X-913-75-3
PREPRINT

NASA TM X- 70827

EXTRACTION AND UTILIZATION OF SPACE ACQUIRED PHYSIOGRAPHIC DATA FOR WATER RESOURCES DEVELOPMENT

(NASA-TM-X-70827) EXTRACTION AND UTILIZATION OF SPACE ACQUIRED PHYSIOGRAPHIC DATA FOR WATER RESOURCES DEVELOPMENT (NASA) 31 p HC $3.75 CSCL 08H

N75-17767

Unclas
G3/43 10789

A. RANGO
J. FOSTER
V. V. SALOMONSON

JANUARY 1975

GSFC — GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

For information concerning availability of this document contact:

Technical Information Division, Code 250
Goddard Space Flight Center
Greenbelt, Maryland 20771

(Telephone 301-982-4488)

CONTENTS

ILLUSTRATION

TABLES

X-913-75-3
Preprint

EXTRACTION AND UTILIZATION OF SPACE ACQUIRED PHYSIOGRAPHIC DATA FOR WATER RESOURCES DEVELOPMENT

A. Rango

J. Foster

V. V. Salomonson

January 1975

GODDARD SPACE FLIGHT CENTER
Greenbelt, Maryland

EXTRACTION AND UTILIZATION OF SPACE ACQUIRED PHYSIOGRAPHIC DATA FOR WATER RESOURCES DEVELOPMENT

A. Rango,* J. Foster,** and V. V. Salomonson*

ABSTRACT

ERTS-1 satellite imagery has been evaluated as a means of providing useful watershed physiography information. From these data physiographic parameters such as drainage basin area and shape, drainage density, stream length and sinuosity, and the percentage of a watershed occupied by major land use types were obtained in three study areas. The study areas were: (1) Southwestern Wisconsin; (2) Eastern Colorado; and (3) portions of the Middle Atlantic States. Using ERTS-1 imagery at 1:250,000 and 1:100,000 scales it was found that drainage basin area and shape and stream sinuosity were comparable (within 10%) in all study areas to physiographic measurements derived from conventional topographic maps at the same scales. Land use information can be usefully extracted for watersheds as small as 30 mi^2 (78 km^2) in area. Improved drainage network and density information is obtained from ERTS-1 imagery in dissected areas such as Southwestern Wisconsin, but in heavily vegetated areas (Middle Atlantic States) or areas with little physical relief (Eastern Colorado) low order streams are difficult to detect and the derived drainage densities are significantly smaller

*Hydrology and Oceanography Branch, Goddard Space Flight Center, Greenbelt, Maryland 20771
**Geology Department, University of Maryland, College Park, Maryland 20742

than those obtainable from standard maps. It is concluded that ERTS-1 imagery can be employed to advantage in mean annual runoff prediction techniques and in providing or maintaining land use information used in the calibration and operation of watershed models.

(KEY TERMS: physiography; land use; drainage density; watershed area; ERTS-1)

EXTRACTION AND UTILIZATION OF SPACE ACQUIRED PHYSIOGRAPHIC DATA FOR WATER RESOURCES DEVELOPMENT

INTRODUCTION

In some areas, such as developing countries and certain parts of the United States, base maps exist at scales no larger than 1:250,000 if they exist at all. In these situations analysis of high resolution satellite imagery, such as from the first Earth Resources Technology Satellite (ERTS-1), provides an efficient and rapid means of obtaining physiographic information in unsurveyed and remote regions. In surveyed areas these data can be used to quickly update existing information. In general topographic maps do not possess the dynamic hydrologic information available from the 18 day repetitive coverage provided by ERTS-1 (Freden and Mercanti, 1973). In addition, the cartographic fidelity of the imagery from ERTS-1 is unrivaled by data from other satellites.

The drainage basin is the basic areal unit in which various physiographic features can be measured and studied. The measurement of these watershed characteristics is important because they are intimately related to basin water yield and sediment load. Physiographic parameters measurable from space platform include stream order, stream length, basin area, basin shape, drainage density, drainage pattern and stream sinuosity or meander wavelength. Additional drainage basin parameters such as the percent of the basin in forests, swamps, surface water, open area, and urban or impervious area can also be delineated from high resolution satellite imagery and are valuable in characterizing the hydrologic response of a basin. The physiographic and associated land use information thus extracted is suitable for use in mean annual streamflow and/or mean annual flood regression models and can also be used to calculate basic information necessary for the calibration of watershed models which simulate daily discharge.

The evaluation of physiographic data extracted from ERTS-1 was conducted in three different climatic and physiographic areas: (1) Southwestern Wisconsin — this area receives about 32 inches (81 cm) of precipitation annually, summer being the wettest season, and produces about 10 inches (25 cm) of runoff. The area is composed of two different physiographic regions or subdivisions, the Lake-Swamp-Moraine Plains and the highly dissected "driftless" area; (2) Eastern Colorado — this area receives only about 10-15 inches (25-38 cm) of precipitation each year and yields less than one inch (2.5 cm) of runoff. The study watersheds lie in an area of high plains and tablelands; and (3) Middle Atlantic States (Maryland, Virginia, Delaware, and Pennsylvania) — this area receives a seasonally well-distributed 40 inches (102 cm) of precipitation annually, 15-20 inches (38-51 cm) of which eventually appear as runoff. The study area covers parts of the Coastal Plain, Piedmont, Ridge and Valley, and Plateau Provinces.

BACKGROUND

Studies carried out in the northeastern United States by Sopper and Lull (1970) demonstrated that streamflow and its distribution are primarily functions of climate, physiography, and land use. A number of studies have also illustrated that certain drainage basin characteristics are useful in estimating information about watershed yield. Trainer (1969) used drainage density as an indicator of base flow in part of the Potomac River Basin and concluded that base flow is inversely proportional to drainage density. This relationship can be used to estimate base flow even in an area of rather diverse geology such as the Piedmont and Blue Ridge Provinces of the Potomac River Basin. DeWalle and Rango (1972) employed stream channel width and basin area to explain 78 percent of the variation in mean annual runoff. They demonstrated the utility of collecting fluvial geomorphic data for predicting mean annual runoff and, subsequently, for evaluating the possible effects of weather modification.

Several studies have been conducted using ERTS-1 to investigate various physiographic characteristics of drainage areas. Kesik (1973) analyzed the regional characteristics of the drainage presentation on ERTS-1 images, and the applicability of these images to drainage pattern studies in various physical provinces of Canada. He found in his study areas that the comparison of ERTS-1 measurements of drainage density with map measurements showed that only in mountainous areas did ERTS-1 images provide more total information regarding drainage pattern than existing maps at 1:1,000,000 scale. Williams, Barker, and Coiner (1973), however, mapped land use, basin area, and stream orders in great detail from ERTS-1 images of the Pawnee River Basin in Central Kansas.

Their study demonstrated the feasibility of using ERTS-1 imagery to map stream networks in non-mountainous areas in greater detail than possible from 1:250,000 scale maps.

METHOD

ERTS-1 images at 1:1,000,000 scale for different seasons were initially inspected to determine the optimum times of year for physiographic mapping in each study area. In the Middle Atlantic area and southwestern Wisconsin, winter scenes seemed to provide the most hydrologic and physiographic information because of less vegetation interference with interpretation. Also, snow-cover generally tends to enhance a drainage network and thus makes mapping easier. In eastern Colorado, however, due to the aridity of the area, vegetation occurring along the stream channel actually aids in the delineation of the stream network. Therefore, in eastern Colorado both summer and winter imagery was used.

The 0.6-0.7μm and 0.8-1.1μm ERTS-1 bands were selected for the physiographic mapping of drainage basins. The near infrared band (0.8-1.1μm) shows the most contrast between land and water features and is best suited for mapping large streams, whereas, the visible red band (0.6-0.7μm) shows good contrast between different land features and vegetated and nonvegetated areas and is most useful for network delineation where streams are not large enough to be detected in the 0.8-1.1μm band. Color composites of various spectral band combinations were also used to enhance drainage features.

In order to facilitate comparisons with USGS topographic maps ERTS-1 images of the study areas were enlarged photographically or with a zoom transfer scope which superimposes an image onto a map with the aid of a series of lenses, mirrors, and scale adjustments. In this study enlargements were generally made to a 1:250,000 scale for comparison, but areas of particular interest were also enlarged to a 1:100,000 scale.

The procedure for extracting data from watersheds was as follows. Physiographic and watershed parameters including drainage area, drainage shape, drainage density, stream length, stream sinuosity, forest, swamp, surface water, open, and urban area were delineated for selected gaged watersheds on U.S. topographic maps at 1:250,000 scale. These same parameters were then extracted from ERTS-1 imagery at a similar scale and compared to information from the topographic maps to determine the utility of ERTS-1 for physiographic feature mapping. For one watershed ERTS-1 temporal data were examined in order to observe seasonal effects on clarity of drainage network representation. Additionally, physiographic parameters extracted from aerial U-2 imagery at a scale of about 1:114,000 over a limited area were compared with topographic map derived parameters at a scale of 1:62,500.

The above mentioned physiographic parameters were calculated from the maps and images with the assistance of a compensating planimeter and a map measurer. The drainage basins were outlined for selected streams and the area was measured with the compensating planimeter. The drainage shape was subsequently quantified by using the following formula:

$$\text{Basin Shape} = \text{Basin Area}/C$$

where C = area of a circle having the same length of perimeter as the basin. A basin shape of 1.0 indicates a perfectly circular watershed.

The perimeter of the basin and the total length of streams within a watershed were calculated using the map measurer. The drainage density was then easily obtained by dividing the drainage area into the total stream length. The stream sinuosity was obtained by measuring the length of the main stream of the basin and dividing this number by the axial length of the drainage basin (a sinuosity of 1.0 would indicate a straight river with no meanders). The other basin parameters—area of forests, swamps, surface water, urban land, and open land—were obtained by identifying the features on the maps and images and planimetering the area of the drainage basin they occupied. Automatic data processing was also used to classify various land use parameters in one of the watersheds for comparison (Dallam and Rango, 1975).

RESULTS

Wisconsin

The watersheds studied in southwestern Wisconsin lie in two distinct physiographic provinces, the Southwest Wisconsin Hills and the Lake-Swamp-Moraine Plains. Six watersheds are located in the Southwest Wisconsin Hills, also known as the "driftless" area, because the province was virtually untouched by the four major glacial advances. The watersheds studied in the Southwest Wisconsin Hills are tributaries of the lower Wisconsin River and the Mississippi River near its junction with the Wisconsin River. The local relief of this area is between 400 and 600 feet (122 and 183 m), and the landscape is deeply dissected by an integrated drainage network. The climate is classified as humid continental with hot summers and cold winters. The vegetation is predominantly Maple-Basswood and pine forests in the valleys, whereas Bluestem prairie grass and Oak savanna dominate the uplands.

As was previously mentioned winter imagery was most often used for mapping in the Wisconsin study. The image most used was a snowcovered scene in January which showed larger rivers frozen at this time. The poor contrast between the frozen rivers and the snowcovered ground, however, made the course of the main stream difficult to discern. Thus, sinuosity measurements were more difficult to make than those obtained from maps at 1:250,000 scale. When viewing summer color composites of this area, however, sinuosity measurements were more easily achieved, because of the good contrast between the vegetation and the free water in the streams.

In the winter ERTS-1 imagery, drainage divides take on the appearance of narrow strips separating the deeply dissected basins. In addition, the difference in spectral signatures between the forested valleys and grassy uplands enables the divides to be easily located. In the summer scenes, heavy vegetation growth tends to obscure the basin divides, thus reducing the comparability of basin area measurements slightly.

In the "driftless" area of Wisconsin, the drainage basin area from 1:250,000 scale ERTS-1 images can generally be measured to within 5% of the area derived from topographic maps at the same scale. Because the basin area can easily be delineated, the basin shape can also be accurately determined. Basin shape can be measured to about 9 percent of that obtained from the topographic maps at a scale of 1:250,000. Table 1 of the Southwest Wisconsin Hills Province is an example of the kind of physiographic data recorded in this study.

Because this section of Wisconsin escaped glaciation, streams were able to incise themselves into the topography and produce a hilly, dissected landscape with an integrated drainage system. The high contrast exhibited between the deeply incised stream valleys and the interfluvial areas permits detailed mapping of drainage networks, and in some instances seven stream orders can be identified from an ERTS-1 image of this area. The drainage density as extracted from ERTS-1 data is approximately 1.75 times greater than that obtained from topographic maps, both at a scale of 1:250,000. Figure 1 illustrates that drainage density as mapped from ERTS-1 imagery at 1:100,000 scale (1.35 km/km^2) is also greater than values extracted from topographic maps (1.20 km/km^2) at a scale of 1:62,500. Topographic maps show about a one third greater drainage density than ERTS-1 summer imagery (June), however, when mapped at 1:250,000 scale.

This results because the lower order streams are masked from view by a canopy of leafy vegetation.

There were virtually no urban, swamp, or surface water areas present to be measured from either ERTS-1 or the topographic maps, but forested and open areas were delineated from ERTS-1 to within about 10 percent of the areas indicated on topographic maps at a 1:250,000 scale.

Four watersheds which are located in the Lake-Swamp-Moraine Plains Province of southwestern Wisconsin were also studied. This area, unlike the "driftless" area, was severely scoured by four glacial advances. The watersheds studied here are tributaries of the Mississippi, Chippewa, and the Upper Wisconsin River.

Climate and vegetation is similar to that of the "driftless" area, but the local relief is not as great, being approximately between 200 and 400 feet (61 and 122 m). The Lake-Swamp-Moraine Plains area is not as dissected as in the "driftless" area nor is the drainage network as well integrated because glaciation flattened the original landscape and interrupted the drainage system. As a result, physiographic characteristics of drainage basins are generally not well delineated from space in this area.

Drainage density from ERTS-1 at a scale of 1:250,000 showed only about 65% of the drainage detail taken from topographic maps of a similar scale.

Drainage basin area could be measured to about 4% of that found on topographic maps, however, and drainage basin shape differed by about 9% from the values obtained on topographic maps.

Lack of dissection does not seem to affect the mapping of land use parameters from space in this area. Forests and open areas can again be measured to about 10% of that found on topographic maps. Swamp areas could also be identified and mapped from space to within about 4% of that obtained from the maps. In the watersheds studied, however, swamp areas accounted for such a small portion of the total drainage area that a percentage comparison between maps and satellite measurements may be academic.

In summary, mapping of drainage basin parameters such as area, shape, density, stream length, forested area, and open area in the deeply dissected Southwest Wisconsin Hills can be accomplished accurately with ERTS winter imagery. Summer imagery can be used to map drainage area, shape, and sinuosity. The mapping of drainage density in the Lake-Swamp-Moraine Plains cannot be accomplished with anywhere near the same detail from ERTS-1 as from topographic maps at a scale of 1:250,000. The other drainage basin characteristics can be extracted, however, with comparable accuracy.

Colorado

The watersheds studied in eastern Colorado are tributaries of the Arkansas, South Platte, and Republican Rivers. This area is a part of the High Plains and is composed of tablelands and prairies of moderate relief (300-500 feet or 91-152 m). The vegetation is predominantly Buffalo Grass and juniper-pinyon woodland, but poplar and cottonwood trees are found in the floodplains.

The 0.6-0.7 μm band was used to map this area in both the winter and summer scenes. There was not enough water present in most streams to be detectable in 0.8-1.1 μm band. Winter snowcovered scenes produced the most detail due to the enhancing effect of the snow. Summer 0.6-0.7 μm imagery was used for mapping the drainage network in those cases where riparian vegetation highlighted the channels. Also, on summer scenes in agricultural areas, the stream course could be located by observing irregularities in field patterns even though the stream channel itself could not be identified.

The detailed mapping of physiographic features in Colorado from ERTS-1 imagery was hampered by the generally poor contrast between the drainage network and the surrounding landscape. Many stream channels are shallow and not well demarcated and so often there was little or no vegetation about the stream to offer contrast to the surroundings. Portions of some streams are incised into the landscape, however, thus providing enough contrast to facilitate their delineation.

Overall, it would be difficult to determine relative streamflow amounts in eastern Colorado from ERTS-1 observations alone. For example, Timpas Creek is barely discernable from ERTS-1 imagery, but it has the highest discharge of all the streams mapped in Colorado, and Cherry Creek which is much easier to detect from ERTS imagery has extremely low discharge rates.

In the watersheds studied in eastern Colorado, ERTS-1 imagery at a scale of 1:250,000 generally does not show the same degree of detail as USGS topographic maps at the same scale. Drainage density as mapped from ERTS-1 is only about 75 percent of that indicated on topographic maps, and sinuosity values are also slightly less when measured from ERTS than from maps. Watershed area and shape, however, can generally be mapped to within 5 percent of the values obtained from maps, and forested and open area are comparable to measurements taken from the 1:250,000 maps.

Middle Atlantic States

The watersheds studied in the Middle Atlantic area are tributaries of the Potomac, Patuxent, Monocacy, and Susquehanna Rivers and also the Chesapeake Bay. These drainage areas lie in 4 physical provinces; the Appalachian Plateau, the Ridge and Valley, the Piedmont and the Coastal Plain. Relief is less than 100 feet (30 m) on the Coastal Plain, between 100 and 500 feet (30 and 152 m) on the Plateau and Piedmont, and about 1000 feet (305 m) in the Ridge and Valley Province. The climate is borderline between Subtropical and Continental with hot summers and moderately cold winters. Vegetation is predominantly Oak-Hickory and pine forests.

Physiographic mapping of most watersheds in the Middle Atlantic area is hindered by small stream size, abundant stream bank vegetation, and the poor contrast between streams and land features. The amount of detail extracted from ERTS-1 imagery does not vary appreciably between the Coastal Plain, Ridge and Valley, and Piedmont Provinces, and in these areas considerably more physiographic information can be extracted from 1:250,000 topographic maps than from ERTS-1 imagery at the same scale.

Although it is a tedious process to map drainage systems in these three provinces because of the problems mentioned above, drainage basin area can be mapped to within 9 percent of the area measured from topographic maps, and basin shape can be measured to about 6 percent of that calculated from maps. Stream sinuosity can be measured accurately from ERTS-1 when the main stream can be identified, but in a few cases only the stream valley can be located. If stream meandering cannot be recognized, sinuosity values will be very low. Drainage density as extracted from ERTS-1 in these three areas was only about 55 percent of that measured on the 1:250,000 scale topographic maps. The low densities result from the inability to detect streams which are obscured by vegetation and from a lack of contrast which conceals drainage detail from the multispectral scanner on the ERTS-1 satellite. Additional complication results in the Ridge and Valley Province because streams running parallel to the folds are often hidden by shadows.

In the Coastal Plain, Piedmont, and Ridge and Valley Provinces, physiographic mapping from ERTS-1 was performed from January through March because more detail could be seen during this time of minimum leaf cover. On one occasion snow covered the entire Middle Atlantic area, and conditions were ideal for snow enhancement of the drainage network. A 3-8 inch (8-20 cm) snowfall, with very little drifting, covered the area. The temperature was about 25°F at the time of the ERTS-1 pass, twelve hours after it had stopped snowing, so the snow was not yet melting. Despite these optimal conditions only slightly greater detail was achieved when mapping with the benefit of snowcover than with no snow. It seems that in the Middle Atlantic area, a snowcover enables one to see gross drainage features more easily, but does not necessarily allow for more detailed enhancement of subtle features.

Much more physiographic information can be extracted from the Appalachian Plateau Province than from the other provinces of the Middle Atlantic area. The ERTS-1 images of this area at a scale of 1:250,000 provide more information than topographic maps at the same scale. Like the southwestern Wisconsin area and unlike the other three Middle Atlantic provinces, this area is deeply dissected, and there is a high contrast between the stream valleys and the interfluvial area.

For the most part, watersheds on the plateau were mapped from winter imagery. Drainage area from ERTS-1 was generally measured to within 4 percent of that measured from maps at 1:250,000 scale, and drainage basin shape from ERTS-1 was within 15 percent of that taken from topographic maps. In regard to drainage density, six watersheds on the Plateau were mapped from ERTS-1 and were so extensively dissected that an average of twice as much drainage detail was obtained from ERTS-1 images at 1:250,000 scale as from maps of the same scale. Stream sinuosity values on the other hand, as in the other Middle Atlantic provinces, were slightly less when measured from ERTS-1 than from the maps at similar scale due to the previously mentioned difficulty in detecting the actual stream channel in the smaller watersheds.

For one watershed in the Plateau Province, ERTS-1 imagery was mapped during fall, winter, spring and summer to determine if seasonal analysis would yield varying degrees of detail. Table 2 shows that during March, May, and November when obscuring leafy vegetation is at a minimum, more drainage network detail can be extracted than during the end of the growing season in September. Even the less detailed September imagery in this area provided much more information than that available on larger scale topographic maps. Generally, the amount of drainage information available on the ERTS-1 images changes from season to season as the density of the vegetation changes.

In the Middle Atlantic study area high altitude U-2 photography flown on April 25, 1974 was used to see if this higher resolution data could improve drainage network definition on three watersheds in the Piedmont Province. Watershed area, circularity ratio, and sinuosity were still measured adequately, and on two of the three watersheds drainage network definition, i.e., drainage density, from U-2 imagery at 1:114,000 scale was comparable or better than that obtained from 1:62,500 scale maps. On the third watershed, the Little Patuxent River, drainage density was markedly poorer than that shown on the maps. Very few stream channels were evident at all on the imagery; further checking revealed that the map was compiled before the construction and development in the 1960's of the planned community of Columbia, Maryland which had the effect of removing or drastically modifying the individual channels. It was concluded that the imagery was reflecting the true nature of the drainage network at the time of the flight. Similar results were also observed from ERTS-1.

The mapping of cover type parameters such as forest, open, urban, surface water, and swamp area from ERTS-1 at 1:250,000 scale can be accomplished in all four Middle Atlantic physiographic provinces to within approximately 8-10 percent of that area indicated on the topographic maps at the same scale. Such differences can be expected because of cover type changes occuring between map preparation and ERTS-1 image acquisition. Compared with topographic maps of the same scale, updated forest and urban area percentages can be obtained from ERTS-1. This is especially useful in those areas where recent urban and suburban development has occurred since the time of the last USGS mapping, e.g., on the Little Patuxent River watershed. In addition, some ponds and marshy areas can be observed from ERTS-1, at a scale of 1:100,000, which do not appear on topographic maps at a scale of 1:62,500.

DISCUSSION

The above results demonstrate that ERTS-1 is a useful tool for the physiographic mapping of drainage basins. Drainage density, however, can only be extracted adequately in those areas where the landscape is sufficiently dissected to permit detailed drainage mapping. As stated previously, dissected areas provide better contrast and thus better detail than non-dissected areas. When viewing an ERTS-1 mosaic of the United States at a scale of 1:2,500,000 many dissected areas can be identified which appear suitable for this kind of physiographic parameter delineation. For the most part these areas are characterized by moderate or high relief, non-glaciated landscapes, and resistant and impermeable lithologies. Local relief of approximately 300 feet (91 m) or more between basin divide and valley bottom in watersheds of less than 1000 mi^2 (2600 km^2) usually provides enough contrast to accurately map the drainage network from high resolution satellite imagery. An exception to this was found in the Ridge and Valley Province where adequate local relief existed, but where most stream development has occurred on the flat, wide valley floor. Drainage areas which were once covered by glacial ice often exhibit a lack of structural and bedrock control as well as a lack of drainage patterns with a significant degree of integration or dissection. Streams which encounter resistant rocks tend to form valleys with steep slopes regardless of the climate, and landscapes of this type are conducive to physiographic mapping from high resolution space sensors.

In some cases where ERTS-1 imagery does not provide much drainage network detail, additional information may be obtained by using snow enhanced winter scenes, studying vegetation patterns adjacent to the stream channel, and analyzing different spectral band scenes. The inspection of seasonal ERTS-1 data over a given watershed greatly increases the chances that detailed drainage network information can be extracted. Many times this temporal analysis is successful during times of minimum leaf coverage.

Because meaningful physiographic and land use information is extractable from ERTS-1 data, and, in addition, because these data are similar to the kinds of data used by Sopper and Lull (1970) for predicting average streamflow amounts and distribution, the space-acquired data seem most useful for characterizing mean yield from ungaged watersheds. Also pertinent is a recent comparison of the kinds of physiographic and land use data necessary for calibration of the Stanford Watershed Model with the type of data that can be obtained with remote sensing as shown in this study. Table 3 presents the data that are commonly used for model calibration. The only information in Table 3 that might not be easily extracted from space is the impervious area (although urban area determinations are directly connected to the impervious area total) and some drainage network detail in areas like the Middle Atlantic States. Work in progress at Goddard Space Flight Center has initially shown that all the parameters listed in Table 3 may be suitably extracted from ERTS-1 data for watersheds as small as 30 mi^2 (78 km^2). Thus, the space data can be used in part for the simulation

CONCLUSIONS

1. Watershed area, shape, and stream sinuosity measurements from ERTS-1 are generally comparable to similar physiographic measurements derived from topographic maps regardless of study area. Various natural and artificial land cover types are also easily extracted from ERTS-1 and may be used to update the existing data base.

2. Drainage networks are well delineated in dissected areas with detail on 1:100,000 scale ERTS-1 enlargements commensurate with information on 1:62,500 topographic maps. Low order streams are difficult to detect in heavily vegetated areas with little local relief or in areas where stream channel development is limited. In these areas ERTS-1 derived drainage densities are generally less than those obtained from equivalent scale topographic maps, however, temporal ERTS-1 analysis or the use of high altitude U-2 photography will usually bring out greater detail.

3. The physiographic and land use information extracted from ERTS-1 imagery is compatible for use in general mean annual runoff prediction techniques for ungaged watersheds as well as for use in watershed model calibration. Such application makes ERTS-1 data a useful new supplemental information source for water resources development.

LITERATURE CITED

Dallam, W. C. and A. Rango. 1975. Hydrologic land use classifications of the Patuxent River Watershed using ERTS-1 digital data. Proceedings of the 41st Annual Meeting of the American Society of Photogrammetry, March 9-14, Washington, D. C.

DeWalle, D. R. and A. Rango. 1972. Water resources applications of stream channel characteristics on small forested basins. Water Resources Bulletin, 8:697-703.

Freden, S. C. and E. P. Mercanti. 1973. Symposium on Significant Results Obtained From Earth Resources Technology Satellite-1, Vol. 3 - Discipline Summary Reports, Document X-650-73-155, Goddard Space Flight Center, Greenbelt, Maryland, 118 pp.

Kesik, A. B. 1973. Analysis of the drainage pattern of selected areas of Canada using ERTS-1 imagery as a base. Remote Sensing and Water Resources Management, American Water Resources Association, 209-224.

Sopper, W. F. and H. W. Lull. 1970. Streamflow characteristics of the northeastern United States, Pennsylvania State University, Agricultural Experiment Station, Bulletin 766, 129 pp.

Trainer, F. W. 1969. Drainage density as an indication of base flow in part of the Potomac River Basin. U.S. Geological Survey Professional Paper 650-C, 177-183.

Williams, D. L., B. Barker, and J. C. Coiner. 1973. Interpretation of land use and stream order, Pawnee River Basin, Kansas. University of Kansas, Center for Research, Inc., ERTS Detailed Image Interpretation Report CRINC-DIIR 2264-8, 5 pp.

Table 1

Physiographic Data Extraction — Southwest Wisconsin Hills Province

Watershed	Watershed Area (km^2)		Circularity Ratio (km^2/km^2)		Drainage Density (km/km^2)		Sinuosity (km/km)	
	ERTS-1 Image (1:250,000)	USGS Map (1:250,000)	ERTS-1	Map	ERTS-1	Map	ERTS-1	Map
1. Kickapoo at La Farge	666	668	0.62	0.57	1.08	0.72	1.3	1.4
2. Kickapoo at Gay Mills	1,572	1,567	0.46	0.49	1.06	0.71	1.4	1.4
3. Kickapoo at Steuben	1,756	1,785	0.38	0.42	1.11	0.71	1.4	1.5
4. Platte River	378	358	0.65	0.59	0.55	0.20	1.3	1.3
5. Grant River	625	679	0.72	0.71	0.52	0.24	1.5	1.5
6. Black Earth Cr.	141	128	0.56	0.48	0.56	0.38	1.0	1.2

Table 2

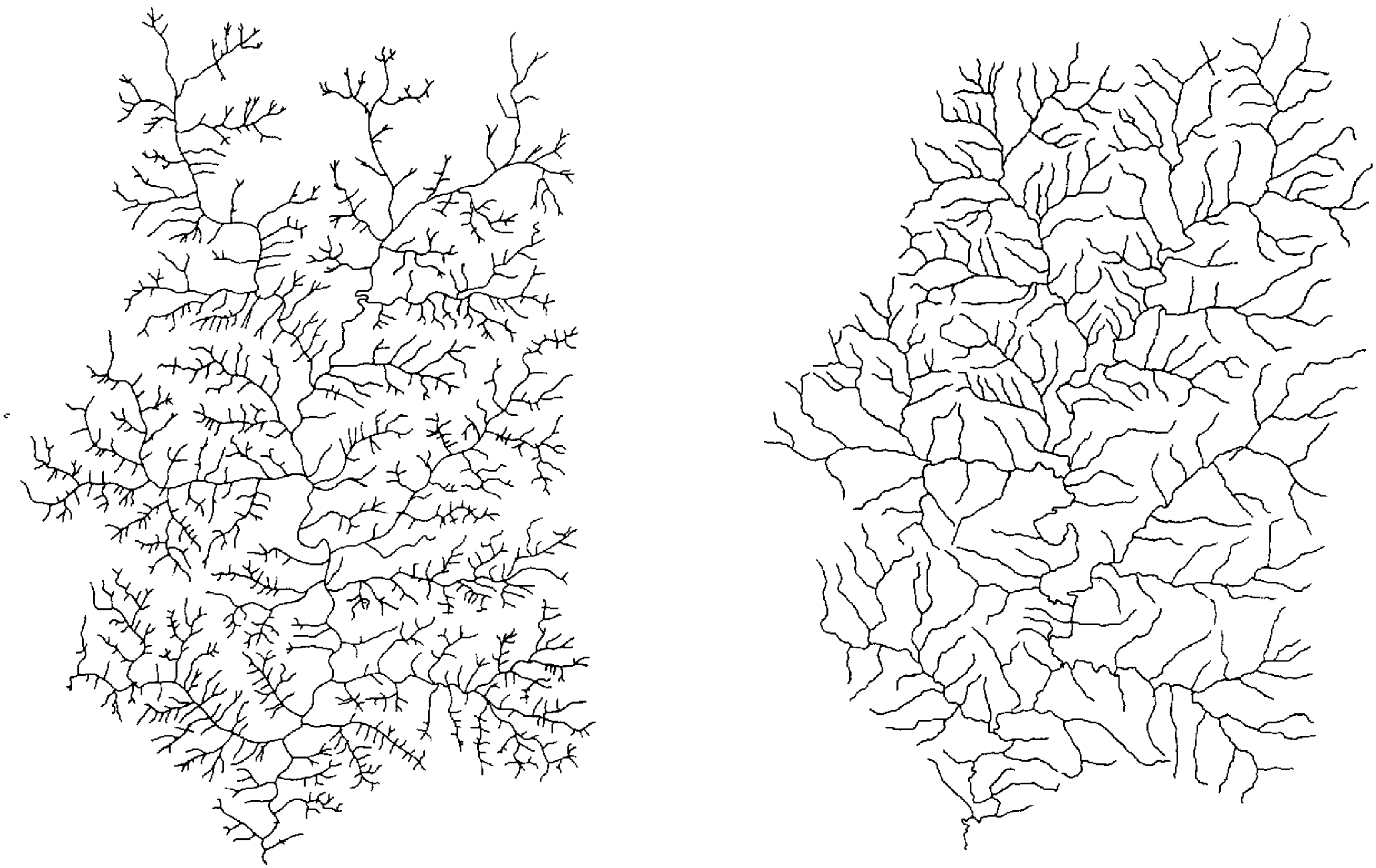
Seasonal ERTS-1 Comparison of Total Stream Length and Drainage Density Data Extraction on Loyalsock Creek, Pa.

ERTS-1 Date	Stream Length (km)	Drainage Density (km/km^2)
6 Sept 72	296	0.25
23 March 73	753	0.65
16 May 73	663	0.58
30 Nov 73	652	0.57

Table 3

Physiographic and Land Use Data Necessary For Stanford Watershed Model Calibration

Physiographic	Land Use
Watershed Area	Impervious Area (Urban Area)
Drainage Network	Percent Forest Cover
Stream Length	Other Cover Types (Grassland, Open, etc.)
Average Overland Flow Length	Surface Water Area
	Swamp Area



ERTS 1:100,000 SCALE ENLARGEMENT OVERLAY, JANUARY 2, 1973

USGS 1: 62,500 SCALE TOPOGRAPHIC MAP OVERLAY

Figure 1. Kickapoo River (above La Farge) Drainage Network Taken from ERTS and USGS Maps