Visual Analysis of Landsat Thematic Mapper Images for Hydrologic Land Use and Cover

Laurie J. Trolier and *Warren R. Philipson*
Cornell Laboratory for Environmental Applications of Remote Sensing, Cornell University, Ithaca, NY 14853

ABSTRACT: Two Landsat Thematic Mapper (TM) scenes of upstate New York were examined by experienced and novice image interpreters to determine the ease of identifying 22 land-use or cover classes that have a major effect on the quality and quantity of watershed runoff. Individual bands and selected composites of one scene were analyzed at a scale of 1:35,000, with the aid of topographic maps, to familiarize the interpreters with the appearance of the classes. Bands and composites of the second scene were then interpreted at a scale of 1:70,000 with no aids. With this preparation, even novice interpreters could identify most classes at 1:70,000. Best results were obtained with bands 3, 4, and 5 or a composite of these three bands. Overall, visual analysis of enlarged TM images can provide an accurate and cost-effective inventory of hydrologically important land use and cover.

INTRODUCTION

THE QUALITY, quantity, and timing of watershed runoff are strongly dependent on land use and cover (Soil Conservation Service, 1972 and 1975; Environmental Protection Agency, 1973; Novotny and Chesters, 1981; Daniel *et al.*, 1982; Ostry, 1982). Landsat Multispectral Scanner (MSS) data have been used to identify land use and cover classes relevant to runoff studies (Bondelid *et al.*, 1980; Ragan and Jackson, 1980; Slack and Welch, 1980; Harvey and Solomon, 1984; Jackson and Bondelid, 1984). Despite geographical differences, a common set of classes has been identified in most MSS analyses: highly impervious (commercial, industrial, parking lots), residential, forestland, agricultural, bare ground/extractive, and water. This is a rather coarse classification, insufficient for some hydrologic models.

Compared to the MSS, the Landsat Thematic Mapper (TM) offers higher spatial resolution (30 m versus 79 m), more spectral bands (seven versus four), and increased quantization levels (256 versus 128), and should thus provide greater detail in inventorying land use and cover (Williams *et al.*, 1984). This has been demonstrated with digital analysis of TM data (e.g., Gervin *et al.*, 1983; Quattrochi, 1983) but, even when the facilities for digital image analysis are available, the cost for TM computer-compatible tapes is high. Presently, TM photographic products are a small fraction of the cost of digital data.

The purpose of this study was to determine how well hydrologically important land-use and cover classes can be identified through visual analysis of TM images. The main advantages of visual analysis are cost and accessibility: the lower costs of TM photographic products make them far more accessible than the digital data to many potential users. These advantages increase if visual analysis requires fewer than the full seven TM bands.

PROCEDURE

IDEAL LAND USE AND COVER LIST

The first step was to develop an ideal list of land-use and cover classes for runoff studies. The Soil Conservation Service (1972, 1975), Algazi and Suk (1977), Novotny and Chesters (1981), and others have developed such classifications which vary slightly due to objective and differences in methods of data acquisition. Another more general land-use and cover classification was developed by Anderson *et al.* (1976) for use with remotely sensed data in a variety of environmental applications. These classifications were synthesized to arrive at 22 classes which are listed here with a brief description or justification for inclusion.

RURAL LAND

(1) CROPLAND - All row, grain, vegetable, or other cultivated crops. In areas where steep slopes are farmed, it would be important to further subdivide this class by observable soil conservation measures (e.g., contour tillage).
(2) ORCHARDS/VINEYARDS - Although superficially similar to forest or brushland, this class is subject to management practices that disturb or expose the soil and introduce pesticides and fertilizers.
(3) FEEDLOTS/BARNYARDS - In some areas, this class is an important source of nutrient pollutants such as nitrogen and phosphorus (Daniel *et al.*, 1982).

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(4) PASTURE - Improved grazing land. It is generally not plowed and, if not overgrazed, the grasses are kept at a level which trap sediment and nutrients.
(5) BARE SOIL - Fallow land which has little or no living vegetation or other exposed soil areas at the time of the image.
(6) FOREST - Forested areas yield little runoff because the tree canopies and forest litter intercept or absorb much of the moisture.
(7) BRUSHLAND - A mixture of shrubs, weeds, and grasses, undisturbed by urban development and not currently under cultivation.
(8) WETLANDS - Serve as natural filtration zones, where pollutants and sediment can be trapped and removed from the stream system. Also, storm flows entering a wetland are spread out and subdued (Novotny and Chesters, 1981).
(9) EXTRACTIVE INDUSTRIES - Quarries, pits, strip mines, etc.
(10) BEACHES - Large sandy areas which are highly pervious.
(11) WATER BODIES - Ponds, lakes, streams, and rivers.

Urban Land

(12) CENTRAL BUSINESS DISTRICT - City area with the highest concentration of buildings, roads, and impervious surfaces, and almost no vegetation.
(13) COMMERCIAL - Commercial and light industrial complexes which are composed of large buildings, warehouses, institutions, shopping centers, large parking lots, and, often, vegetated areas.
(14) HEAVY INDUSTRIAL - Manufacturing facilities, refineries, stock piles, storage tanks, etc. Although commercial and heavy industrial areas are both highly impervious, they release different pollutants into runoff and should be distinguished (Cermak *et al.*, 1981; Daniel *et al.*, 1982; Environmental Protection Agency, 1973; Ostry, 1982).
(15) HIGH DENSITY RESIDENTIAL - Multiple family housing, mature trees, and little grass.
(16) MEDIUM DENSITY RESIDENTIAL - Suburban developments and homes lined along one or both sides of a road in less urbanized areas, with more grass, shrubs, and younger trees.
(17) LOW DENSITY RESIDENTIAL - Farmsteads or isolated single family homes.
(18) TRANSPORTATION - Roads, highways, bridges, railways, airports.
(19) TENDED GRASS - Parks, sports fields, large lawns, cemeteries, golf courses.
(20) DEVELOPING URBAN - Areas under construction.
(21) WASTE DISPOSAL - Water and sewage treatment facilities, land-fills, junkyards, etc.
(22) MIXED BUILT-UP - Mixed urban land uses/covers.

Imagery and Analysis

Two areas in upstate New York were chosen for study because of their variety of rural and urban land use and cover: Tonawanda, located north of Buffalo (TM path 17, row 30), and Rochester, including Irondequoit Bay (TM path 16, row 30). TM computer-compatible tapes for these areas were already available to the study through an unrelated investigation. Tonawanda was imaged on 13 September 1982 and Rochester (Figure 1) was imaged on 17 July 1984.

Because the tapes and a digital image processing system were readily available, 35-mm photographic slides of each band and selected band composites were taken from the digital image display, where the study areas were seen at a scale of approximately 1:60,000. The 35-mm slides were then projected and analyzed at scales of 1:35,000 and 1:70,000. Although enlargements of the 1:1,000,000-scale standard TM photographic product by approximately 15 and 30 times may seem unreasonable, they are within the magnification range of such mapping devices as the Procom-2 (Gregory *et al.*, 1982). Moreover, if an enlarged TM photographic product is initially purchased or photographically processed, the required magnification could be obtained with a projector or Zoom Transfer Scope. Although photographically enlarging an already enlarged, digitally displayed TM scene is obviously different from photographically or optically enlarging a TM photographic product, the results should be comparable and provide a reasonable indication of results that would be achieved with the photographic product.

Analysis of the slides was done by five individuals whose image interpretation experience ranged from none to many years. The interpreters evaluated the seven individual bands and two composites. One composite consisted of band 2 colored blue, band 3 colored green, and band 4 colored red (the "234 composite"), and the other composite consisted of band 3 colored blue, band 5 colored green, and band 4 colored red (the "354 composite"). Bands 3, 4, and 5 and the 354 composite for the central portion of Figure 1 are shown in Plate 1. A classification map of this area is provided in Figure 2. Verification of the land-use and cover classes was accomplished by analyzing low altitude aerial photographs.

The Tonawanda study area was analyzed first at a scale of 1:35,000 with the aid of U.S. Geological Survey 1:24,000-scale topographic maps. This was done primarily to familiarize the interpreters with the appearance of the different land-use and cover classes on the TM images. The Rochester study area was then analyzed at a scale of 1:70,000 with no aids. For both study areas, the interpreters rated the ease of identifying the ideal 22 land-use and cover classes as "yes" for positive identification, "no" for lack of identification, and "maybe/marginal" for possible or inconsistent identification. They did not produce classified maps of the areas. The ratings for the 1:70,000-scale analyses were averaged to provide an assessment of the value of TM images for inventorying hydrologic land use and cover.

Results and Discussion

General Assessment of TM Bands

Most interpreters found it easiest to first locate a particular class on a composite (especially the 354

FIG. 1. Thematic Mapper band-4 image of Rochester, N.Y., study area (17 July 1984). The central business district of Rochester is in the lower left (southwest), Irondequoit Bay is the linear water body in the center, and Lake Ontario is on the upper left (northern) edge of the image.

composite) and then review each band to see if that class could be found. Ratings of the interpretive capacity of TM bands and composites, based on the 1:70,000-scale images of the Rochester areas, are presented in Table 1. Judging from the table, it is clear that there is a fair amount of redundant information in the seven bands. For example, interpretations of the first three visible bands (bands 1 to 3) were nearly identical for both the rural and urban classes. Of the three, band 3 would be the best because it is least affected by atmospheric scattering and offered positive identification of some classes where bands 1 and 2 did not.

Interpretation of band 4 (near-infrared) separated many classes. This band provided unique information with the strong absorption of water, the high reflectance of vegetation, and the clarity of street patterns highlighted by vegetation. Although band 4 provided good contrast between classes, detail within urban classes was usually lost. For example, all features within the commercial and industrial areas appeared generally dark, whereas constituent features of these classes (roads, buildings, parking lots, etc.) were apparent only with bands 3, 5, and 7.

Band 5 (mid-infrared) was useful for identifying cropland, wetlands, beaches, water bodies, tended grassland, and detail within commercial areas; however, it was not good for identifying residential areas. Water absorbs strongly in the band 5 image, while bare soil areas and grass-type vegetation are highly reflective.

Band 6 (thermal infrared) was not particularly useful because of the lower spatial resolution (120 m versus 30 m) and relatively low contrast of the daytime thermal image. Forest and water bodies were the only two classes which could be easily identified.

Band 7 (mid-infrared) appeared very similar to band 3. The land/water interface and the various rural and vegetative cover classes were better defined with band 7, while band 3 showed urban features better.

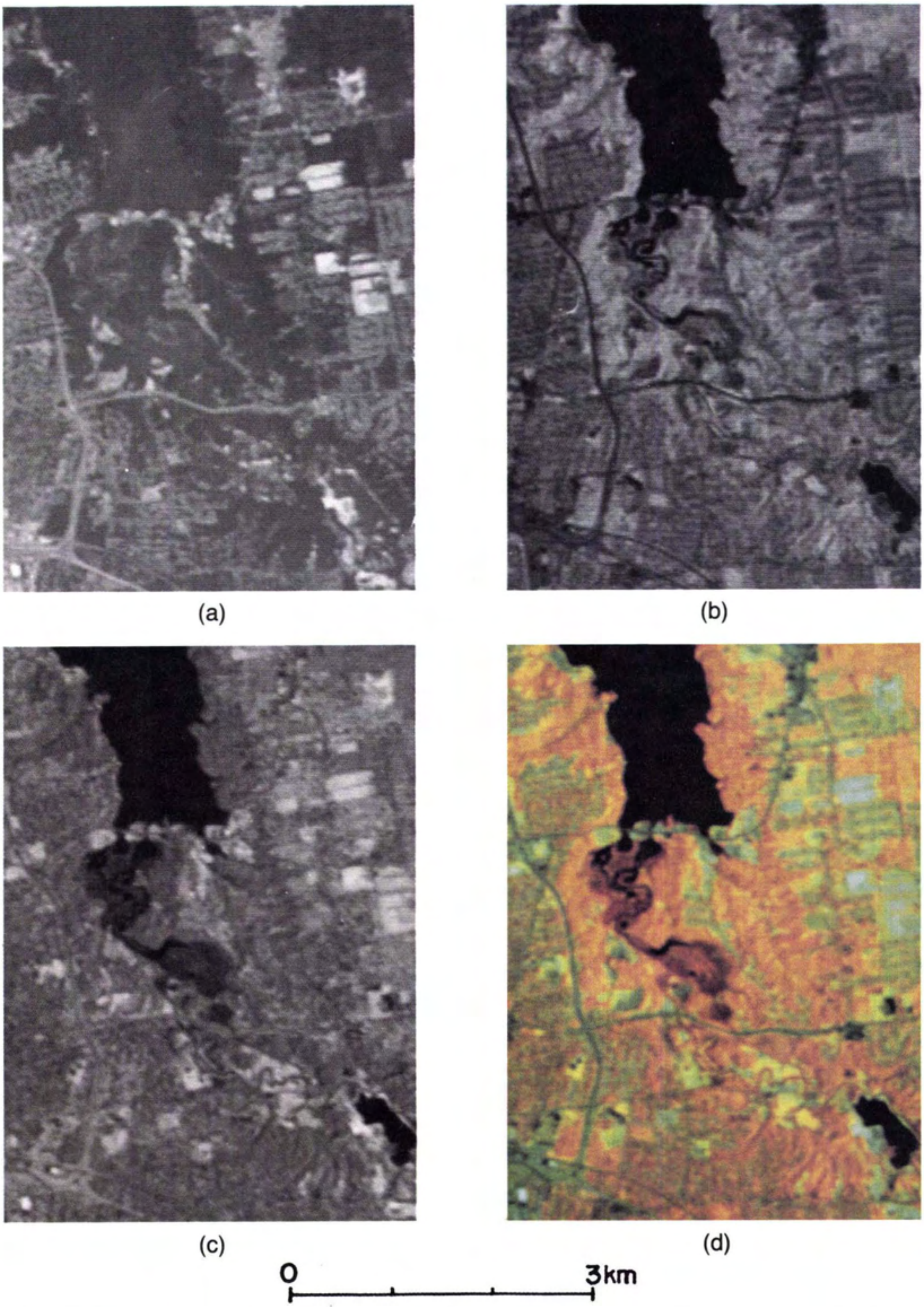

PLATE 1. Central portion of Rochester, N.Y., study area on Thematic Mapper band 3 (a), band 4 (b), band 5 (c), and 354 composite (d).

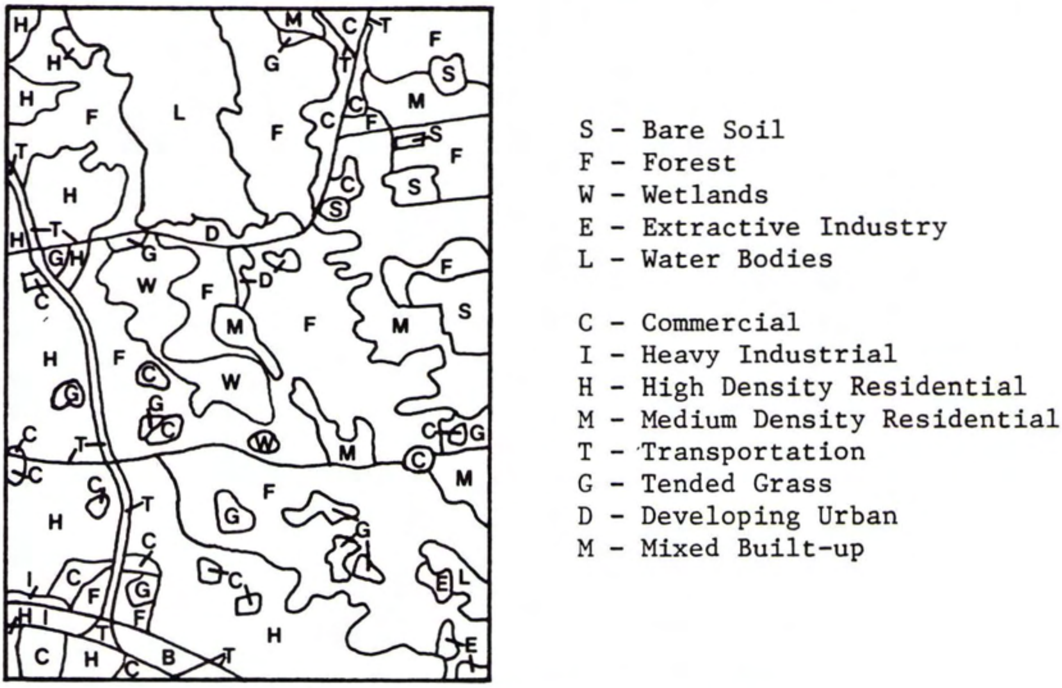

FIG. 2. Land-use and cover map of central portion of Rochester, N.Y., study area.

In general, recognition of hydrologic land use and cover could generally be accomplished best with the individual bands 3, 4, and 5. Further, the 354 composite was the best overall image, even though the residential classes were not always distinguished. Urban classes were separated best with visible bands, while most rural and vegetative cover types were separated best with infrared bands. These results are in agreement with studies by Staenz *et al*. (1980), Gervin *et al*. (1983), and Chavez *et al*. (1984), who found that it would be sufficient to include one band each from the visible, near-infrared, and mid-infrared portions of the spectrum to extract most of the information in a TM scene.

Specific class interpretations from the 1:70,000-scale TM images of the Rochester area follow (Table 1).

RURAL LAND USE CLASSES

(1) CROPLAND - Cropland could be easily identified based on field boundaries, shapes, and tones. The 354 composite was the most useful single image for separating cropland from other vegetative types. Although several different crops could be separated, they were combined for this study. Contour tillage and strip cropping should be easily observable though they are not practiced in the study areas.

(2) ORCHARDS/VINEYARDS - Orchards and vineyards were confused with crops and brush. No distinctive row or canopy patterns were observed.

(3) FEEDLOTS/BARNYARDS - The small feedlots and barnyards in the New York study areas could not be distinguished from low density residential units or other single structures in rural areas. These results would likely differ where feedlots cover larger areas.

(4) PASTURE - The identification of improved pasture is dependent on the date of the image and the size of the field. Most interpreters were able to recognize pastures on the 1:35,000-scale Tonawanda images with the presumption that pastures were spectrally similar to tended grass but located outside urban limits. On the 1:70,000-scale Rochester images, however, pastures could not be identified with confidence. The Rochester scene was acquired in mid-July when there is a great deal of spectral similarity between young crops and pasture; the Tonawanda scene was recorded in mid-September when most crops have been harvested and grass covered areas beyond urban development are more distinctive. Also, in more rural areas, large improved pastures might be more obvious because of their size.

(5) BARE SOIL - Bare soil was distinctive on most bands and both composites. These areas appear highly reflective in the visible and dark in the near-infrared, presenting a direct contrast with vegetative classes. In the thermal band 6, the bare soil areas were slightly warmer than the surrounding cropland, though boundaries were not clear.

(6) FOREST - Forest was easily separated on the visible bands, band 7, and the 354 composite. Forested land on the thermal band 6 was cooler than cropland.

TABLE 1. INTERPRETER'S ABILITY TO RECOGNIZE HYDROLOGICALLY IMPORTANT LAND USE AND LAND COVER ON 1:70,000-SCALE THEMATIC MAPPER IMAGES (ROCHESTER, N.Y.)

	TM Bands and Composites								
	1*	2	3	4	5	6	7	234	354
RURAL LAND									
Cropland	M**	M	Y	Y	Y	N	Y	Y	Y
Orchards/Vineyards	N	N	N	N	N	N	N	N	N
Feedlots/Barnyards	N	N	N	N	N	N	N	N	N
Pasture	N	N	N	N	N	N	N	N	M
Bare Soil	Y	Y	Y	N	M	M	Y	Y	Y
Forest	Y	Y	Y	M	M	Y	Y	Y	Y
Brushland	N	N	N	N	N	N	N	N	N
Wetlands	N	N	N	Y	Y	N	M	Y	Y
Extractive Indust.	Y	Y	Y	Y	N	N	Y	Y	Y
Beaches	Y	Y	Y	N	Y	N	Y	Y	Y
Water Bodies	M	M	M	Y	Y	Y	Y	Y	Y
URBAN LAND									
Cent. Business Dist.	M	M	Y	Y	Y	N	Y	Y	Y
Commercial	M	M	Y	Y	Y	N	M	Y	Y
Heavy Industrial	M	M	Y	Y	M	M	Y	Y	Y
High Density Res.	M	Y	Y	Y	N	N	N	Y	Y
Medium Density Res.	Y	Y	Y	Y	N	N	Y	Y	Y
Low Density Res.	M	M	M	N	N	N	N	N	M
Transportation	Y	Y	Y	Y	M	N	Y	Y	Y
Tended Grass	N	N	N	Y	Y	N	N	Y	Y
Developing Urban	M	M	Y	M	M	N	N	Y	Y
Waste Disposal	N	N	N	N	N	N	N	N	M
Mixed Built-up	M	M	M	M	N	N	Y	Y	Y

*Bands 1 to 7 are, respectively, band 1, 0.45 - 0.52 μm; band 2, 0.52 - 0.60 μm; band 3, 0.63 - 0.69 μm; band 4, 0.76 - 0.90 μm; band 5, 1.55 - 1.75 μm; band 6, 10.40 - 12.50 μm; and band 7, 2.08 - 2.35 μm. The 234 and 354 composites were formed with the first band blue, the second green, and the third red.

**Y = Yes (identification is possible)
M = Marginal (identification is marginal)
N = No (identification is not possible)

(7) BRUSHLAND - Brushland was not distinguishable from other natural vegetation. Areas composed of a mixture of trees, brush, and weeds appeared the same as forested areas.

(8) WETLANDS - Wetlands were easily distinguished, appearing darker than forested or other vegetated areas on all bands. The composites and band 5 were especially useful.

(9) EXTRACTIVE INDUSTRIES - Although highly reflective in the visible bands, and thus similar to developing urban, beach, and bare soil classes, this class has a distinctive size, shape and location. Bands 1 to 4, 7, and both composites were useful.

(10) BEACHES - All but bands 4 and 6 were good for identifying beaches. These bright reflecting areas are easily recognized on lake perimeters but can be confused with roadways along the shores.

(11) WATER BODIES - Water was easily recognized on the reflective infrared bands (4,5,7), where it appears black due to the strong infrared absorption. As more sediment clouds the water or as the water becomes shallow, identification becomes more difficult. Similarly, as the scale decreases, smaller water bodies became nearly impossible to identify.

URBAN LAND-USE CLASSES

(12) CENTRAL BUSINESS DISTRICT - This class was most clear on band 4 and the composites. The spatial pattern of converging roads, concentration of buildings, lack of vegetation, and the surrounding high density residential areas make it geographically distinct.

(13) COMMERCIAL - When commercial structures were accompanied by large grassed areas, they were easily identified; however, it was impossible to separate commercial from industrial structures along strip developments. The 354 composite was useful for identifying the large rooftop and pavement materials associated with commercial land use.

(14) HEAVY INDUSTRIAL - Not all of the interpreters felt confident about separating commercial from heavy industrial areas at both scales. Location of industrial areas (e.g., along railways) was a reliable indicator, and on the 354 composite, industry was darker toned.

(15) HIGH DENSITY RESIDENTIAL - This class could be recognized using bands 1 through 4 or the composites. The density of street patterns was enhanced best by the contrast with vegetation in band 4 and the 234 composite. The proximity to the central business district was also a useful aid.

(16) MEDIUM DENSITY RESIDENTIAL - This suburban class could be easily identified with the same bands as were best for recognizing high density residential. Separation of medium from high density residential was based on street patterns and amount of vegetation.

(17) LOW DENSITY RESIDENTIAL - Individual homes or farmsteads could not be seen because they blended with the surrounding cropland, bare soil, or forest.

(18) TRANSPORTATION - Highways and railways could be recognized on most bands, though smaller roads were harder to identify. Some roads were seen because structures and vegetation high-lighted the corridors. Band 4 was by far the most useful image.

(19) TENDED GRASS - Parks and golf courses appeared distinctive on bands 4 and 5 and the composites. On band 4, the tended grass was lighter in tone than other vegetation; on band 5, the different vegetative classes were also separable.

(20) DEVELOPING URBAN - Areas under construction were recognized as very bright reflectors in the visible bands, but the two composites were most useful. The spatial pattern and location of this class was important in separating it from other land uses. Most small areas under construction could not be detected at 1:70,000.

(21) WASTE DISPOSAL - Sewage or water treatment plants could not be identified. The associated buildings and tanks were identified as heavy industrial or commercial classes, and although settling ponds were marginally visible as small water bodies, their purpose could not be determined. Multi-date imagery might be useful for locating larger landfills, though they could still be confused with extractive industries or construction.

(22) MIXED BUILT-UP - This class was helpful for those areas where structures, roads, and vegetation could be seen, but a specific land use could not be determined.

CONCLUSION

In this TM analysis of upstate New York study areas, only six of an ideal list of 22 hydrologic land-use and cover classes could not be recognized at a scale of 1:70,000 — orchards/vineyards, brushland, pasture, low density residential, waste disposal, and feedlots/barnyards. Of these, feedlots were not well represented in the study areas; brushland was confused with forestland, but the two could be combined as "natural vegetation"; pastures were confused with young crops; orchards/vineyards were confused with cropland and brushland; low density residential was confused with most rural land-use/cover types because individual homes could not be located; and waste disposal sites were confused with industrial, commercial, and bare soil classes. Because the confused classes have similar effects on runoff, these errors are not especially serious. Similarly, although there was some confusion between commercial and industrial areas, especially in strip development along roadways, these three classes could be redefined and recognized as central business district, isolated commercial units, and industrial/commercial strips.

The single most useful band for recognizing both urban and rural classes was band 4, while the 354 composite provided maximum class separability. Band 3 provided detail in cultural features, band 4 enhanced boundaries between cultural and vegetative classes, and band 5 revealed subtle vegetative differences and added detail in cultural features. Bands 3, 4, and 5 are recommended, preferably as individual bands from which a diazo or color-additive composite can be produced. This would allow the assessment of the separate and combined bands. Judging from the two dates used for analysis, 17 July and 13 September, and considering seasonal changes, a mid- to late-summer scene for temperate zones would be best for distinguishing land-use and cover classes important for runoff analysis.

Overall, visual analysis of enlarged TM images can provide enough spatial and spectral detail to accurately identify most of the important hydrologic land-use and cover classes — possibly twice as many classes as could be derived through digital analysis. Defining land-use classes in greater detail shoud allow more accurate characterization of pollutant loads or runoff. While the approach in this study — photographically enlarging an already enlarged, digitally displayed TM scene — is quite different from photographically or optically enlarging a TM photographic product, it is clear that visual analyses of enlarged TM images can provide cost-effective inventories of hydrologic land use and cover.

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