Evaluating Remote Sensing Methods for Targeting Erosion in Riparian Corridors

Laura E. Christianson, Ph D.
Research Agricultural Engineer, The Conservation Fund Freshwater Institute, Sheperdstown, West Virginia

Meagan B. Smith
Former undergraduate student, Biosystems and Agricultural Engineering, Oklahoma State University, Stillwater, Oklahoma

Daniel E. Storm, Ph D.
Professor, Biosystems Engineering and Agricultural, Oklahoma State University, Stillwater, Oklahoma

Michael J. White
Agricultural Engineer, USDA Agricultural Research Service, Grassland Soil and Water Research Laboratory, Temple, Texas.

Scott H. Stoodley
Director, Environmental Science Graduate Program, Oklahoma State University, Stillwater, Oklahoma

Abstract. **State agencies in the United States and other groups developing water quality programs have begun using satellite imagery with hydrologic/water quality modeling to identify possible critical source areas of erosion. To optimize the use of available funds, quantitative targeting of areas with the highest potential for water quality improvement is required. The objective of this research was to compare land cover classification accuracy of SPOT 5 and Landsat 7 satellite imagery with aerial photography to identify land cover categories thought to be critical sources of erosion in riparian corridors. Land cover for 24 km^2 of riparian corridor in the Turkey Creek Watershed in Oklahoma was manually digitized from existing color aerial photography and used as a surrogate layer for assessing the SPOT 5 and Landsat 7 accuracy. Land cover percentages derived from each image type were compared. Weighting factors based on the type of land cover classification error were used to evaluate the magnitude and spatial distribution of the errors. Manual classification using aerial photography was determined to be the best option for areas up to twice the study size. For areas that exceed this critical size, Landsat 7 was recommended over SPOT 5 as the more cost effective satellite option.**

Introduction

Sediment is the most prevalent agricultural non-point source pollutant in US surface waters (USEPA, 2005). Research has shown that erosion can be reduced by best management practice (BMP) implementation (USEPA, 1995; USEPA, 1993; Ripa et al., 2006). One mechanism used to encourage BMP implementation is Section 319 of the Clean Water Act. Section 319(h) establishes funds to help states and tribal nations address nonpoint source water pollution (USEPA, 2003). However, these funds are limited and thus quantitatively targeting areas with the highest potential for water quality improvement is required to optimize their expenditure (Ripa et al., 2006).

Erosion rates are highly dependent upon the amount of surface residue or biomass. In order to target critical sediment source areas, an accurate land cover map is required. This map is typically created by either extensive ground surveys or limited ground-truth surveys in combination with aerial photography and/or satellite imagery. For large areas, aerial photography and satellite imagery are far less expensive and less time consuming than ground surveys (Jakubauskas et al., 1992; Harvey and Hill, 2001). After an accurate land cover map is developed, areas can be targeted for BMP implementation using hydrologic/water quality models or simpler Geographic Information System (GIS) based methods (Jakubauskas et al., 1992).

Past research recommends the use of different image sources, either aerial photography and/or satellite imagery, based upon the desired accuracy (Mosbech et al., 1994; Rowlinson et al., 1999; Harvey and Hill, 2001). For detailed land cover mapping, satellite imagery may not provide adequate spatial resolution (Mosbech et al., 1994; Harvey and Hill, 2001). If high levels of detail are required, aerial photography is the most accurate and most cost effective (Rowlinson et al., 1999). Manual visual interpretation of aerial photography provides higher land cover specificity compared to computer algorithms used to classify satellite imagery (Jakubauskas et al., 1992; Ventura and Harris, 1994). Nevertheless, due to the high cost of aerial photography, time required for manual interpretation and flying restrictions in some areas, satellite imagery is often the optimal choice for small-scale area studies (Mosbech et al., 1994; Harvey and Hill, 2001). This is particularly true with the emergence of new satellite sensors with high spectral and spatial resolution.

With satellite imagery, some researchers have favored Landsat data over SPOT (Satellite Probatoire d'Observation de la Terre) imagery. Although SPOT data have a higher spatial resolution, Landsat thematic mapper (TM) provides a wider spectral range (Lunden and Wester, 1988; Chavez and Bowell, 1988; Solberg and Strand, 1992; Harvey and Hill, 2001). Several studies show Landsat TM (Landsat 4/5) imagery yielded higher land cover classification accuracies than SPOT imagery, though not as high as aerial photography (Lunden and Wester, 1988; Joria et al., 1991). Moreover, the lower cost of Landsat TM imagery makes it an attractive satellite option (Solberg and Strand, 1992). However, other authors have concluded that SPOT imagery may be more effective than Landsat. Wheeler et al. (1988) found that SPOT was more effective at providing information about fine resolution items such as roads. Moreover, Jakubauskas et al. (1992) determined that SPOT was more cost effective than Landsat and provided slightly higher classification accuracies in a rural setting. Many of these studies were conducted using 30 m resolution Landsat TM images and 20 m resolution SPOT images (Solberg and Strand, 1992), while currently 10 m SPOT spectral imagery is available. Also, note that Landsat data costs have varied dramatically through time, which may significantly alter these conclusions. With the launching of Landsat 8 in February 2013, data are now available for free and within 24 hours of reception.

Previous comparisons have identified

manually interpreted aerial photography as the most cost effective for small study areas (Jakubauskas et al., 1992; Ventura and Harris, 1994). Jakubauskas et al. (1992) developed a formula to calculate cost effectiveness of an image classification based on study area size. With the use of one Landsat TM and one SPOT image, SPOT was found to be more cost effective than aerials for areas smaller than 141 km2 and TM data became most cost effective for areas larger than 261 km2. Ventura and Harris (1994) stated that the critical area size for the use of aerial imagery combined with manual interpretation was up to 80 km2. For areas larger than 130 km2, automated processing of satellite imagery was the most cost effective. Again, the cost of imagery has changed significantly since these previous studies were completed.

While the use of satellite imagery has proven to be promising for many studies, it is not without limitations. The largest barrier to the use of satellite imagery is the fact that some land cover patches are much smaller than the satellite pixel size (Harvey and Hill, 2001). Another limitation is that satellite imagery often lacks the land cover specificity that aerial photography provides. In other words, the number of classification categories is less for satellite classification compared to visual interpretation of aerials (Ventura and Harris, 1994; Harvey and Hill, 2001). Note, however, that many of these comparison studies were completed prior to the deployment of new higher spatial resolution satellite sensors. Lastly, a major obstacle in imagery comparison studies is the temporal difference in the image capture for the varying images. Temporal effects were noted by Ioka and Koda (1986), Wheeler et al. (1988), Jakubauskas et al. (1992), and Harvey and Hill (2001). Errors from temporal variations were typically found in areas that experienced annual or inter-annual land use changes, such as developing urban areas or agricultural areas undergoing crop rotation. The primary objective of this research was to compare the accuracy of SPOT 5 and Landsat 7 imagery for identifying land covers thought to be critical sources of erosion in the riparian corridor. This research utilized aerial photography, SPOT 5, and Landsat 7 satellite imagery (Figure 1). The Landsat program is a joint effort by the United States Geological Survey (USGS) and the National Aeronautics and Space

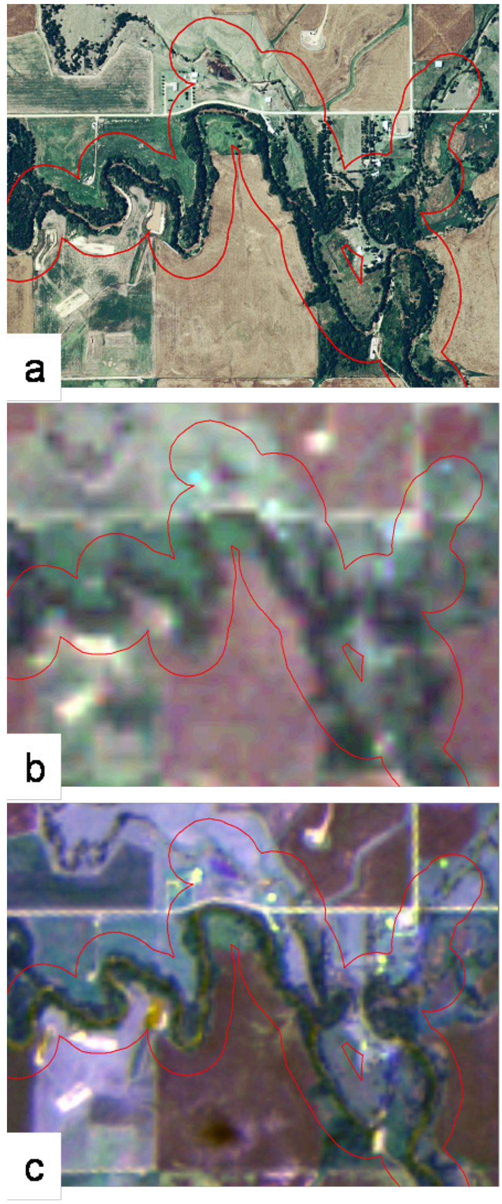

Figure 1. A 90 m riparian corridor in the Turkey Creek watershed for different image sources: (a) aerial photograph, (b) Landsat 7 and (c) SPOT 5.

Administration (NASA). Landsat 7 was launched in 1999 and its primary sensor, the Enhanced Thematic Mapper (ETM), provided multi-spectral imagery at a 30 m resolution. Landsat 7 had a Scan Line Corrector (SLC) failure in 2003 and no longer provides imagery that is useful over large areas. As noted previously, it has now been replaced by Landsat 8. The SPOT program is primarily funded through the Centre National d'Etudes Spatiales (CNES), the French space agency. SPOT 5 was launched in 2002 providing multispectral imagery at a spatial resolution of 10 m.

Several secondary project objectives included comparison of total classified land cover percentages among images, development of a method to quantify the extent of misclassified areas, development of visual aids to illustrate location and magnitude of errors, and evaluation of the riparian corridor width to determine impacts on accuracy for erosion targeting. The last objective was a cost comparison for the mapped area among aerial photography, Landsat 7, and SPOT 5.

The study area was the Turkey Creek watershed, which is on Oklahoma's 303(d) list for impaired waterbodies and thus is a high priority watershed for the Oklahoma Conservation Commission. The 1080 km^2 watershed is located in the northwestern Oklahoma counties of Alfalfa, Major, Garfield, and Kingfisher (Figure 2) which is similar to many other watersheds in central and western Oklahoma in that its primary land use is agricultural. Crop rotation was a widespread agricultural practice in the watershed. Within the rotation, the most common agricultural crop was winter wheat, which was used as forage in the winter and then harvested in early summer. This part of Oklahoma received approximately 76 cm of rainfall annually (Haan et al., 1994).

Methodology

Applied Analysis, Inc. (AAI) obtained raw Landsat 7 imagery captured on June 8, 2003 and SPOT 5 imagery captured on May 27, 2003 and performed an unsupervised land cover classification for the entire Turkey

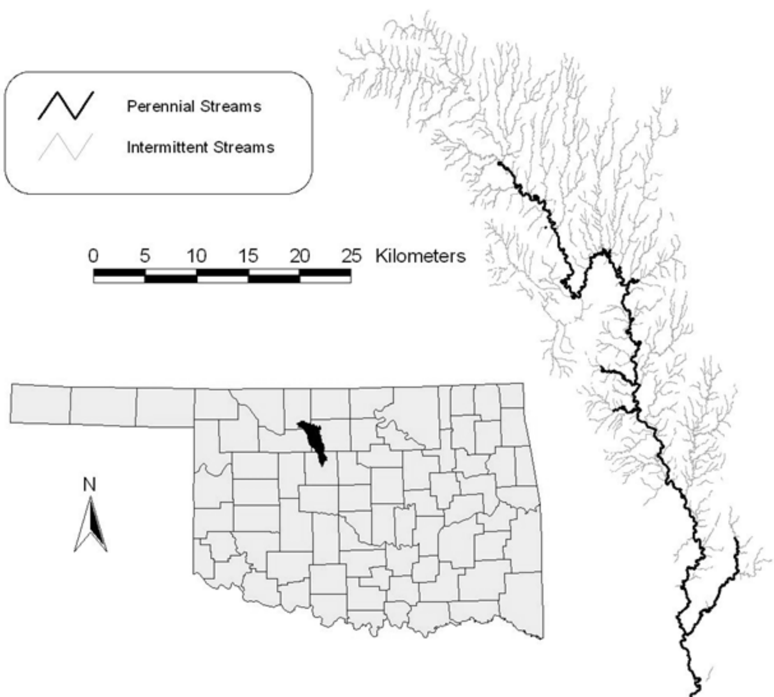

Figure 2. Study area of Turkey Creek watershed, Oklahoma.

Creek watershed. For this study, only land cover classes along the perennial streams were analyzed. Initially, data from the National Hydrography Dataset (NHD) identified perennial and intermittent streams. However, these data contained significant errors in their stream type classifications; these NHD data mislabeled all streams in Major County as perennial. Therefore, in order to obtain higher accuracy stream-type data, USGS 1:24000 Digital Raster Graphs (DRGs) based on 1969 to 1982 USGS topographic maps were used. The perennial streams were digitally adjusted using the ESRI ArcView 3.x GIS tool to account for stream migration occurring between the creation of the topographic maps and the recent aerial photographs.

Based on the perennial stream layer, a 90-meter riparian buffer layer around the streams was created using the ESRI ArcView 3.x GIS tool. Using the National Agriculture Imagery Program (NAIP) aerial photography from June 30, 2003, land cover classes within the buffer area were manually digitized. For consistency and comparison purposes, the same land cover categories derived by AAI from Landsat 7 and SPOT 5 imagery were used, which included water, shrub (sparse, woody vegetation), bare soil, crop (tramlines or rows), forest (dense trees), pasture (no rows, higher management than shrub category), and urban. In order to minimize misclassifications in the digitized land cover, field ground truthing was performed on June 18 and June 30, 2004. Ninety, 60, and 30 m riparian buffers were delineated and the percentage of each land cover within each buffer was calculated.

For the purposes of this study, the ground-truthed digitized layer was assumed correct. The classified land cover layers from Landsat 7 and SPOT 5 imagery were compared to the digitized layer and misclassified areas were quantified using contingency tables (Congalton, 1991), one for each of the assessed satellite sensors. These tables display a matrix of the area in each classification. For targeting critical sources of erosion, a misclassification involving bare soil would have a greater impact compared to a misclassification involving forest. To compare the magnitude of errors between SPOT 5 and Landsat 7, as compared to the digitized layer, it was necessary to differentiate among these error types. In order to do this, sediment-yield based weighting factors were used to quantify each error in an objective fashion.

While sediment yields were used to support our assessment, they were not used as absolute measures of erosion. Sediment yields were extrapolated from two sources. Sediment yields for crop and forested lands were obtained from a study of the Fort Cobb watershed, which was located approximately 100 km southwest of Turkey Creek (Storm et al., 2003a). The Fort Cobb study was selected due to similar topography, precipitation, and landcover to the Turkey Creek watershed. Sediment yields for shrub, pasture, and urban areas were taken from a study conducted by Storm et al. (2003b). Because most of the urban land cover in this study was county dirt roads, sediment yield estimates for roads from Storm et al. (2003b) were utilized as the weighting factor for the urban land cover. Since the available studies did not provide sediment yield estimates for bare soil, a Universal Soil Loss Equation (USLE) Cover Management (C) factor ratio method was used. Based on the proportional relationship between the C factor and erosion in the USLE, bare soil sediment yield was estimated to be 4.5 times the crop sediment yield or 29 Mg/ha (Haan et al., 1994; Storm et al., 2003a).

Once the sediment yields were defined, a sediment-yield based weighted error matrix was calculated (Table 1). Errors were calculated as the difference in sediment yield between each of the satellite classifications and the digitized layer based on land cover. The error matrix was then multiplied by the percent area contingency tables, yielding an area weighted sediment-yield based error matrix for each satellite classification.

Table 1. Estimated sediment yield error matrix (percent) by land cover. Estimated sediment yields (Mg/ha) are shown in parenthesis.

Digitized	Satellite Imagery						
	Crop (6.38)	Pasture (0.40)	Shrub (0.20)	Forest (0.01)	Urban (13.3)	Bare Soil (28.7)	Water (0.00)
Crop (6.68)	0	5.98	6.18	6.37	-6.92	-22.3	6.38
Pasture (0.40)	-5.98	0	0.20	0.39	-12.9	-28.3	0.40
Shrub (0.20)	-6.18	-0.20	0	0.19	-13.1	-28.5	0.20
Forest (0.01)	-6.37	-0.39	-0.19	0	-13.3	-28.7	0.01
Urban (13.3)	6.92	12.9	13.1	13.3	0	-15.4	13.3
Bare Soil (28.7)	22.3	28.3	28.5	28.7	15.4	0	28.7
Water (0.00)	-6.38	-0.40	-0.20	-0.01	-13.3	-28.7	0

Lastly, costs were estimated based on 2005 US dollars. Although the aerial images used in this project were purchased from the US Department of Agriculture Aerial Photography Field Office for the cost of reproduction only, the cost for an independent flyover is shown in Table 2, along with the other approximate project costs. Also, note that the raw imagery costs listed were for one Landsat 7 image and two SPOT 5 images. Though the study area size was only 24 km^2, two SPOT 5 images were required because the watershed fell in two different scenes. It should be noted that the spatial extent of the satellite image tiles were significantly greater than the aerial images while the processing costs of the satellite images remain the same regardless of the area cover.

Results and Discussion

The land cover percentage graph (Figure 3) illustrates that Landsat 7 and SPOT 5 images produced similar land cover percentages, but generally were not consistent with the aerial photography classification. This was especially apparent in the pasture and shrub categories. The spectral similarities between these two land cover types may be a possible source of error. For all three buffer widths, the satellite imagery identified a large percentage of shrubs as pasture (data not shown). However, due to the small sediment-yield based weighting factors for errors between these categories, this error did not play a significant role in the sediment-yield based weighted error.

The error matrix developed to estimate the classification accuracy for all land cover categories resulted in 45 and 50% errors for Landsat 7 and SPOT 5, respectively. Contingency tables were used to identify errors of commission and omission for each satellite classification. For example, Table 3 shows that for the 90 m buffer 7.0% of the forested land was misclassified as pasture in Landsat

Table 2. Imagery cost comparison for the Turkey Creek watershed project in 2005 US dollars.

Image type	Raw Imagery Cost per Scene	Processing Cost	Number of Scenes	Total Cost
Aerial Photography	$9,000	$2,600	N/A	$11,600
Landsat 7	$600	$20,000	1	$20,600
SPOT 5	$7,000	$30,000	2	$44,000

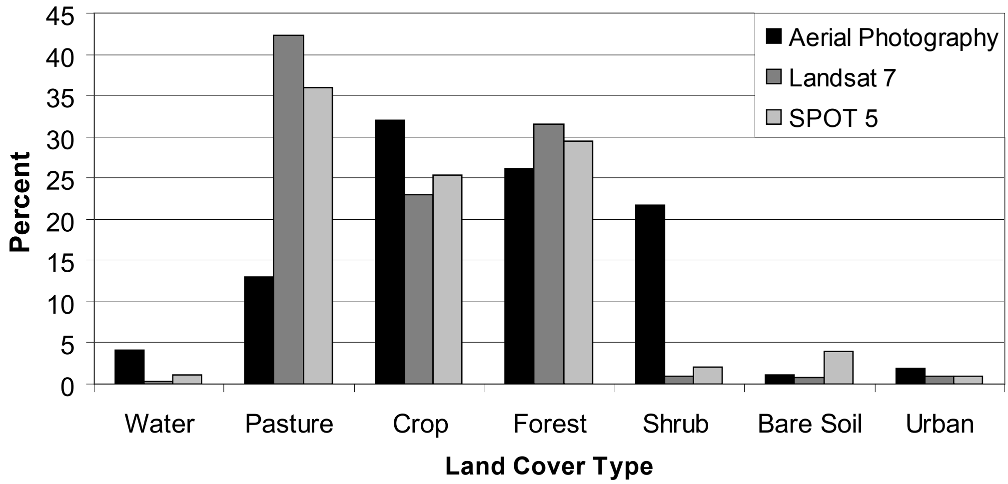

Figure 3. Ninety meter buffer land cover percentages by satellite imagery for the Turkey Creek riparian corridor.

Table 3. Land cover contingency tables for Landsat 7 (a) and SPOT 5 (b) within the 90 m riparian corridor in the Turkey Creek watershed.

A

Digitized	Landsat 7 Satellite							
	Crop	Pasture	Shrub	Forest	Urban	Bare Soil	Water	**Total**
Crop	17.7	10.0	0.19	3.53	0.42	0.14	0.06	**32.0**
Pasture	0.57	9.93	0.20	1.98	0.08	0.16	0.04	**13.0**
Shrub	2.06	12.9	0.24	5.89	0.23	0.25	0.08	**21.7**
Forest	1.98	7.00	0.13	16.9	0.09	0.10	0.05	**26.2**
Urban	0.21	1.13	0.08	0.26	0.14	0.03	0.02	**1.88**
Bare Soil	0.17	0.50	0.02	0.42	0.01	0.05	0.02	**1.18**
Water	0.32	0.91	0.02	2.67	0.02	0.07	0.04	**4.06**
Total	**23.0**	**42.4**	**0.88**	**31.7**	**0.98**	**0.80**	**0.32**	**100.0**

B

Digitized	SPOT 5 Satellite							
	Crop	Pasture	Shrub	Forest	Urban	Bare Soil	Water	**Total**
Crop	19.5	10.3	0.15	1.32	0.17	0.46	0.03	**32.0**
Pasture	0.77	9.13	0.59	1.91	0.06	0.52	0.02	**13.0**
Shrub	2.00	11.5	0.96	5.95	0.19	0.88	0.24	**21.7**
Forest	1.25	3.60	0.38	19.7	0.05	0.86	0.22	**26.1**
Urban	0.30	0.87	0.01	0.05	0.45	0.21	0.01	**1.90**
Bare Soil	0.53	0.32	0.01	0.09	0.02	0.13	0.09	**1.19**
Water	1.34	0.56	0.02	0.80	0.01	0.88	0.47	**4.09**
Total	**25.7**	**36.3**	**2.13**	**29.9**	**0.95**	**3.94**	**1.07**	**100.0**

7, while this misclassification percentage was only 3.6% in SPOT 5. An error matrix was developed for each buffer width and satellite type with their overall accuracies shown in Table 4; the overall accuracy increased as the buffer width increased for both satellites. This is to be expected given the spatial resolution of the satellite sensors. Multiplying Table 3 results by the Table 1 error matrix and dividing by 100 percent allowed more quantifiable comparisons. The resulting weighted error factors were summed over the entire table to give the net weighted error; Table 5 shows the net weighted error by buffer width. A negative error indicated that on average the satellite classification over predicted sediment yield as compared to the digitized land cover. For example, when a forested area with a very small sediment yield was misclassified as crop that had relatively higher sediment yield, the resulting error was negative. Likewise, a positive error indicated sediment yield was under predicted by the sensor classification.

The negative errors identify areas where there was actually less erosion occurring than what the satellite classification indicated. If satellite images were used for targeting, these areas might be incorrectly identified as BMP investment sites. Conversely, the positive errors indicates areas where there was actually more erosion occurring than shown by the satellite classification. In this case, if satellite images were used for targeting erosion these areas might be missed for consideration of BMP implementation.

Table 5 shows that the net weighted error pattern in the buffer width was different between Landsat 7 and SPOT 5 classifications. For SPOT 5, as the buffer narrowed, the proportion of the bare soil and water classified from the stream channel became larger. Because of the large weighting factor for bare soil errors, the net weighted error increased. In reality, these bare soil areas within the stream channel should not be considered in the upland sediment yield estimates. For the Landsat 7 classification, the net weighted error decreased as the buffer narrowed, which was consistent with the overall accuracy change presented in Table 4. Because the spatial resolution of Landsat 7 imagery was relatively large compared with the buffer width, conclusions drawn from Table 4 may be spurious. While the majority of the area was classified correctly, small details were typically misclassified. Figure 4 shows visual representation of the magnitude and distribution of the net weighted errors for a section of the stream. The darker blue areas indicated areas in which sediment yield was over predicted using the satellite classification, as compared to the digitized land cover. The darker green areas indicated areas in which sediment yield was under predicted, and white represented areas with no error.

One source of error resulted from landowners rotating between crop and pasture in this temporally dynamic watershed. This was an unavoidable issue because all images were captured in summer 2003, while the ground truthing was performed in summer 2004. Aerial photographs were taken in summer 2003, the Landsat 7 images were captured on June 8, 2003 and the SPOT 5 images were captured on May 27, 2003. The lack of temporal coincidence among data sources and ground-truth data collection were sources of error.

Table 4. Overall accuracy (percent) by buffer width and satellite type.

Image Type	Buffer Width (m)		
	30	60	90
Landsat 7	37	41	45
SPOT 5	42	47	50

Table 5. Net weighted error (Mg/ha) by buffer width and satellite type.

Image Type	Buffer Width (m)		
	30	60	90
Landsat 7	0.12	0.49	0.73
SPOT 5	-2.00	-0.84	-0.32

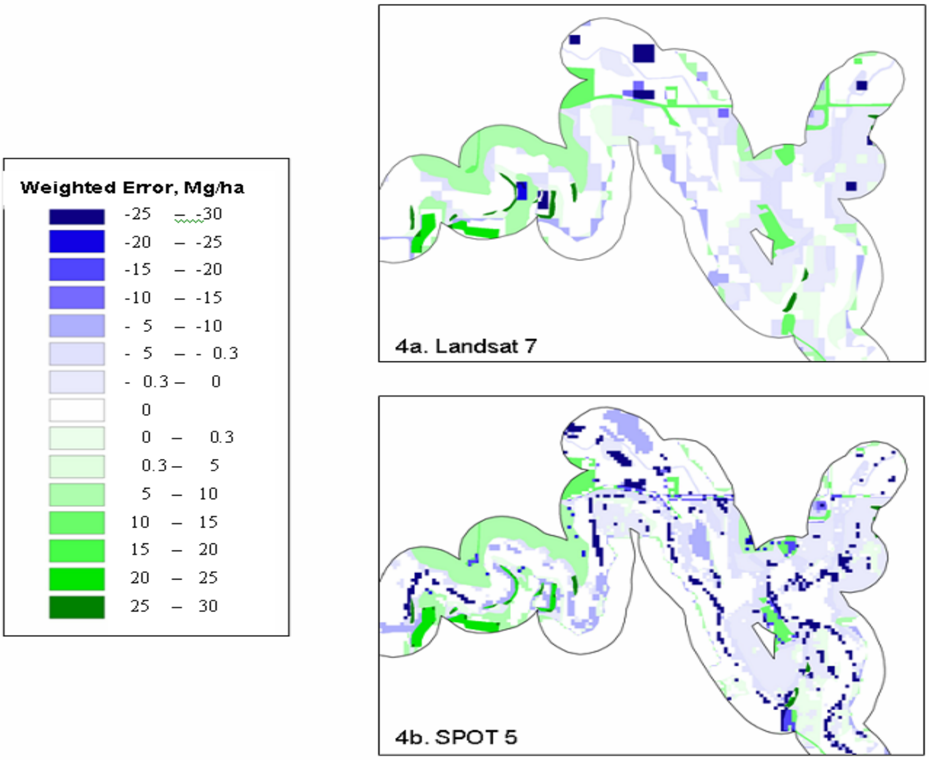

Figure 4. Landsat 7 (a) and SPOT 5 (b) net weighted errors (Mg/ha) for 90 m riparian corridor for a typical stream reach in the Turkey Creek watershed.

For the Turkey Creek watershed, doubling the study area would increase the number of aerial photography scenes required, but not the number of satellite scenes. Therefore, the aerial raw imagery costs, as well as the aerial processing costs, would increase. The satellite imagery and processing costs would remain constant. Under this scenario, the increased total cost of the aerial digitizing method would exceed the total cost of the Landsat 7 approach. Based on the number of images used in this project and the amount of manually interpreted area, it would be more cost effective to use aerial imagery on areas under twice this study size.

In general, with increasing area size, increased numbers of images are needed. For large area projects, Figure 5 illustrates that satellite imagery was more cost effective than aerial photography. Landsat 7 imagery was more cost effective than aerial photography for areas larger than 50 km2 and was always more cost effective than SPOT 5 imagery (Figure 5). SPOT 5 imagery was more cost effective than aerials at approximately 65 km2 (Figure 5). However, it is important to note that the level of accuracy needed as well as the cost must be considered in choosing imagery type.

Conclusions

This study showed that Landsat 7 and SPOT 5 classified land cover similarly, both in terms of percent areas and overall accuracy, but with accuracies lower than the digitized aerial photography. These factors, along with the cost comparison, indicated that

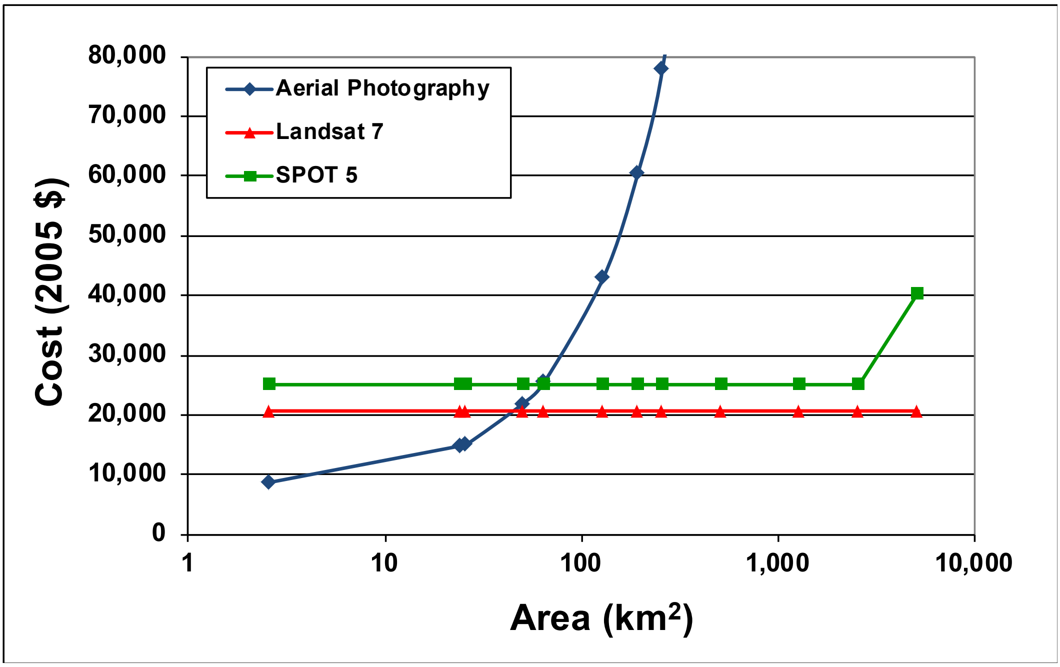

Figure 5. Imagery cost comparison in 2005 US Dollars.

Landsat 7 was a better satellite option than SPOT 5 for this application. There was not enough available data to make substantial conclusions regarding riparian corridor width effects on accuracy. The accuracy was driven more by the size and type of features rather than the width of the buffer. Considering the cost comparison, aerial images were recommended for study areas less than 50 km^2 and Landsat 7 images were recommended for areas greater than 50 km^2, which was approximately twice the study size of 24 km^2. These conclusions were based only on this study, which utilized one Landsat 7 image and two SPOT 5 images. In general, for studies requiring fine-scale detail, aerial photography can be used cost effectively for areas up to 50 km^2.

ACKNOWLEDGEMENTS

Partial funding was provided by the National Science Foundation. Special thanks to Dr. Michael Myers, Dr. Thomas Wikle, and Bruce Battles from the Oklahoma State University Geography Department. Also, thanks to Dan Butler with the Oklahoma Conservation Commission. Finally, this project could not have been completed without support from the Oklahoma State University Division of Agricultural Sciences and Natural Resources Oklahoma Agricultural Experiment Station.

REFERENCES

Chavez, Jr. S., & Bowell, J. (1988). Comparison of the spectral information content of Landsat Thematic Mapper and SPOT for three different sites in the Phoenix, Arizona region. *Photogrammertic Engineering and Remote Sensing*, 12, 1699-1708.

Congalton, R. G. (1991). A review of assessing the accuracy of classifications of remotely sensed data. *Remote Sensing of Environment*, 37, 35-46.

Haan, C., Barfield, B., and Hayes, J (1994). *Design Hydrology and Sedimentology for Small Catchments*. San Diego: Academic Press.

Harvey, K. R., & Hill, G. J. E. (2001). Vegetation mapping of a tropical freshwater swamp in the Northern Territory, Australia: a comparison of aerial photography, Landsat TM and SPOT satellite imagery. *International Journal of Remote Sensing*, 22, 911-2925.

Ioka, M., & Koda, M. (1986). Performance of landsat-5tm data in land-cover classification. *International Journal of Remote Sensing*, 7, 1715-1728.

Jakubauskas, M. E., Whistler, J. L., Dillworth, M. E., & Martinko, E. A. (1992). Classifying remotely sensed data for use in an agricultural nonpoint-source pollution model. *Journal of Soil and Water Conservation*, 47, 179-183.

Joria, P. E., Ahearn, S. C., & Connor, M. (1991). A comparison of the SPOT and Landsat Thematic Mapper satellite systems for detecting gypsy moth defoliation in Michigan. *Photogrammetric Engineering & Remote Sensing,* 57, 1605-12.

Lunden, B., & Wester, K. (1988). Landsat TM and SPOT HRV for survey mapping of bedrock outcrops. Proceedings of IGARSS '88 Symposium, Edinburgh, Scotland, 13-16 September 1988. Ref ESA SP-284.

Mosbech, A., &Hansen, B. U. (1994). Comparison of Satellite Imagery and Infrared Aerial Photography as Vegetation Mapping Methods in an Artic Study Area; Jameson Land, East Greenland. *Polar Research,* 13, 139-152.

Ripa, M. N., Leone, A., Garnier, M., & Porto, A. (2006). Agricultural Land Use and Best Management Practices to Control Nonpoint Water Pollution. *Environmental Management,* 38, 253–266.

Rowlinson, L. C., Summerton, M., & Ahmed, F. (1999). Comparison of Remote Sensing Data Sources and Techniques for Identifying and Classifying Alien Invasive Vegetation in Riparian Zones. *Water SA,* 25, 497-500.

Solberg, R., & Strand, G. (1992). Monitoring soil erosion in agricultural fields by optical satellite imagery. Geoscience and Remote Sensing Symposium, IGARSS '92 Proceedings, May 26, 1992, Houston, Texas, U.S.A.

Storm, D. E., White, M.J., & Stoodley, S. H. (2003a). Fort Cobb Basin - Modeling and Land Cover Classification. Final Report Submitted to the Oklahoma Conservation Commission, Oklahoma City, Oklahoma U.S.A., Department of Biosystems and Agricultural Engineering, Oklahoma State University, Stillwater, Oklahoma, U.S.A.

Storm, D. E., White, M. J., & Stoodley, S. H. (2003b). Stillwater Creek - Modeling and Land Cover Classification. Final Report Submitted to the Oklahoma Conservation Commission, Oklahoma City, Oklahoma U.S.A., Department of Biosystems and Agricultural Engineering, Oklahoma State University, Stillwater, Oklahoma, U.S.A.

US Environmental Protection Agency (USEPA) (1993). Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters. EPA 840-B-92-002. Washington, DC: U.S. Environmental Protection Agency, Office of Water.

US Environmental Protection Agency (USEPA) (1995). Economic Benefits of Runoff Controls. EPA 841-S-95-002. Washington, DC: United States Environmental Protection Agency Office of Wetlands, Oceans and Watersheds.

US Environmental Protection Agency (USEPA) (2003). Applying for and Administering CWA Section 319 Grants: A Guide for State Nonpoint Source Agencies. United States Environmental Protection Agency, Washington D.C.

US Environmental Protection Agency (USEPA) (2005). Protecting Water Quality from Agricultural Runoff. EPA 841-F-05-001. Washington, DC: U.S. Environmental Protection Agency Nonpoint Source Control Branch.

Ventura, S. J., & Harris, P. (1994). A comparison of classification techniques and data sources for urban land use mapping. *Geocarto International,* 9, 5-14.

Wheeler, J. R., Jarvis, C., Mitchell, A. J. B., King, R. B., & King, R. J. (1988). Evaluation of Landsat TM and SPOT imagery for agricultural land use planning in less developed countries. Proceedings of IGARSS '88 Symposium, Edinburgh, Scotland, 13-16 September 1988. Ref ESA SP-284.