81-10129
CR-164119

IMPROVING STREAMFLOW ESTIMATES THROUGH THE USE OF LANDSAT

By G. J. Allord[1/] and F. L. Scarpace[2/]

(E81-10129) IMPROVING STREAMFLOW ESTIMATES THROUGH THE USE OF LANDSAT (Geological Survey, Malaysia.) 16 p HC A02/MF A01 CSCL 08H

N81-23542

Unclas

G3/43 00129

1/ Gregory J. Allord *

Cartographer

U.S. Geological Survey, Water Resources Division

Madison, Wisconsin 53706

608 263-7101

2/ Frank L. Scarpace, Associate Professor

Institute for Environmental Studies

University of Wisconsin-Madison

Madison, Wisconsin 53706

608 263-3973/262-1405

ABSTRACT

Estimates of low flow and flood frequency in several southwestern Wisconsin basins have been significantly improved by determining land cover from Landsat imagery. With the use of new estimates of land cover in multiple-regression techniques, the standard error of estimate (SE) for the least annual 7-dav low flow for 2- and 10-year recurrence intervals of ungaged sites were lowered by 9 percent each. The SE of flood frequency in the "Driftless Area" of Wisconsin for 10-, 50-, and 100-year recurrence intervals were lowered by 14 percent. Four of nine basin characteristics determined from satellite imagery were significant variables in the multiple-regression techniques, whereas only 1 of the 12 characteristics determined from topographic maps was significant. The percentages of land-cover categories in each basin were determined by merging basin boundaries, digitized from quadrangles, with a classified Landsat scene. Both the basin boundary X-Y polygon coordinates and the satellite coordinates were converted to latitude-longitude for merging compatibility.

KEY TERMS: Low Flow, Peak Discharge, Regression Analysis, Land Use, Wisconsin, Landsat

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INTRODUCTION

Comprehensive water-resources management needs information on streamflow characteristics. Complete streamflow information requires techniques to extrapolate available information to ungaged sites.

Thomas and Benson (1970) demonstrated that streamflow characteristics can be related to basin characteristics. This method regresses a streamflow characteristic against the basin characteristics of the gaged sites. The technique provides equations that define streamflow characteristics in terms of statistically significant basin characteristics. These equations then may be used to estimate streamflow characteristics at ungaged sites where long-term records are not available.

Land use is one of the basin characteristics shown to influence streamflow. Traditionally, the U.S. Geological Survey (USGS) has measured these land-use areas in Wisconsin from topographic maps, these being the best data available on a statewide basis. Landsat imagery can be used to provide up-to-date land-cover information over large areas with the advantage of spacial and temporal consistency.

Two basins in southwestern Wisconsin were selected to demonstrate that determination of land use through Landsat imagery could improve the equations developed to predict streamflow characteristics at ungaged sites. The basins were selected because relations had been developed for the two basins, and for many subbasins within each basin, based on basin characteristics determined by conventional techniques.

BASIN DESCRIPTION

The two basins selected for study are the lower Wisconsin River basin and the Pecatonica-Sugar River basin (fig. 1). The major part of both basins lies in the "Driftless Area" of Wisconsin. This area is termed "Driftless Area" because it is not covered by glacial drift, except for some alluvial and lake deposits in valleys (fig. 1). The topography of the "Driftless Area" consists of rugged, steep-walled valleys and high relief. Agriculture, especially in the lower Wisconsin River basin, is confined to valley floors and hilltops because of the steepness of the slopes. The remaining part of each basin consists of rolling hills and wide valley floors formed by the unconsolidated glacial deposits that overlie the sandstone bedrock.

LANDSAT IMAGE CLASSIFICATION

The Landsat scene (5386-15325, May 9, 1976) that covers the two river basins was analyzed to provide land-cover information. This particular Landsat scene was selected because it covered both basins, the season was well suited for determination of land-cover types, and atmospheric conditions and image quality were acceptable.

The digital-image processing of the Landsat scene (fig. 2) was begun on the Image-100 System[3/] at the EROS Data Center. Final classification, digitizing of the cartographic data base, and the merging of the map information with the Landsat scene was completed on the University of Wisconsin-Madison Univac 1110[3/] Computer System. The land-use and land-cover classification system suggested by Anderson and others (1976) was used as a guide for the definition of Level I (Landsat type of data) land-use categories.

[3/] The use of trade names in this report is for identification only and does not imply endorsement by the U.S. Geological Survey.

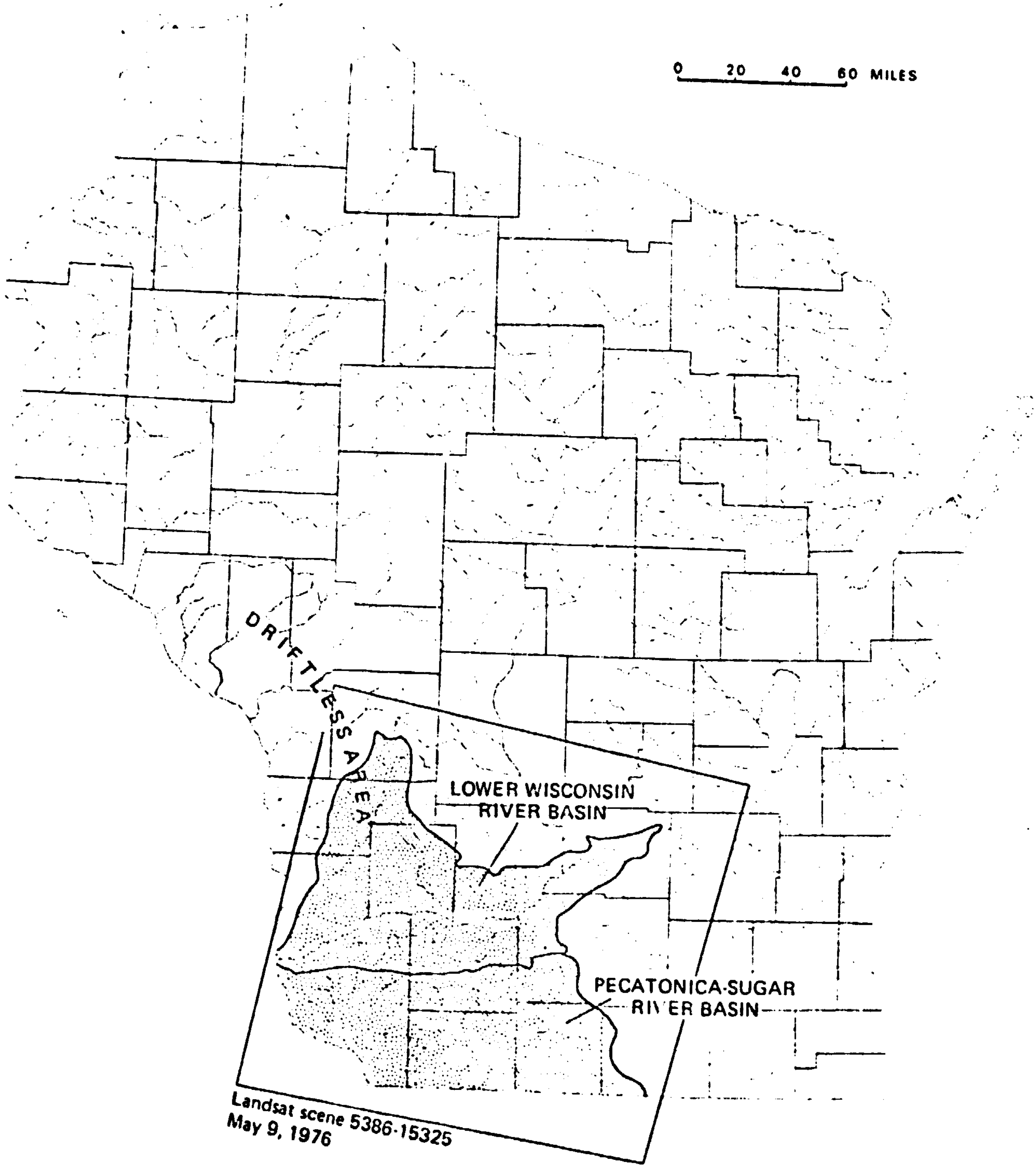


Figure 1. Location of Pecatonica-Sugar and lower Wisconsin River basins in Wisconsin.

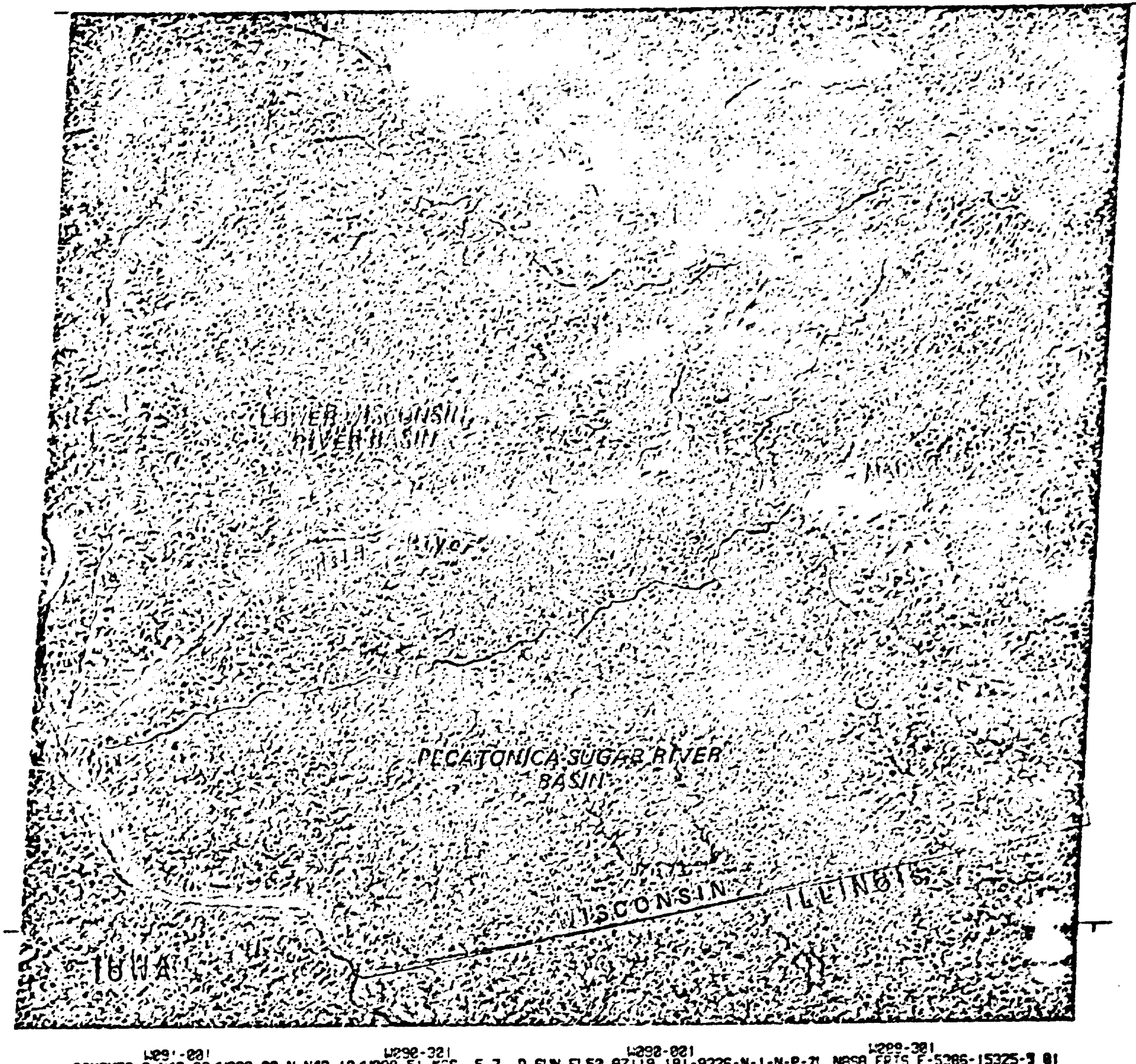


Figure 2. Annotated color-composite Landsat-1 image of southwestern Wisconsin (5385-15325).

The following land-use categories were classified: forest, grassland, water, wetland, mixed vegetation types, bare soil, and cropland. Areas known to be representative of each land-use category were selected, and the spectral signatures from each area were determined. These signatures then were used to classify the rest of the image into land-use categories. Final classification of the land uses was done through the use of an unsupervised parallelepiped classifier with a minimum distance-to-mean check for potentially overlapping classes. The results of this classification were stored on a computer tape and merged with the digitized basin boundaries provided by the technique described in the following section.

CARTOGRAPHIC DATA BASE

Basin boundaries, drawn on U.S. Geological Survey 1:24,000 and 1:62,500 quadrangles, were digitized at the University of Wisconsin-Madison Cartographic Laboratory. The line segments were converted from digitizer coordinates to latitude and longitude coordinates and stored in a data base, identified by the site-identification code assigned by the USGS downstream site-numbering system. The site-identification code is used to retrieve all the coordinates that would draw the polygon outline of the basin. The computer program provides the outline of a basin composed of several subbasins by compiling only the outside boundaries of the individual subbasins.

MERGING LANDSAT AND CARTOGRAPHIC INFORMATION

Although the geometry of the Landsat scene is, in general, stable and relatively good, individual nonlinearities and irregularities may be present. Accurate merging of satellite coordinates and latitude and longitude coordinates requires registry based on established ground-control points. Regression procedures are used to develop equations relating the Landsat scene coordinates to latitude/longitude coordinates at each control point. A detailed discussion of this procedure by Fisher and others is published in "Photogrammetric Engineering and Remote Sensing", April 1979. Control points usually selected are conspicuous land features, such as penninsulas and islands. Residual errors of less than two pixels (picture element) in predicted versus actual row-column coordinates were determined.

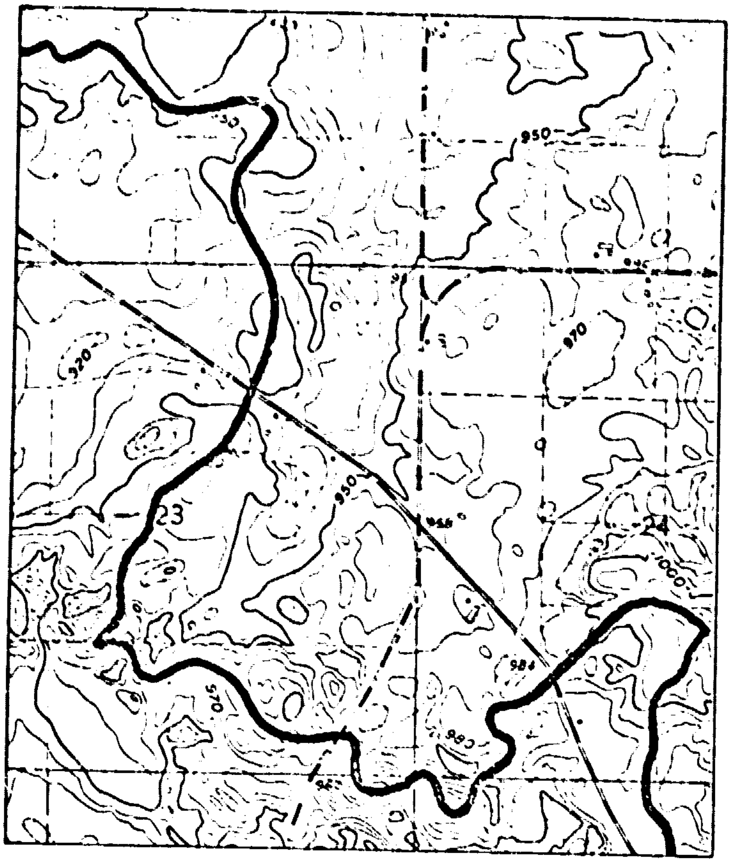
The basin boundary latitude and longitude coordinates stored in the cartographic base are converted, by the geometrically controlled regression equations, to Landsat row-column coordinates. The selected drainage basin is outlined, and the total amount of each land-use type within that individual basin is tabulated Fig. 3 digitally and printed out (fig. 3).

Landsat coordinates were determined for an area on the west side of Madison, Wis., to verify the accuracy of the conversion technique. Land use was also classified to verify the classification technique. The predicted basin boundary agreed to actual location with an accuracy error of ± one pixel. The land-use classifications agreed with visual spot checks.

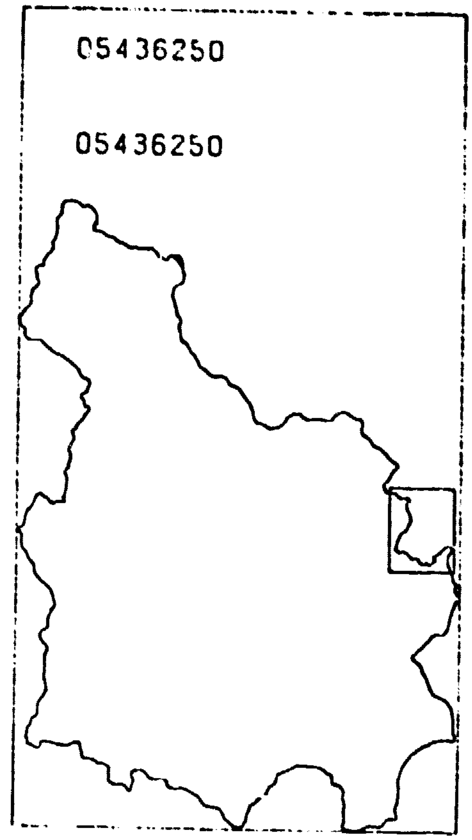
LOW-FLOW REGRESSION ANALYSIS

The land-use data obtained from the Landsat imagery were used in a step-forward regression analyses, as outlined by Thomas and Benson (1970), to develop relations for low flow and floodflows. The equations with the lowest standard error of estimate with all variables significant at the 99 percent or the 95 percent confidence level were selected as the best equations for prediction. The resultant equations were compared to those developed using conventional land-use data.

Low-flow relations were developed for the lower Wisconsin River basin Fig. 4 (fig. 4) based on data for 27 subbasins. The standard error of estimate (SE)



Part of a 1:24,000 U.S.G.S. topographic quadrangle used to digitize the Allen Creek near Albany basin.



Digitized output at 1:250,000 of Allen Creek near Albany basin.

Land-use classification of Allen Creek near Albany.

Tabular total for Allen Cr near Albany

No.	Theme	No. of Pixels
0	Unclassified	1386
1	Forest	8426
2	Grass	8021
3	Water	186
4	Wetlands	1813
5	Mixed veg.	2847
6	Bare soil	9996
7	Crop land	7003

Figure 3. Steps for extracting land-use areas for a basin.

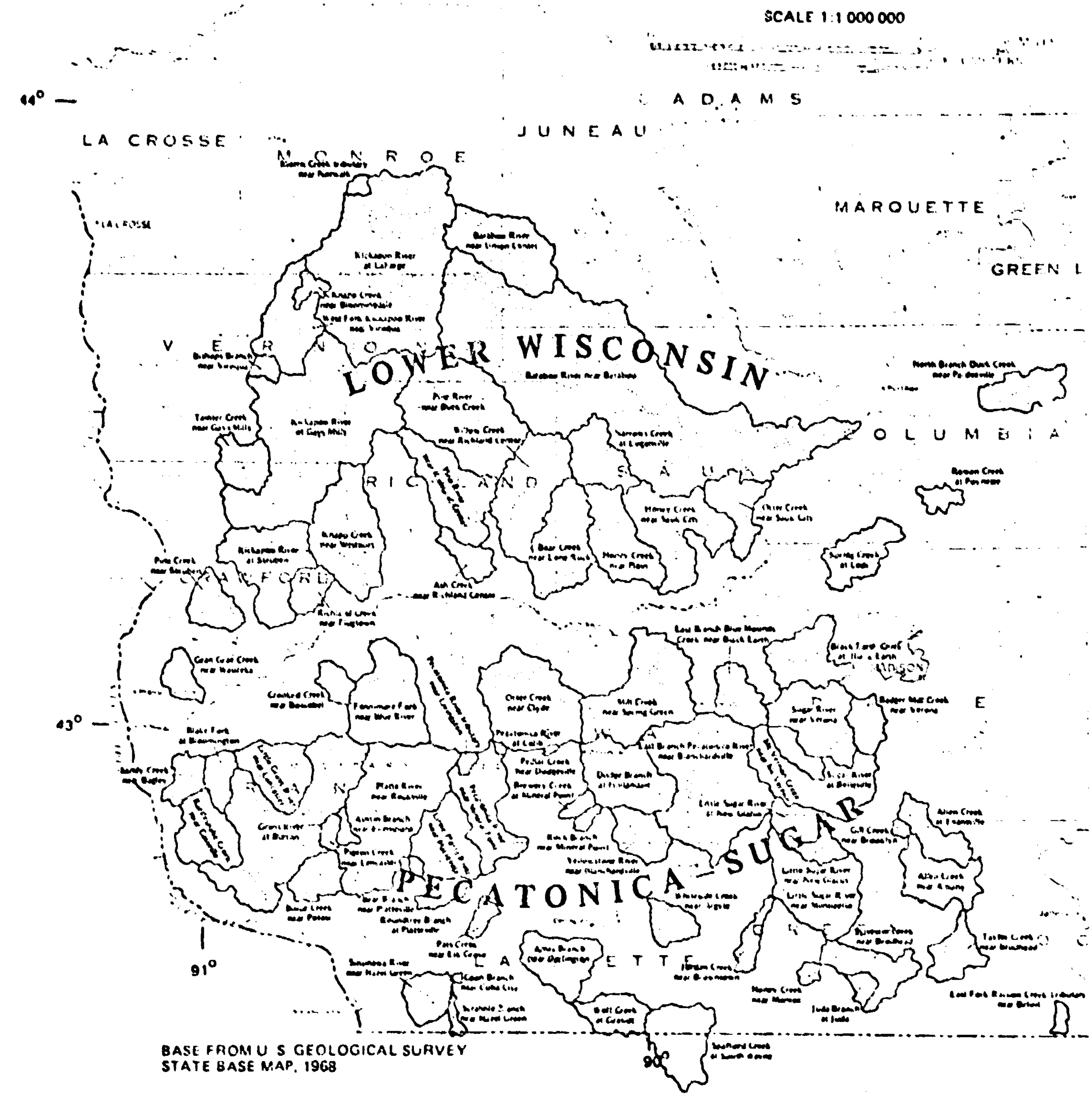


Figure 4. Location of basins used for estimating low-flow characteristics.

for the relation $Q_{7,2}$ (least annual 7-day low flow for 2-year recurrence intervals) developed using Landsat imagery was 35 percent (table 1) as compared to an SE of 44 percent for the relation developed using conventional land-use data. The SE for the $Q_{7,10}$ (10-year recurrence intervals) relation was reduced from 52 to 41 percent (table 1) when Landsat data were used. A reduced standard error of estimate indicates less variance about the relation, therefore the predictive capability of equation is improved.

Gebert (1977) showed that the $Q_{7,2}$ and $Q_{7,10}$ relations were improved by using an additional basin characteristic, the base-flow index (Gebert, 1977, p. 15). The improved relations reported by Gebert are equations 3 and 5 in table 1. Through the use of land-use data obtained from Landsat imagery and including the base-flow index, the SE for the $Q_{7,2}$ relation decreased from 23 to 19 percent, and the SE for the $Q_{7,10}$ relation decreased from 32 to 26 percent (table 1).

Table 1

Land-use data based on Landsat imagery for 43 subbasins (fig. 4) were used to develop $Q_{7,2}$ and $Q_{7,10}$ relations for the Pecatonica-Sugar River basin as well. The SE's for these new relations showed no reduction. This occurred because only area and the base-flow index were significant in the relations. The land use of this basin apparently does not affect low flow as it does in the lower Wisconsin River basin.

FLOOD-FREQUENCY REGRESSION ANALYSIS

Flood-frequency relations were also developed for the sections of the lower Wisconsin River and the Pecatonica-Sugar River basins in the "Driftless Area". The relations were developed through the use of Landsat land-use data, and these were compared to similar relations developed from conventional sources. Data

Table 1.--Comparison of regression results using Landsat data in lower Wisconsin River basin

Equation number	Equation	Standard error of estimate	Source of information
1	$Q_{7,2} = 0.218A^{1.05}$	44 percent	Quads
1 LS	$Q_{7,2} = 0.486A^{0.93}We^{0.52}Mv^{0.86}Cl^{-1.12}$	35 percent	Landsat
2	$Q_{7,10} = 0.615A^{1.04}$	52 percent	Quads
2 LS	$Q_{7,10} = 0.612A^{0.90}We^{0.59}Mv^{0.94}Cl^{-1.37}$	41 percent	Landsat
3	$Q_{7,2} = 0.262A^{1.00}Ft^{0.34}In^{0.12}Bfi^{0.91}$	23 percent	Quads
3 LS	$Q_{7,2} = 0.00169A^{1.00}Ft^{0.71}Mv^{0.30}Bs^{0.16}Bfi^{0.80}$	19 percent	Landsat
5	$Q_{7,10} = 0.172A^{0.98}Ft^{0.45}In^{0.19}Bfi^{1.02}$	32 percent	Quads
5 LS	$Q_{7,10} = 0.00245A^{0.96}Ft^{0.76}Wa^{-0.87}Bs^{0.30}Bfi^{0.90}$	26 percent	Landsat

A = area in square miles, We = percent of wetland, Mv = percent of mixed vegetation, Cl = percent of cropland, Ft = percent of forest, In = infiltration rate, Bs = percent of bare soil, Bfi = base-flow index, and Wa = water.

Table 2.--Comparison of flood-frequency regression results through the use of Landsat data in the "Driftless Area" of Wisconsin

Equation	Standard error of estimate	Source of information
$P_{10} = 1.65X10^{-4}A^{0.665}(Pr-20)^{5.63}$	29 percent	Quads
$P_{10} = 0.786A^{0.677}(Pr-20)^{2.47}Wa^{-3.95}Mv^{-0.513}Cr^{0.402}$	16 percent	Landsat
$P_{50} = 4.4X10^{-5}A^{0.672}(Pr-20)^{6.32}$	31 percent	Quads
$P_{50} = 1.01X10^{3}A^{0.767}Ft^{-0.298}Wa^{-4.41}$	17 percent	Landsat
$P_{100} = 3.01X10^{-5}A^{0.674}(Pr-20)^{6.52}$	34 percent	Quads
$P_{100} = 1.22X10^{3}A^{0.773}Ft^{-0.315}Wa^{-4.57}$	17 percent	Landsat

A = area in square miles, Pr = precipitation, Wa = percent of water, Mv = percent of mixed vegetation, Cr = percent of cropland, and Ft = percent of forest.

for 14 subbasins were used to develop relations representing flood peaks with recurrence intervals of 10, 50, and 100 years (P_{10}, P_{50}, and P_{100}). The P_{10} and P_{50} relations developed through the use of Landsat imagery had SE's of [illegible] and 17 percent, respectively, compared with SE's of 29 and 31 percent, respectively, for the relations developed using conventional land-use data (table 2). The SE for the P_{100} relation was reduced from 34 to 17 percent when Landsat data were used. These represent significant improvements in the predictive relations.

SUMMARY

The $Q_{7,2}$ and $Q_{7,10}$ low-flow relations in the lower Wisconsin River basin were improved 17 to 20 percent when Landsat land-use data were used in developing the relations. Land use did not prove to be a significant variable in the Pecatonica-Sugar River basin for low-flow estimates. Estimates for the flood-frequency relations with recurrence intervals of 10, 50 and 100 years were improved 45 to 50 percent.

Landsat data can be used to significantly improve relations for predicting streamflow characteristics. These improvements will result in a more accurate determination of water resources and will aid in management decisions.

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ILLUSTRATIONS