douglas J. Wheeler and Merrill K. Ridd
Center for Remote Sensing and Cartography
University of Utah Research Institute
391 Chipeta Way, Suite D
Salt Lake City, Utah 84108

ABSTRACT

This paper outlines procedures followed in developing a test case geographic information system derived primarily from remotely sensed data, for the North Cache Soil Conservation District (SCD) in northern Utah. The North Cache SCD faces serious problems regarding water allocation, flood and geologic hazards, urban encroachment into prime farmland, soil erosion, and wildlife habitat. Four fundamental "data planes" were initially entered into the geo-referenced data base: (1) Land use/land cover information for the agricultural and built-up areas of the valley obtained from various forms of aerial photography; (2) Vegetation/land cover in mountains classified digitally from Landsat; (3) Geomorphic terrain units derived from aerial photography and soil maps; and (4) Digital terrain maps obtained from DMA digital data. The land use/vegetation/land cover information from manual photographic and Landsat interpretation were joined digitally into a single data plane with an integrated legend, and segmented into quadrangle units. These were merged with the digitized geomorphic units and the digital terrain data using a Prime 400 minicomputer. All data planes were geo-referenced to a UTM coordinate grid. The output plot maps and raster maps are scaled to overlay 1:24,000 USGS quadrangles. The utility of the North Cache GIS was evaluated by SCD officials.

INTRODUCTION

Resource managers and planners have become increasingly aware of the need for developing and using automated data structures to deal with complex issues in resource and growth management. Since many management decisions are based on a spatial or geographic basis, much attention has been given to the timely data derived from remote sensing for automated resource mapping.

Remote sensing data in a digital form, or resource maps derived from remotely sensed data, may be entered directly into a geographic information system (GIS) as "layers" of geographically referenced information to be used for comprehensive resource analysis and decision-making.

To evaluate the merging of GIS and remote sensing technology, the Utah Department of Agriculture selected a test area in

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northern Utah, and requested the Center for Remote Sensing and Cartography (CRSC) to assist in establishing a resource data base. The North Cache Soil Conservation District (SCD) was selected as the test area due to its wide array of resource management issues and the interest and willingness for cooperation among local SCD officials. The district includes the northern half of Cache County, Utah, stretching from Logan to the Utah-Idaho border and involves all or parts of 17 USGS 1:24,000 quadrangles (Figure 1). The district encompasses approximately 324,000 acres with 45 percent as agriculture and wetland on the valley floor and 55 percent as rangeland and forest in mountain areas.

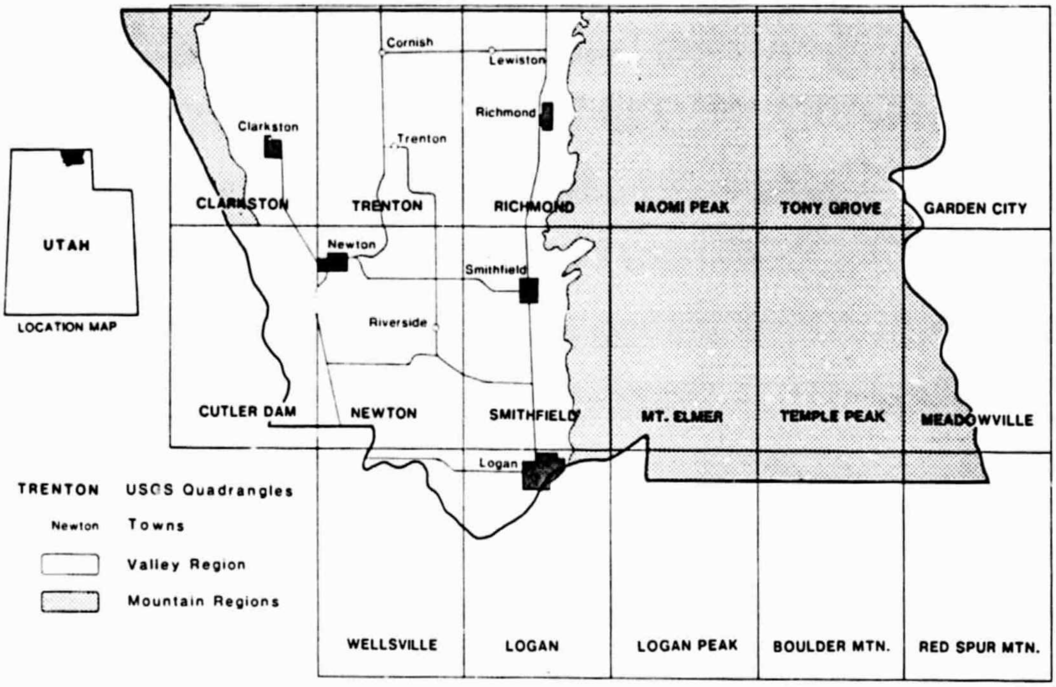

Figure 1. North Cache SCD Study Area with USGS 1:24,000 Quadrangles

Several resource management issues of concern to the North Cache SCD are: (1) site location, impact, and water allocation of prospective dams; (2) flood potential and geologic hazards; (3) urban encroachment into prime farmland; (4) accelerated soil erosion; and (5) condition of wildlife habitat.

These are very complex issues, with many physical, socio-economic, and political ramifications. It cannot be expected to include all information within the initial phase of an interactive data base, so four fundamental data planes were selected as a starting point for the North Cache SCD geographic data base. Each of the data sets involve a different format of remotely sensed data, yet are basic to resource management needs. They include:

1. Land use/land cover information for the valley floor using 1983 as a base year. Data are obtained from

natural color (NC) 35mm slides flown at 5,000 feet, large-scale NC aerial photography, high-altitude color infrared (CIR) photography, and extensive field observations.

2. Vegetation/land cover in the mountains and foothills, using a classification of Landsat digital MSS data.

3. Geomorphic terrain units of the benchlands and basins, using conventional black and white (B/W) photography, soil engineering properties, and field work.

4. Digital terrain mapping of the study area using Defense Mapping Agency (DMA) digital data to derive elevation, slope, aspect, and slope length categories.

Each of these data planes were then merged into a geographically referenced data base using the PRIME/ELAS system at CRSC. This was accomplished by digitizing the land use and geomorphic terrain units mapped from aerial photography and combining them with the Landsat vegetation and digital terrain elements that were already in digital format. A detailed description of the procedures taken in this study are presented in the CRSC report Integrated GIS/Remote Sensing Data Base for Resource and Growth Management in Cache County, Utah (Wheeler and Ridd, 1984).

METHODS

The methods used in converting remotely sensed data into a geographic information base are quite varied, depending upon the original format of the data and the desired results. In this study, an effort was made to use the most cost-effective data-handling means available. Figure 2 is a flow diagram representing the various steps in processing the four elemental data planes and identifies the products initially stored in the North Cache GIS.

Land Use for Valley Basin

Land use categories in the agricultural valley were photo-interpreted from 35mm ektachrome slides taken at an altitude of 5,000 feet during July and August 1983. Large scale (1:9,600) natural color photos from 1981 and high-altitude CIR photography from 1979 were also used for reference. Land use classes were delineated onto an orthophotoquad base map.

The 5,200 foot contour line was determined to be the best threshold between land cover delineations from aerial photography in the valley basin and Landsat coverage in the mountain areas. There are very few agricultural areas above 5,200 feet and no urbanized areas. Vegetation and land cover above 5,200 feet were determined by classification of Landsat digital data. The few farm fields that do lie above this line were delineated from photography and digitized as polygons for integration into the Landsat data set.

One of the critical issues in a land use/land cover inventory is deciding which categories of information are the most useful to delineate (Wheeler and Ridd, 1984). This entails

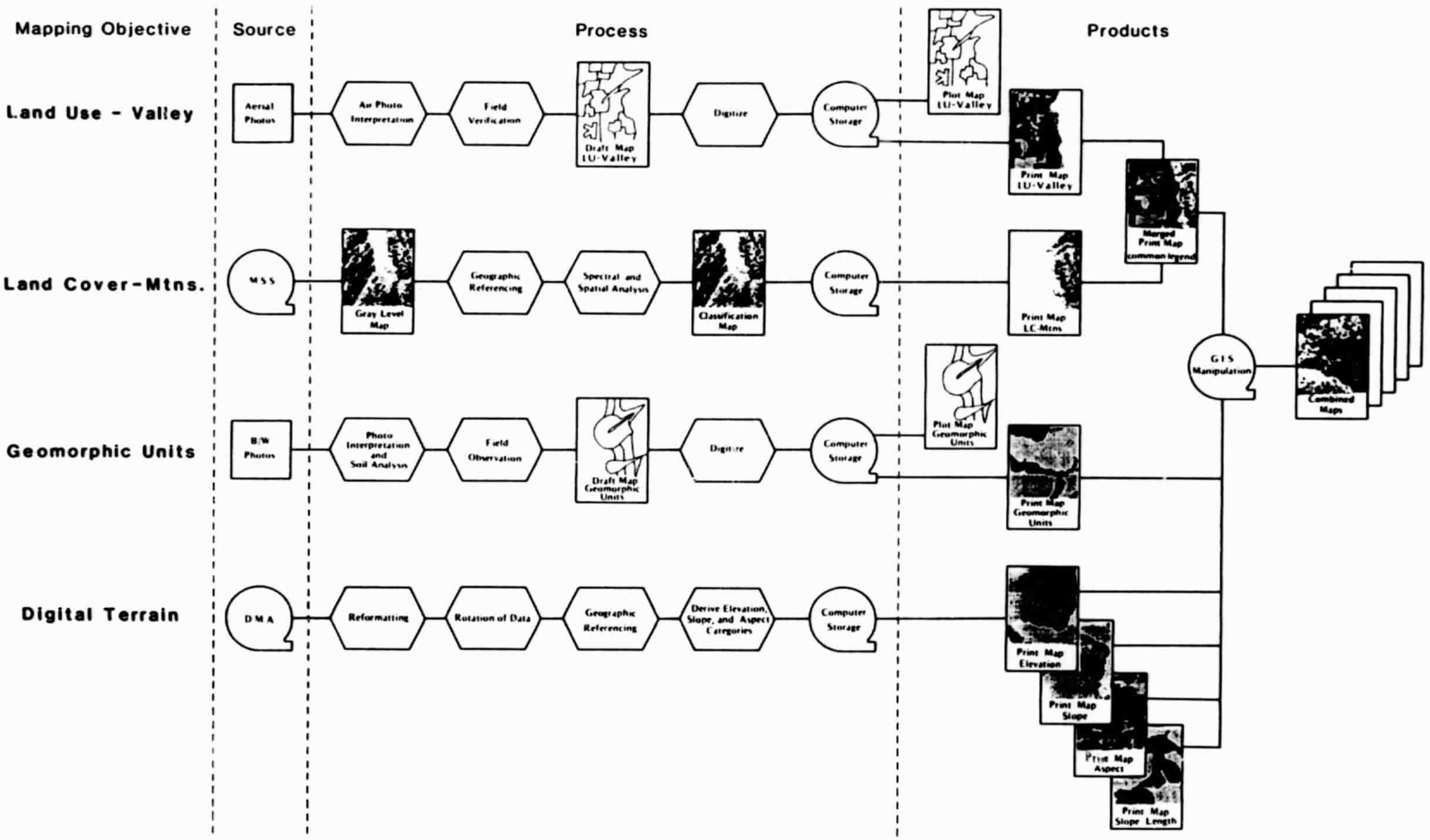

Figure 2. Flow Diagram of Procedures Used in Developing North Cache GIS.

looking at the needs and purposes of the project and determining the detail level that is feasible from the particular medium of observation being used (satellite, aerial photography, ground surveys, etc.) For the specific purposes of this project, an extremely detailed land cover classification would not be functional as a data plane for resource management. Categories must be somewhat generalized or they are outdated from year to year and are costly to update. A legend showing land use categories of the valley portion, along with a merged legend for land use/vegetation/land cover classes for raster maps, is displayed in Table 1.

The draft land use map was then digitized into a geographic data base using a Prime 400 computer and ELAS software (developed by NASA Earth Resources Laboratory). The digitization process consisted of labeling each line segment and tracing them on a Tektronix 4954 digitizing tablet. The software created polygonal units from these segments and plotted out maps on a Zeta 3653sx plotter. ELAS module PGUD also converts polygonal land use data into a raster format for easier storage and GIS manipulation.

Landsat Vegetation/Land Cover Classification of Mountains

Analysis of Landsat digital spectral data has been demonstrated as a successful means of classifying large tracts of forest and rangelands in Utah (Jaynes, 1982; Merola, et al., 1983). Although Landsat may not be as specific or accurate a classifier as aerial photography for small areas, its utility is shown as an economical alternative when mapping extensive areas over several quadrangles. For this reason, as well as the opportunity to experiment with its interface capabilities as a data plane for resource management, Landsat digital data has been utilized in the North Cache GIS. Range and forest types in the foothills and mountains were classified from Landsat MSS data obtained on July 2, 1979.

The first steps in processing Landsat digital data involved reformatting, geographically referencing, and rescaling the data to fit 1:24,000 USGS quadrangles. A program called SRCH was then utilized to generate statistics which characterize pixel groups having similar spectral features across the four Landsat MSS bands. SRCH is a routine in ELAS used to provide training statistics for a program named MAXL, which classifies individual pixels into groups based upon each pixel's highest statistical probability of belonging to a given group. In this study, the SRCH program produced 67 separate signature patterns.

Spectral signatures were then studied statistically to detect similarities and differences. First, a principal components analysis of the mean values for each signature's four MSS bands reduced the data to factor scores for two components. MSS bands 4 and 5 were combined into one component ("visible" light), and bands 6 and 7 were combined to form the second ("infrared" light). Next the factor scores were used in a cluster analysis which grouped spectral signatures according to a similarity index. Finally, the factor scores and group clusters were used in a discriminant analysis of the signatures.

TABLE 1

1.a. Land Use/Land Cover Categories in the Valley (Plotter Maps).

AGRICULTURAL LAND	UPLAND/RANGELAND	OTHER
A - Irrigated agriculture	Ug - Grass and sage	U - Urban communities
Ai - Idle irrigated land	Ur - Deciduous riparian shrub	B - Built-up areas
Ap - Plowed or disked land	Um - Mixed mountain shrub and grass	X - Excavated land
D - Dry farm	Ud - Deciduous forest	W - Wetland environments
P - Nonirrigated pasture (dry)	Uc - Conifer forest	R - Reservoirs
WP - Nonirrigated pasture (wet)		O - Open water

1.b. Merged Land Use/Vegetation/Land Cover Legend for Print Maps.

	AGRICULTURAL LAND		UPLAND/RANGELAND		OTHER
A	Irrigated agriculture		Barren ground	+	Urban communities
I	Idle irrigated land	.	Grass/sage	•	Built-up areas
-	Plowed or disked land	M	Mixed shrub/grass (light)	\	Excavated land
D	Dry farm	M	Mixed shrub/grass (medium)	:	Wetland environments
P	Nonirrigated pasture (dry)	M	Mixed shrub/grass (dense)	B	Reservoirs
W	Nonirrigated pasture (wet)	D	Deciduous trees (sparse)	B	Open water
		D	Deciduous trees (dense)		
		C	Conifer		
		S	Deciduous riparian shrub (dense)		

1.c. Geomorphic Terrain Unit Categories for Plotter Maps.

F1	Old alluvium 1 (above Bonneville level)	M	Montane
F2	Old alluvium 2 (below Bonneville level)	B1	Upper beach (Bonneville Stage)
F3	Recent alluvium	B2	Lower beach (Provo Stage)
RF3	Stream course and flood plain	B2T	Bonneville terrace
G	Deep gullies	L	Lake bottom
P	Pediment	LS	Landslide area

The two-dimensional scatter plot produced in the discriminant analysis allows one to graphically view signature relationships. Figure 3 shows a working copy of the scatter plot and the groups of signatures. The discriminant analysis scatter plot (with two axes -- representing the visible and infrared light components) was then divided into regions or groups of signatures that correspond to similar ground cover types. This process serves a vital link in allowing an often unmanageable number of signatures to be combined into groups of similar signatures. For purposes of this study, the signatures were grouped according to general vegetative cover types of interest to range or wildlife managers.

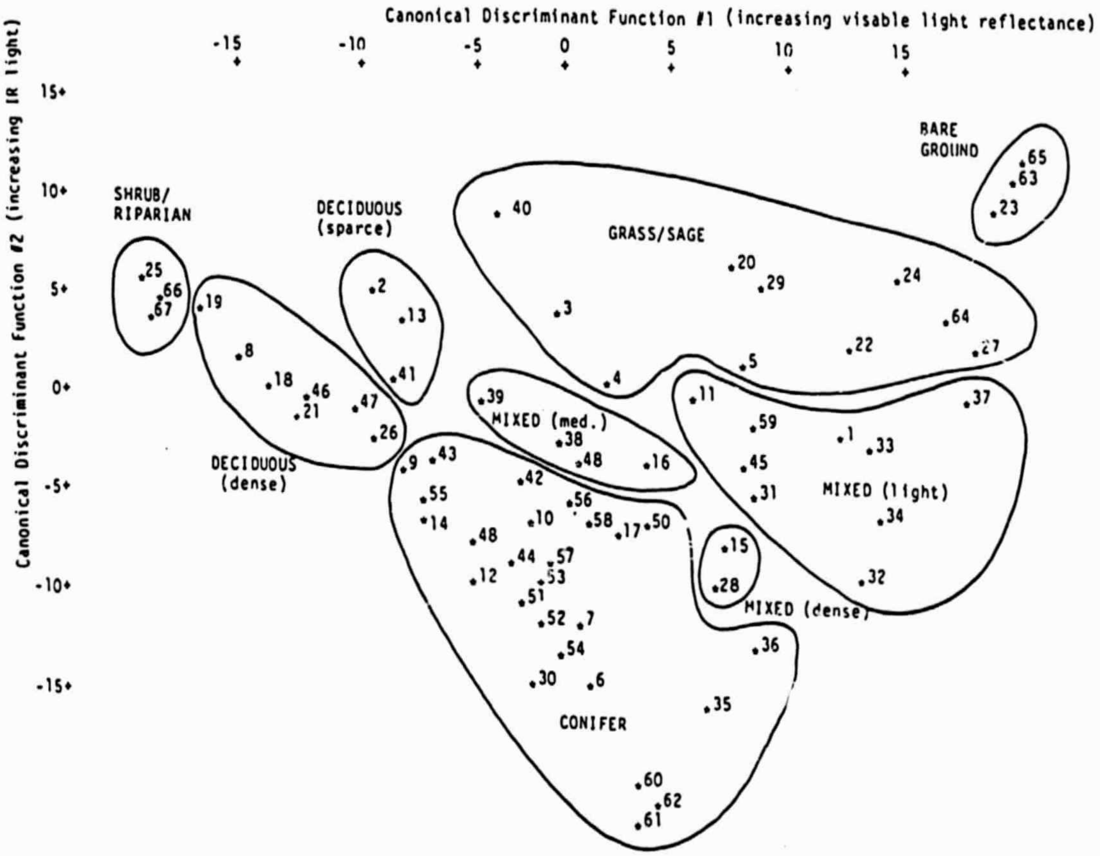

Figure 3. Scatter Plot of Discriminant Scores from 67 MSS Signatures.

After field and photo verification of the vegetative cover types the classification map was merged with the valley use raster file. Those areas above 5,200 feet in elevation are classified by Landsat and areas below 5,200 feet are delineated from photography. An example of the common land use/land cover legend is shown in Table 1.b.

Geomorphic Terrain Units

The main purpose of this data plane is to establish a terrain frame of reference on which to imply general geologic, hydrologic, and engineering characteristics of the landscape.

The basic premise is that geomorphic terrain units exhibit all the natural processes that have interacted at the earth's surface to create the unit. The fact that these geomorphic units are process oriented is evident from their names (beach, river floodplain, alluvial fan, etc.), yet these features were delineated after a careful investigation of soil texture and moisture properties. By using soil properties as identifiers in terrain unit interpretation, it was possible to be more precise in depicting boundaries and makes it possible to use terrain units as surrogates for various other soil engineering properties (permeability, water capacity, strength, shrink-swell potential, etc.)

The initial means of delineating geomorphic terrain units was through stereographic interpretation of B/W and CIR aerial photography. Extensive field observation led to further refinement of geomorphic categories and map units. These preliminary terrain units were then drawn onto a topographic map base. The final refinement came through comparing delineations with the SCS Soil Survey of Cache Valley Area, (1974). Of particular interest in the Soil Survey were the soil engineering properties, which can be used as a general guide to suitability for building permanent structures. Soil texture and moisture holding properties may also be used to infer certain conditions of agricultural suitability. Modifications were made in the geomorphic terrain unit categories and delineations to reflect these properties of the soil. Table 1.c contains a legend for geomorphic terrain maps in the North Cache SCD.

The geomorphic units were digitized in the same manner as the land use delineations for the valley, using ELAS software. Both plotter maps and raster-style print maps of terrain maps were produced, scaled to overlay 1:24,000 USGS topographic quadrangles.

Digital Terrain Information

The purpose behind the digital terrain element of the North Cache GIS was to enable resource managers to utilize elevation, slope, aspect, and various other topographic factors in their decision-making process without having to repetitively digitize factor maps. The Defense Mapping Agency (DMA) digital elevation model data used in this study are recordings of ground position elevations at regularly spaced intervals. The ground distance between each digitized point on the DMA tapes is three arc-seconds of latitude and longitude (approximately 71-92 meters). The vertical accuracy of elevation data is consistent with the accuracy of contours on 1:250,000 USGS topographic maps used to produce the data (7-15 meter root mean square error).

Digital elevation data from DMA tapes were rotated and then transformed into a UTM grid base using topographic routines in the ELAS software. Elevation data were resampled to match pixel size, geographic location, and scale of other data sets in the GIS. Categories of slope, aspect, and slope length were computed by sliding a 3x3 pixel window over the elevational data and calculating the gradient from the center cell. One of the advantages of using digital topographic information is the capacity to quickly change category boundaries to suit the particular purposes of a resource management question. The computer can generate a new topographic factor map in a fraction of the time required for manual delineation.

APPLICATIONS

The true evaluation of a resource-oriented GIS comes from testing its utility in making resource management decisions. Queries to the system must be driven by issues and concerns of managers at the SCD level. Department of Agriculture and North Cache SCD personnel posed a series of questions to help evaluate the utility of a GIS in Cache County. These questions include:

1. What land use categories (with acreages) are most susceptible to flood damage from rising waters on the Bear and Cub Rivers?

2. With installation of the proposed Barren Reservoir in Cache County, what land use types would be innundated and what is the land use within a buffer zone of one mile surrounding the reservoir site?

3. What is the prime farmland being used for; how much is taken over by urban usage?

4. What steep slopes that are presently dry farmed, should be converted to perennial grasses in order to limit soil erosion?

5. Where are the prime deer winter range sites located and how many acres are available?

In order to assess which land uses are most susceptible to flooding from the major rivers in Cache Valley the land use map was stratified by geomorphic units. All of the land uses found within the active river floodplain terrain unit (RF3) were printed out in a raster print map and acreages were automatically tabulated. Using the Trenton quadrangle as an example, 87 percent (3,210 acres) of the river floodplain was listed as wetland or open water, with only one percent of the area developed.

The proposed Barrens Reservoir, which straddles the Newton and Trenton quads, would cover 4,400 acres. The greatest portion of this area is now considered idle agricultural land (54 percent). Of the one mile buffer zone surrounding the reservoir site (10,200 acres), 56 percent contains actively irrigated agriculture and 12 percent is idle or plowed agricultural land.

A Soil Conservation Service map showing prime farmland and land of statewide importance was digitized into the North Cache GIS. Using Richmond quadrangle as an example 7,028 acres (66 percent) of the prime farmland was being used for irrigated agriculture in 1983. Seventeen percent (1,772 acres) was listed as urban or built-up. In lands of statewide importance,59 percent (1,022 acres) was irrigated in 1983 and 14 percent (248 acres) was developed or excavated.

Severe soil erosion from dry farm areas on steep slopes have been a great concern to soil conservationists in the North Cache SCD. Plowed slopes over 20 percent are to be sown with perennial grasses. A demonstration with the Smithfield quadrangle displayed all slope categories within the dry farm regions, showing 640 acres of dry farm with greater than 20 percent slope.

The deer winter range inventory involved several data planes. It was determined that prime winter habitat in Cache Valley encompassed areas on south to west facing slopes, below 5,500 feet in elevation, and with riparian or mixed shrub vegetation types. It was noted that most of the prime deer winter range in Cache County has been impacted by development.

The test case resource management GIS developed for the North Cache SCD is now being expanded to incorporate other data not specifically related to remote sensing (i.e. digitized maps). In order to provide information access to the widest array of users, CRSC is transferring data from the North Cache GIS to the State of Utah's ARC/INFO automated geographic reference system. It is expected that once the transfer of files is complete, the digital analytical data system will provide reasonable access and meaningful answers for local resource managers, and stand as a model for future data acquisition through remote sensing technology.

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