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SKYLAB IMAGERY:

Application to Reservoir Management in New England

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Skylab Imagery:

Application to Reservoir Management

in New England

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PRINCIPAL INVESTIGATOR - - SAUL COOPER

September 1975

Final Project Report

Contract T-4646B

PREFACE

This report was prepared by H.L. McKim, Soil Scientist, L.W. Gatto, Geologist, C.J. Merry, Geologist, and R.K. Haugen, Geographer, Earth Sciences Branch, Research Division, U.S. Army Cold Regions Research and Engineering Laboratory (USACRREL).

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ABSTRACT

The purpose of this investigation was to determine the utility of Skylab S190A and B photography for providing reservoir management information in New England. LANDSAT, Skylab S190A and S190B and RB-57/RC8 images were reduced to a common scale of 1:63,360 for a mapping base to demonstrate the extent to which the imagery could be utilized in the preparation of reconnaissance land use maps. These types of maps are required in the baseline evaluation of areas for reservoir management planning and for future environmental planning activities, i.e. permit evaluation and impact statements. Visual interpretations were accomplished on original NASA color infrared S190A/B and RB-57/RC8 transparencies and a LANDSAT false color print made in-house. Ancillary data were not used during the mapping exercise to eliminate bias in the comparisons and to ensure that the results were derived strictly from interpretations of tones and textures on the photography. The classification scheme was a modified version of the U.S. Geological Survey Land Use Classification System for use with remote sensor data. The mapping units delineated from each of the data products were as follows: LANDSAT-1 MSS - 5 individual level I, 2 combined level I, and 8 level II; S190A - 6 level I and 13 level II; S190B - 6 level I, 17 level II and 1 level III; and RB-57/RC8 - 6 level I, 21 level II and 5 level III. This investigation demonstrates that for land use mapping the Skylab S190B photography compares favorably with the RC8 photography and is much superior to LANDSAT-1 MSS imagery and Skylab S190A photography.

The relative utility of the multiband imagery in identifying and quantifying hydrologic factors was evaluated. The land use statistics for two small watersheds were determined and the effects of these land use factors were appraised for possible contribution to runoff potential. This appraisal indicated that basin topography and the nature of runoff may be more important factors in predicting volume of runoff from a watershed than land use factors.

Significant findings of this investigation were as follows: 1) S190B imagery is superior to the LANDSAT MSS imagery for land use mapping and is as useful for category I and II land use mapping as the high altitude RC8 imagery. Detailed land use mapping at levels III and finer from satellite imagery requires better resolution. However, the larger areal coverage available from the S190B imagery is a great advantage. Thus the S190B imagery was found to be nearly ideal for detailed, regional land use mapping; 2) for evaluating volume runoff potentials the S190B imagery was found to be as useful as the RB-57/RC8 imagery; 3) where regional hydrologic surveys and land use mapping are critical requirements in urban planning and natural resource development, the S190B imagery is of great potential value.

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INTRODUCTION

The New England Division, Corps of Engineers was selected by NASA to participate in an investigation to assess the utility of Skylab Earth Resources Experiment Package (EREP) S190A and S190B data products for reservoir management. This investigation titled "New England Reservoir Management" (#EPN089) commenced on 23 April 1973 with the following tasks:

1. To evaluate the utility of S190A/B imagery for mapping the extent of flooding by visual interpretation and comparison of results with ground truth data from reservoirs and stream gaging stations in the Connecticut River Valley.

2. To compare S190A/B photographs with LANDSAT imagery and existing aerial photographs to determine the optimum type and scale of imagery for monitoring the extent of floods and preparing vegetation/land use maps.

3. To prepare vegetation/land use maps of the Merrimack River basin from S190A/B photographs.

4. To analyze the hydrologic characteristics of selected sub-basins of the Connecticut and/or Merrimack Rivers to determine the effects of factors such as vegetation and land use patterns on watershed runoff characteristics.

Reservoir management includes the procedures required to insure proper regulation and maintenance of a reservoir such as: daily adjustments of water flow, monitoring water quality, assessing slope stabilization, conducting post-flood clean-up operations and managing reservoir recreational facilities. Data on flood damage, ice and snow are required periodically for these operational/maintenance procedures[1].

As reservoir projects increase in number and complexity the need for effective management becomes greater. This is especially true as national concern has recently focused on the impact of man's activities on environmental conditions, water quality control and recreation. In the past significant environmental information has surfaced late in the planning stage or after project construction. Consequently, the Corps has recognized the need for more detailed and comprehensive environmental information in water resources activities. The Corps has outlined an environmental information system consisting of reconnaissance inventories, detailed project inventories, baseline studies and monitoring programs. Data acquired are being used in preparation of environmental impact statements.

Acquisition of information required for reservoir management can be costly and time consuming. New remote sensing techniques, utilizing high altitude aircraft and satellite multispectral imagery, provide the capability to augment or, in some instances, replace the data collection procedures presently employed. The primary purpose of this investigation was to determine the utility of the Skylab S190A and S190B imagery for reservoir management activities in the New England Division, Corps of Engineers.

BACKGROUND

LANDSAT

As principal investigator for LANDSAT-1 and -2 projects, Mr. Saul Cooper of the New England Division has been actively engaged in the assessment of satellite imagery and data relay capabilities for potential use in the management of flood control reservoir systems. A final report of the results of the LANDSAT-1 investigation, "The Use of ERTS Imagery in Reservoir Management and Operation", was submitted to NASA in March 1975 and is available from the National Technical Information Service (NTIS). The principal tasks of the LANDSAT-2 follow-on investigation are:

a. Define various hydrologic features utilizing the LANDSAT-2 computer compatible tapes which we found to be more useful for our purposes than the LANDSAT imagery;

b. Construct and test an automated satellite ground receiving station for collection of data from in-situ sensors and an extension of the successful testing of the LANDSAT-1 data collection system.

Skylab

The Earth Resources Experiment Package (EREP) provided for the first time an opportunity to compare high resolution satellite photographic data products with LANDSAT multispectral imagery and high-altitude aircraft photography. To accomplish the four tasks of this experiment the following data products were used: LANDSAT Multispectral

Scanner imagery, Skylab S190A and S190B photographs and RB-57/RC8 high-altitude aircraft photographs.

It was agreed that accomplishment of these tasks was dependent on acquisition of usable Skylab data products. Cloud-free Skylab photographs of a significant flood event in New England were not obtained; consequently, it was not possible to evaluate the usefulness of the imagery for mapping the extent of flooding. Acquisition of LANDSAT or Skylab imagery during a short term event, such as flooding, is extremely difficult. These satellites made regular orbits over a particular location on a pre-determined schedule and a flood had to occur during an orbital pass to be observed. During the analytical stages of this investigation, LANDSAT-1 provided imagery of the same location every 18 days. Since the launch of LANDSAT-2 in January 1975, imagery of a particular site could be obtained every 9 days. This increases the possibility of acquiring LANDSAT imagery during a flood. Geostationary satellites would be especially useful for studies of short term events. Two geostationary satellites could provide imagery of specific locations throughout the entire U.S. on command.

Several investigators[2-5] had demonstrated earlier the utility of LANDSAT-1 imagery in mapping areas inundated by flooding. Vegetative damage that resulted from the 1973 June-July flood in New England was observed on the RC-8 color infrared (CIR) photographs acquired during the RB-57 flight in September 1973. Considering the similarity of detail observable on the S190B and RB-57/ RC8 photographs (Tables 6 and

8), it is reasonable to assume that this damage would also be detectable on the S190B product. Since the resolution of the S190A multispectral imagery is better than that of the LANDSAT imagery, it, too, is no doubt sufficient to define the areal extent of flooding along the larger rivers in New England.

DATA PRODUCTS

LANDSAT-1 Imagery

The LANDSAT-1 Multispectral Scanner (MSS) imagery is acquired in four separate spectral bands: band 4, 0.5-0.6μ; band 5, 0.6-0.7μ; band 6, 0.7-0.8μ; and, band 7, 0.8-1.1μ. Complete LANDSAT coverage of New England is available on 20 scenes from five orbital passes (a-e, Fig. 1). The imagery covers approximately 185 km on a side, has 10% overlap in the along track direction and approximatley 40% sidelap between adjacent tracks. The imagery is available as 5.7 cm x 5.7 cm black and white transparancies, 18.6 cm x 18.6 cm black and white (B/W) transparencies or prints and 18.6 cm x 18.6 cm "false color" transparencies and prints. The imagery used in this investigation was 18.6 cm x 18.6 cm B/W transparencies acquired on 10 and 29 August 1973.

S190A Photographs

The Skylab EREP data products utilized in this study consisted of the S190A and S190B photographs. EREP photographic coverage of New England during the 28 day Skylab 2 (SL-2) mission was not acquired due to the failure of the solar panels on the Orbital Workshop. During the

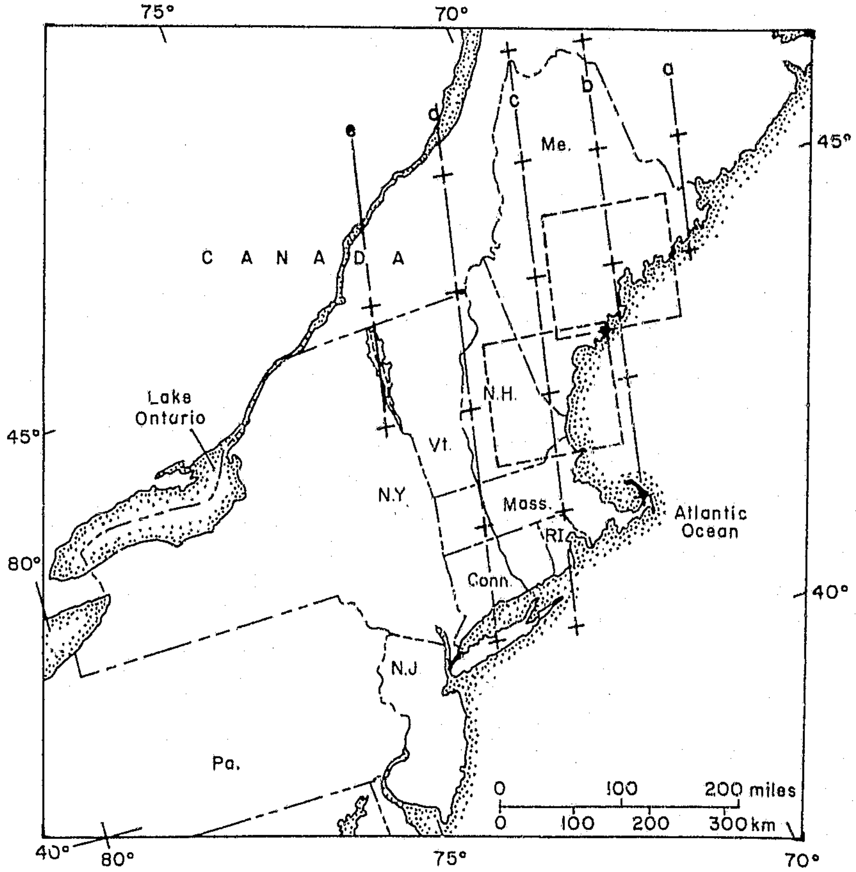

Figure 1. LANDSAT orbital tracks (a–e) over New England; +, image centers; dashed outlines show ground coverage per frame and image overlap and side lap.

59 day Skylab 3 (SL-3) mission four passes occurred over the New England test site (No. 338613), but only the 21 September 1973 pass was cloud-free and usable for analysis. The only Skylab 4 (SL-4) pass over new England during its 84 day mission occurred on 14 January 1974 but the test site was cloud covered (Fig. 2, Table 1).

The S190A Multispectral Photographic Camera had six high-precision, f/2.8 lenses with matching optical systems and a 15.2 cm

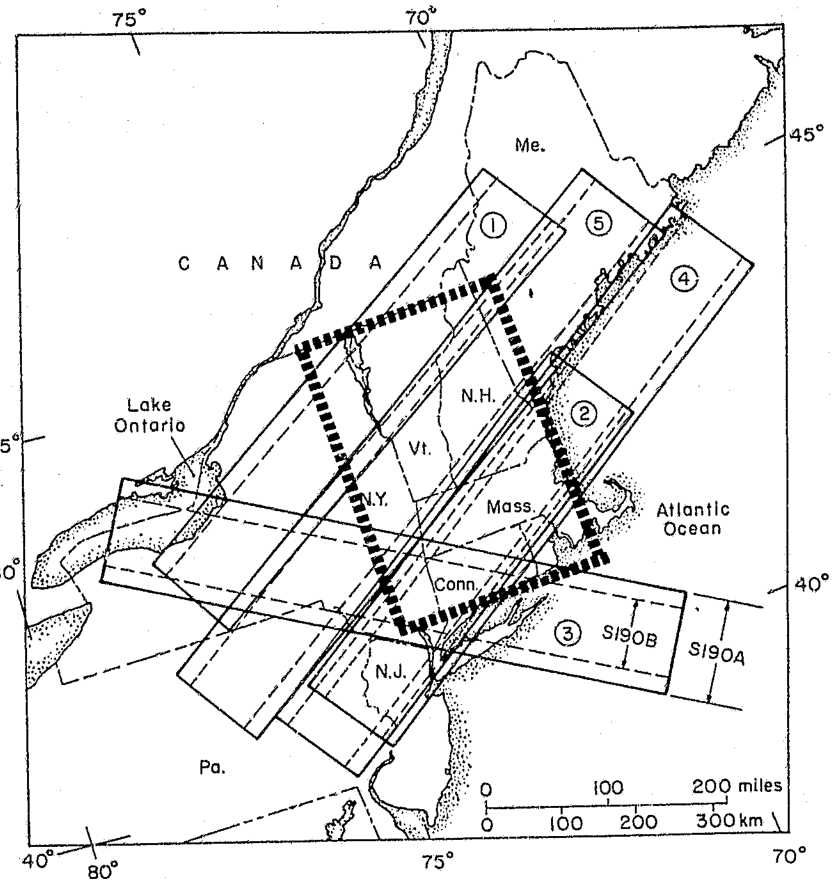

Figure 2. Skylab 3 and 4 S190A/B photographic coverage of New England; dashed outline shows location of test site No. 338613.

Table 1. Skylab 3 and 4 ground track data for passes over New England (see Figure 1 for locations of areas 1-5).

Area	Date	Cloud Cover, %	Orbit	Ground Track
1	10 Sep 73	0	30	15
2	16 Sep 73	0-90	44	29
3	19 Sep 73	0-60	50	4
4	21 Sep 73	0	52	29
5	14 Jan 74	0-90	83	29

focal length. This system provided 5.7 cm x 5.7 cm and 22.8 cm x 22.8 cm photographs covering 163 km^2. The S190A films used on the satellite are listed in Table 2a, the duplicating films provided to the investigators are shown in Table 2b.

Table 2. S190A Multispectral Camera photography.[6]
a. First generation films used onboard the satellite.

Film Type	Filter	Filtered Spectral Bandwidth (μ)
Panatomic-X B and W, SO-022	AA	0.5-0.6
Panatomic-X B and W, SO-022	BB	0.6-0.7
B and W infrared, EK 2424	CC	0.7-0.8
B and W infrared, EK 2424	DD	0.8-0.9
Hi-resolution color, SO-356	FF	0.4-0.7
Color infrared (CIR), EK 2443	EE	0.5-0.88

b. Second (5.7 cm x 5.7 cm format) and third (22.8 cm x 22.8 cm format) generation films received for areas 1-5 in Table 1.

Film Type	Spectral Bandwidth (μ)
Finegrained aerial duplicating film, EK 2430	0.5-0.6
Finegrained aerial duplicating film, EK 2430	0.6-0.7
Aerographic duplicating film, EK 2420	0.7-0.8
Aerographic duplicating film, EK 2420	0.8-0.9
Aerographic duplicating film, SO 360	0.4-0.7
Aerographic duplicating film, SO 360	0.5-0.88

S190B Photographs

The S190B Earth Terrain Camera was equipped with a f/4, 45.7 cm focal length lens that gave a ground coverage of 109 km^2. The film format was a 11.4 cm by 11.4 cm. The S190B films used on the satellite are listed in Table 3a, the investigators received data products made from the duplicating films listed in Table 3b.

Table 3. S190B Earth Terrain Camera photography.[6]
a. First generation films used onboard the satellite.

Film Type	Wratten Filter	Filtered Spectral Bandwidth (μ)
Hi-resolution color, SO 242	none	0.4-0.7
High-definition aerial B and W, EK 3414	12 (-blue)	0.5-0.7
Infrared color, EK 3443	12	0.5-0.88
Hi-resolution color infrared, SO 131	12	0.5-0.88

b. Second generation films (11.4 cm x 11.4 cm format) received; third generation films received were 18.8 cm x 18.8 cm format for area 4 and 22.8 cm x 22.8 cm format for areas 1-5 in Table 1.

Film Type	Spectral Bandwidth (μ)	Area
Aerographic duplicating film, SO 360	0.4-0.7	2,3,5
Finegrained aerial duplicating film, EK 2430	0.5-0.7	1
Aerographic duplicating film, SO 360	0.5-0.88	4

RB-57/RC8 Photographs

A NASA RB-57 high altitude aircraft mission was flown over New England on 26 September 1973 (Fig. 3) in support of the Skylab-3

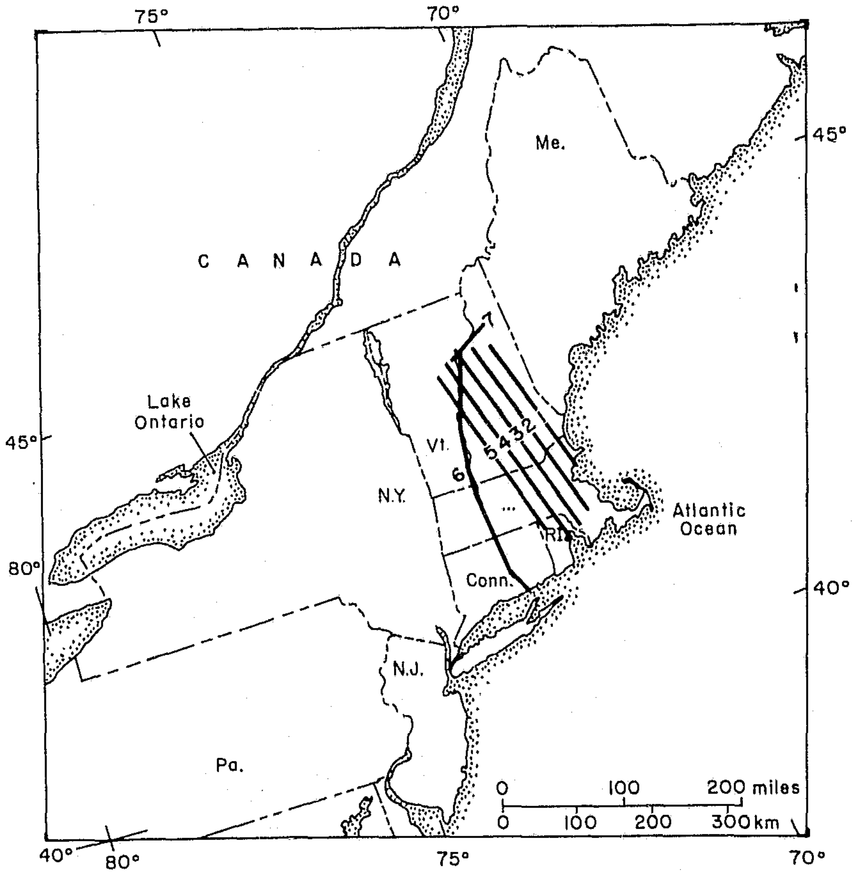

Figure 3. RB-57 aircraft flight lines flown on 26 September 1973, mission 248.

mission.[7] Photographs (scale 1:120,000) were obtained at an altitude of 18.3 km. Two 15.2 cm focal length RC-8 cameras were used. One was equipped with Aerochrome color infrared film, EK 2443, and a Wratten 12 filter. The spectral bandwidth recorded was 0.5-0.88 μ. The other camera was equipped with color positive film, 2445, and a 2a filter. The spectral bandwidth for this film/filter combination was 0.5-0.7 μ. The photographs provided to the investigators were 22.9 cm x 22.9 cm transparencies on SO 360 duplicating film.

Basic Imagery Characteristics

The general characteristics of the LANDSAT, Skylab and RB-57 imagery are given in Table 4. The minimum detectable object size (ground resolution) was determined by inspection (Table 5).

Table 4. Characteristics of NASA standard data products provided to the investigators.

Sensor	Image Dimension per side inch (cm)	Nominal scale	Ground Coverage per side n.mi. (km)	Areal Ground Coverage per image n.mi.^{2} (km^2)
LANDSAT Multi-spectral Scanner	2.25(5.7)	1:3,238,400	100(185)	10,000(34,225)
	7.3(18.6)	1:1,000,000	100(185)	10,000(34,225)
S190A Multi-spectral Photo-graphic Camera	2.25(5.7)	1:2,850,000	88(163)	7,744(26,569)
	9.0(22.8)	1:712,448	88(163)	7,744(26,569)
S190B Earth Terrain	4.5(11.4)	1:955,328	59(109)	3,481(11,881)
	7.4(18.8)	1:580,943	59(109)	3,481(11,881)
	9.0(22.8)	1:477,664	59(109)	3,481(11,881)
RB-57/RC-8 Camera	9.0(22.8)	1:120,000	14.8(27)	219(729)

Table 5. Ground resolution.

	LANDSAT 18.6cmx18.6cm Tranparancies*	S190A 22.8cmx22.8cm Transparancy	S190B 22.8cmx22.8cm Transparency	RB-57/RC8 22.8cmx22.8cm Transparency
Linear features (width,m)	70	25	12.5	5
Circular features (area,m^2)	24,300	4,900	3,200	800

*the 4 bands were tested

In general, the smallest features that can be clearly recognized on the LANDSAT imagery are those linear features such as roads, bridges, etc. about 70 m in width that contrast sharply with the surrounding terrain.[8] The minimum sizes of circular or oblate objects detectable on the Skylab S190A color infrared (22.8 cm x 22.9 cm) and LANDSAT (18.6 cm x 18.6 cm) transparencies are about 4900 m^2 and 24,300 m^2, respectively. Consequently, the accuracy of maps prepared from Skylab photography is superior to that of maps prepared from LANDSAT imagery.

IMAGERY EVALUATION

An evaluation was made of the utility of LANDSAT MSS, 18.6 cm x 18.6 cm, Skylab S190A/B, 22.8 cm x 22.8 cm, and RB-57/RC8, 22.8 cm x 22.8 cm, imagery in quantifying factors that are important in the planning and design of reservoir systems. The values in Table 6 were determined by analyzing transparencies of the spectral bands for each image type; the detail of each environmental factor that was observable on specific bands is reflected as a utility value ranging from 0 to 3. This is a subjective method of evaluation based on imagery available for New England. The relative utility of the various spectral bands and image types may change for other locations where topographic relief, land use and geologic setting are different.

The results show how different spectral bands and ground resolutions of the four sensors effect their utility in measuring environmental factors that include drainage basin characteristics. The factors shown include components of a basin hydrologic cycle that can be extracted and

Table 6. Utility of LANDSAT MSS, Skylab S190A/B and RB-57/RC8 imagery in quantifying environmental factors that affect runoff and are required for reservoir management.

FACTORS	LANDSAT MSS 0.5–0.6μ H.R.	S.R.	0.6–0.7μ H.R.	S.R.	0.7–0.8μ H.R.	S.R.	0.8–1.1μ H.R.	S.R.
BASIN MORPHOLOGY								
Shape/Area	1-	0	1	0	1+	0	1+	0
Topography/Slope	1-	0	1	0	1+	0	1+	0
Drainage Pattern	1-	0	1	0	1	1-	1	1-
Drainage Density	1-	0	1	0	1	0	1	0
Stream Network								
Channel pattern	1-	0	1-	0	1-	0	1-	0
Channel segment lengths	1-	0	1-	0	1-	0	1-	0
Stream order	0	0	1-	0	1-	0	1-	0
Bifurcation ratios	0	0	1-	0	1-	0	1-	0
Relative depth	1-	1-	1	1-	0	0	0	0
LAND USE								
Urban/Built-up Land								
Residential	1-	1-	1-	1	0	0	0	0
Industrial/Commercial	1-	1-	1-	1	0	0	0	0
Extractive	1-	1-	1-	1-	0	0	0	0
Transportation	1-	1-	1-	1-	0	0	0	0
Communication	0	0	0	0	0	0	0	0
Agricultural Land								
Crop land	1-	1-	1-	1	0	0	0	0
Pasture	1-	1-	1-	1	0	0	0	0
Conservation practices	0	0	0	0	0	0	0	0
Orchards	0	0	0	0	0	0	0	0
Irrigation practices	0	0	0	0	0	0	0	0
Forest Land								
Deciduous	0	0	0	0	0	0	0	0
Coniferous	0	0	0	0	0	0	0	0
Mixed	1	1	1	1	0	0	0	0
Logging practices	1-	1-	1-	1-	0	0	0	0
Burnt areas	1-	1-	1-	1-	0	0	0	0
Management practices	0	0	0	0	0	0	0	0
Water								
Stream	1-	1-	1	1	1	1	1	1
Lake	1-	1-	1	1	1+	1+	1+	1+
Pond	1-	1-	1	1-	1+	1+	1+	1+
Reservoir	1-	1-	1	1	1+	1+	1+	1+
Wetlands								
Nonforested	0	0	0	0	0	0	0	0
Forested	0	0	0	0	0	0	0	0
GEOLOGY								
Surficial Materials	0	0	0	0	0	0	0	0
Geomorphology	1-	0	1	0	1+	1-	1+	1-
Structure	1-	0	1	0	1+	1-	1+	1-
Bedrock	0	0	0	0	0	0	0	0
SOILS								
Soil Moisture	0	0	0	0	0	0	0	0
Erosion	0	0	0	0	0	0	0	0
Infiltration	0	0	0	0	0	0	0	0
SNOW/ICE								
Distribution	2	2	2	2	2-	2-	2-	2-
Accumulation/Ablation	2	2	2	2	2-	2-	2-	2-
TOTAL UTILITY VALUE	26-	18-	28-	18-	18+	11-	18+	11-

FACTORS	SKYLAB 190A 0.5–0.6μ H.R.	S.R.	0.6–0.7μ H.R.	S.R.	0.7–0.8μ H.R.	S.R.	0.8–0.9μ H.R.	S.R.	0.4–0.7μ H.R.	S.R.	0.5–0.88μ H.R.	S.R.
BASIN MORPHOLOGY												
Shape/Area	1	1	1	1	1	0	1	0	1-	1-	1	1-
Topography/Slope	1	0	1	1	1	0	1	0	1	0	1	1-
Drainage Pattern	1	1	1	1	1	1	1	1	1	1	1	1+
Drainage Density	1	1	1	1	1	1	1	1	1	1	1	1+
Stream Network												
Channel pattern	1	1	1	1	1	1	1	1	1	1	1	1
Channel segment lengths	1	1	1	1	1+	1	1+	1	1	1	1+	1+
Stream order	1	1	1	1	1+	1	1+	1	1	1	1+	1+
Bifurcation ratios	1	1	1	1	1+	1	1+	1	1	1	1+	1
Relative depth	1	1	1	1	0	1	0	0	1-	1-	1-	1-
LAND USE												
Urban/Built-up Land												
Residential	1	1	2	2	0	0	0	0	2	2	2-	2-
Industrial/Commercial	1	1	2	2	0	0	0	0	2	2	2-	2-
Extractive	1	1	1	1	0	0	0	0	1+	1+	1	1
Transportation	1	1	1	1	0	0	0	0	1+	1+	1+	1+
Communication	0	0	0	0	0	0	0	0	0	0	0	0
Agricultural Land												
Crop land	1	1	1	1	0	0	0	0	1+	1+	1	1
Pasture	1	1	1	1	0	0	0	0	1	1+	1	1
Conservation practices	0	0	1	1	0	0	0	0	1	1	1	1
Orchards	0	0	0	0	0	0	0	0	0	0	0	0
Irrigation practices	0	0	0	0	0	0	0	0	0	0	0	0
Forest Land												
Deciduous	0	0	0	0	0	0	0	0	0	0	0	0
Coniferous	0	0	0	0	0	0	0	0	0	0	0	0
Mixed	2	2	2	2	0	0	0	0	2	2	2	2
Logging practices	1	1	1	1	0	0	0	0	1	1	1	1
Burnt areas	1	1	1	1	0	0	0	0	1	1	1	1
Management practices	0	0	0	0	0	0	0	0	0	0	0	0
Water												
Stream	1	1	1	1	1+	1	1+	1	1	1	2	1
Lake	2	2	2	2	2	2	2	2	2	2	2+	2
Pond	1	1	1	1	2	2	2	2	2	2	2+	2
Reservoir	1	1	1	1	2	2	2	2	2	2	2+	2
Wetlands												
Nonforested	0	0	0	0	0	0	0	0	1-	1-	1	1
Forested	0	0	0	0	0	0	0	0	1-	1-	1	1
GEOLOGY												
Surficial Materials	0	0	0	0	0	0	0	0	0	0	0	0
Geomorphology	1	1	1	1	1+	1+	1+	1	1	1	1+	1+
Structure	1	1	1	1	2+	2	2+	2	1	1	2	2-
Bedrock	0	0	0	0	0	0	0	0	1	1-	1	1-
SOILS												
Soil Moisture	0	0	0	0	0	0	0	0	0	0	0	0
Erosion	0	0	0	0	0	0	0	0	0	0	0	0
Infiltration	0	0	0	0	0	0	0	0	0	0	0	0
SNOW/ICE												
Distribution	2	2	2	2	2	2	2	2	2	2	2	2
Accumulation/Ablation	2	2	2	2	2	2	2	2	2	2	2	2
TOTAL UTILITY VALUE	30	29	33	33	22+	21+	22+	20	37-	36-	39+	39-

FACTORS	SKYLAB S190B 0.4–0.7μ H.R.	S.R.	0.5–0.7μ H.R.	S.R.	0.5–0.88μ H.R.	S.R.	RB-57/RC8 0.5–0.88 H.R.	S.R.
BASIN MORPHOLOGY								
Shape/Area	1+	1	1+	1	2	1	2	1+
Topography/Slope	1+	1	1+	1	2	1	2	1+
Drainage Pattern	1	1	1	1	1+	1	2	2-
Drainage Density	1	1	1	1	1+	1	2+	2
Stream Network								
Channel pattern	1+	1+	1	1	1+	1+	2	2-
Channel segment lengths	1+	1+	1	1	1+	1+	2	2-
Stream order	1+	1	1+	1	1+	1	2	2-
Bifurcation ratios	1+	1	1+	1	1+	1	2	2-
Relative depth	1	1	1	1	1-	1	1	1
LAND USE								
Urban/Built-up Land								
Residential	2+	2+	2	2-	2+	2+	3	3
Industrial/Commercial	2+	2+	2	2-	2+	2+	3	3
Extractive	2+	2+	2	2-	2+	2+	3	3
Transportation	2+	2+	2	2-	2+	2+	3	3
Communication	2	2	1+	1	2+	2+	3	3
Agricultural Land								
Crop land	2	2	2	1	2+	2+	3	3
Pasture	2	2	1+	1	2+	2+	2+	2+
Conservation practices	2	2	1+	1	2	2	2	2
Orchards	2-	2-	1	1	2-	2-	3	3
Irrigation practices	2	2	1	1	2	2	2+	2+
Forest Land								
Deciduous	1	1	1	1-	1+	1	3-	2-
Coniferous	1	1	1	1-	1+	1	3-	2-
Mixed	2+	2+	2	2-	2+	2+	3	3
Logging practices	2	2	2	1+	2	2	3	3
Burnt areas	1+	1+	1	1	2	2	3	3
Management practices	1	1	1	1-	1	1	2	2
Water								
Stream	1+	1+	1	1	2+	2+	3	3
Lake	2+	2+	2	2	2+	2+	3	3
Pond	2+	2+	2	2-	2+	2+	3	3
Reservoir	2+	2+	2	2	2+	2+	3	3
Wetlands								
Nonforested	1+	1+	1	1	2	2	2+	2+
Forested	1+	1+	1	1	2	2	2+	2+
GEOLOGY								
Surficial Materials	1-	1-	1-	1-	1	1	2-	2-
Geomorphology	2+	2	2	1+	2+	2	3	3
Structure	2+	2	2	1+	2+	2+	3	3
Bedrock	1+	1+	1	1	2	1+	2-	2-
SOILS								
Soil Moisture	1	1	1-	1-	2	2	2+	2+
Erosion	1-	1-	1-	1-	2	2	2	2
Infiltration	0	0	0	0	0	0	1-	1-
SNOW/ICE								
Distribution	2+	2+	2+	2+	2+	2+	3	3
Accumulation/Ablation	2+	2+	2+	2+	2+	2+	3	[illegible]
TOTAL UTILITY VALUE	58+	58+	53+	48-	67+	64+	98+	94-

H.R.: For High Relief Areas
S.R.: For Subdued Relief Areas

Rating Scale: 3 = Most useful
2 = Useful
1 = Marginally useful
0 = Not useful

quantified from aircraft and satellite imagery. Quantification of climatic factors, i.e. the intensity, frequency and areal distribution of precipitation, wind velocity and direction, and evapotranspiration and stream flow factors (type of flow, velocity, discharge and river stage) cannot be done with imagery but require the Data Collection Platform and data relay capabilities of LANDSAT and GOES satellite systems.

The evaluations were made with imagery of areas with high relief and subdued relief to show that more detail on basin morphology, geomorphology and geologic structure is observable in areas with greater topographic relief. Generally, the shadowing in high relief areas contrasts the terrain shape which enhances the topographic features. This evaluation also shows that observable detail of the other factors is not necessarily greater in areas of high relief. The Hartford-Middletown, Connecticut area was the subdued relief area with generally less than 800 feet relief. The high relief areas were the Green Mountains in northwestern Vermont near Lake Champlain, the Catskill Mountains in eastern New York and the White Mountains in New Hampshire. Relief in these areas varied from 2000 to 3500 feet.

The RB-57/RC8 high altitude aerial photographs had the highest total utility values, the values for the S190B photographs were next, the S190A third and the LANDSAT imagery had the lowest total values. There are several general observations apparent from this evaluation. First, LANDSAT and S190A 0.6-0.7μ imagery would be significantly more useful than the 0.7-0.8μ, 0.8-0.9μ, and 0.8-1.1μ imagery, but only slightly more useful than the 0.5-0.6μ imagery. Less atmospheric haze is recorded in the 0.6-0.7μ portion of the electromagnetic spectrum; as a result, the imagery has more contrast and some of the features are more easily defined. This would be an important consideration in selecting the most appropriate band in areas where haze is a common problem.

Second, most of the land use features are better defined on the 0.5-0.6μ and 0.6-0.7μ images while basin morphology, water, geomorphology and geologic structure are more apparent on the 0.7-0.8μ, 0.8-0.9μ and 0.8-1.1μ images. Variations in sun angle change the shadowing effects in the mountainous areas and the amount of incident light irradiating the flat areas; consequently, with higher sun angles the agricultural and urban areas located on flat terrain are better defined and observable topographic detail is reduced.

Third, the color photographs had the highest utility values for the respective sensors. Color aids the interpreter in differentiating patterns that have similar shapes and textures. Such patterns may produce identical gray tones on black and white photographs; with the addition of color, the difference is clearly visible. The color photography also records reflected light from 0.4-0.7μ or 0.5-0.88μ. These bands include the portion of the spectrum, 0.5-0.8μ, that provides most of the information.

Color LANDSAT imagery can be obtained when the radiometric data from individual bands are combined to produce "false color" images.

These images can be formed by combining the data from 3 of the 4 spectral bands, band 4, 0.5-0.6μ, band 5, 0.6-0.7μ, and band 6, 0.7-0.8μ or band 7, 0.8-1.1μ. The "false color" images include information from 3 of the 4 bands and make interpretation easier because of the additional contrast produced by the color. Band ratioing techniques are also useful in extracting additional information from the digital LANDSAT images. Several publications[9-13] provide additional information regarding the false color imagery and band ratioing techniques.

Fourth, imagery of high relief areas provided more detail on basin morphology, geomorphology and geologic structure than imagery of subdued relief areas. Differences in topographic relief had a minor effect on the observable detail of the other factors.

MERRIMACK RIVER ESTUARY

Test Site Selection

By the end of summer 1973 Skylab photography from only one cloud-free pass had been obtained (ground track 4). An urbanized area of the Merrimack River watershed (Figure 4) lying within this ground track was found to contain the largest variety of mappable land use categories conveniently accessible. Since this area was also of current interest to the New England Division, Corps of Engineers, it was selected as an appropriate test site for addressing objectives 2 and 3.

Analytical Procedures

The scales of the satellite imagery were adjusted to approximately 1:800,000, 1:400,000, 1:200,000, 1:63,360 and 1:24,000 to determine

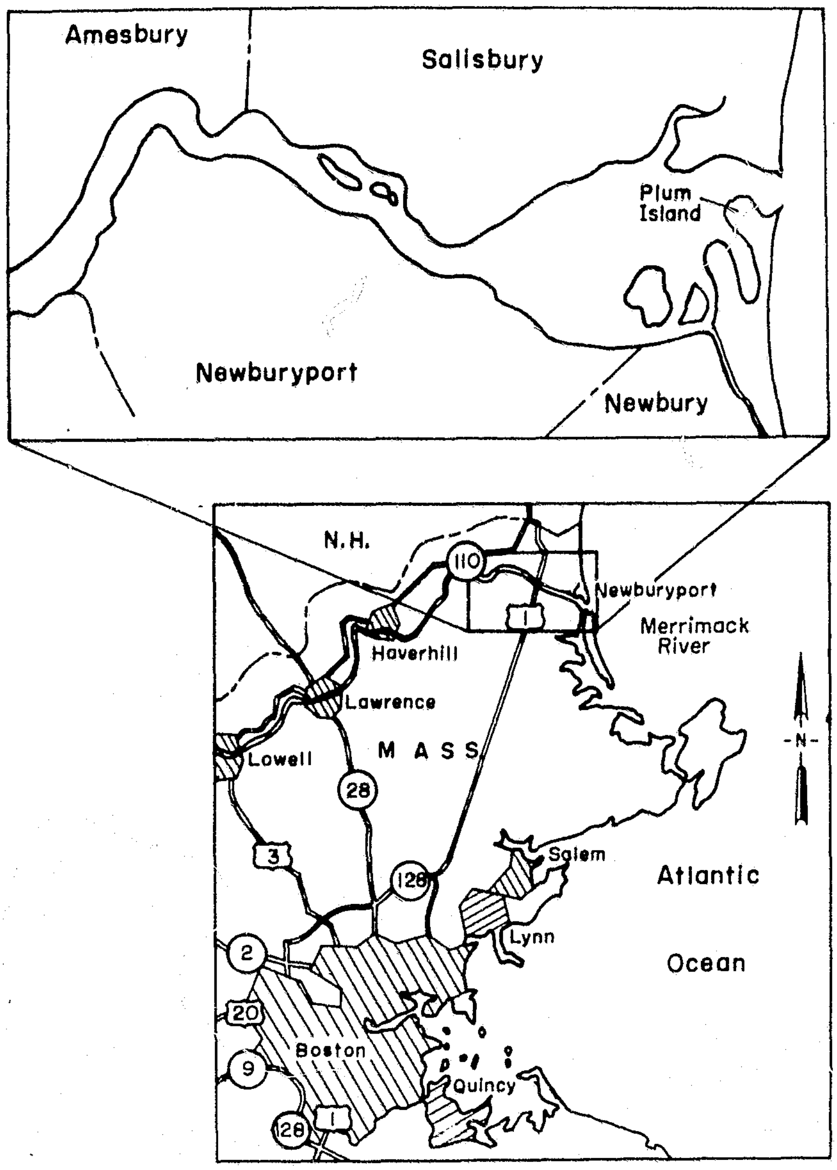

Figure 4. Test site location - Merrimack River estuary.

the most useful mapping scale. Detail on the imagery at the small scales (1:800,000-1:200,000) was sufficient but not practical for level I (see Table 7) land use mapping. At the 1:24,000 scale the

Table 7. Land use classification system (modified from Anderson[14]).

Level I		Level II	Level III
Urban/built-up land (U)	1.	Residential-single	
	2.	Residential-multi	
	3.	Commercial	Parking lot
	4.	Industrial	
	5.	Extractive	
	6.	Mixed	
	7.	Transportation, communication, utilities	
	8.	Institutional	School
	9.	Open and Other	Park
			Cemetery
Agrucultural land (A)	1.	Pasture	
	2.	Row crop	
	3.	Orchard	
Forest land (F)	1.	Deciduous	
	2.	Coniferous	
	3.	Mixed	
Water (W)	1.	Stream	
	2.	Lake	
	3.	Reservoir	
	4.	Bay/estuary	
	5.	Tidal channel	
	6.	Ocean	
Nonforested wetlands (N)	1.	Vegetated	Tidal Marsh
	2.	Bare	
Barren land (B)	1.	Beach	
	2.	Bare exposed rock	
	3.	Other	

S190A photograph appeared "grainy" and the scan lines on the LANDSAT imagery became prominent, reducing image clarity. Consequently, mapping units, while sometimes recognizable, could not be accurately delineated. It was found that accurate data transfer and mapping were possible at the 1:63,360 scale and it corresponded to that of the U.S.G.S. 15-minute quadrangle sheets.

The classification scheme (Table 7) adopted was a modified version of the U.S. Geological Survey Land Use Classification System.[14] Four land use maps were prepared independently. Black and white contact prints of a LANDSAT MSS band 5 (0.6-0.7μ) image, a S190A (0.6-0.7μ) photograph, a S190B color infrared (CIR) photograph, and a RB-57/RC8 CIR photograph were prepared as base maps. Contrast enhancement was accomplished photographically to portray the maximum number of gray tones. The 0.6-0.7μ wavelength LANDSAT and S190A images were used as base maps because the image evaluation (Table 6) showed that land use patterns are prominently displayed in this wavelength.

The two RC8 and S190B maps were prepared simultaneously by experienced analysts. The S190A and LANDSAT maps were completed subsequently in the same manner. Unit distinctions were made based on the tonal and textural differences visible on the original NASA S190A/B and RB-57/RC8 color infrared standard data products. A Spectral Data Corporation Multispectral Viewer was used to produce a LANDSAT band 4, 5 and 7 false color image. This approach is somewhat different than conventional land use mapping methods; only information extractable from the color images without reference to ancillary data entered into the interpretation. This was done to eliminate bias in the comparisons insofar as possible and to ensure that the results were derived solely from imagery interpretation.

Results and Discussion

The following factors should be considered in assessing the potential usefulness of remote sensing data in the planning, design and operation of reservoir systems: information content, repetitiveness, scale, ground resolution and the cost effectiveness of analysis. LANDSAT imagery currently is available at 18-day intervals. If LANDSAT I & II were operated simultaneously, it would be possible to obtain coverage more frequently. If additional polar orbiting satellites were available, even more frequent coverage would be possible. Nevertheless, at present we are limited by this system to an 18 day cycle. The imagery cannot be usefully enlarged to a scale greater than approximately 1:63,360. At this scale, ground resolution (Table 5) is such that only five individual level I and eight level II units were readily delineated on the LANDSAT MSS band 5 and the false color images (Fig. 5a, b; Table 8). In addition, it was possible to distinguish two combined level I units (A-U, U-A). In those cases where open water could not be clearly differentiated it was included in the N_1 (vegetated, nonforested wetland) and F_3 (mixed forest) units on the LANDSAT map. Tidal channels and intermittent streams have reflectance characteristics similar to those of the

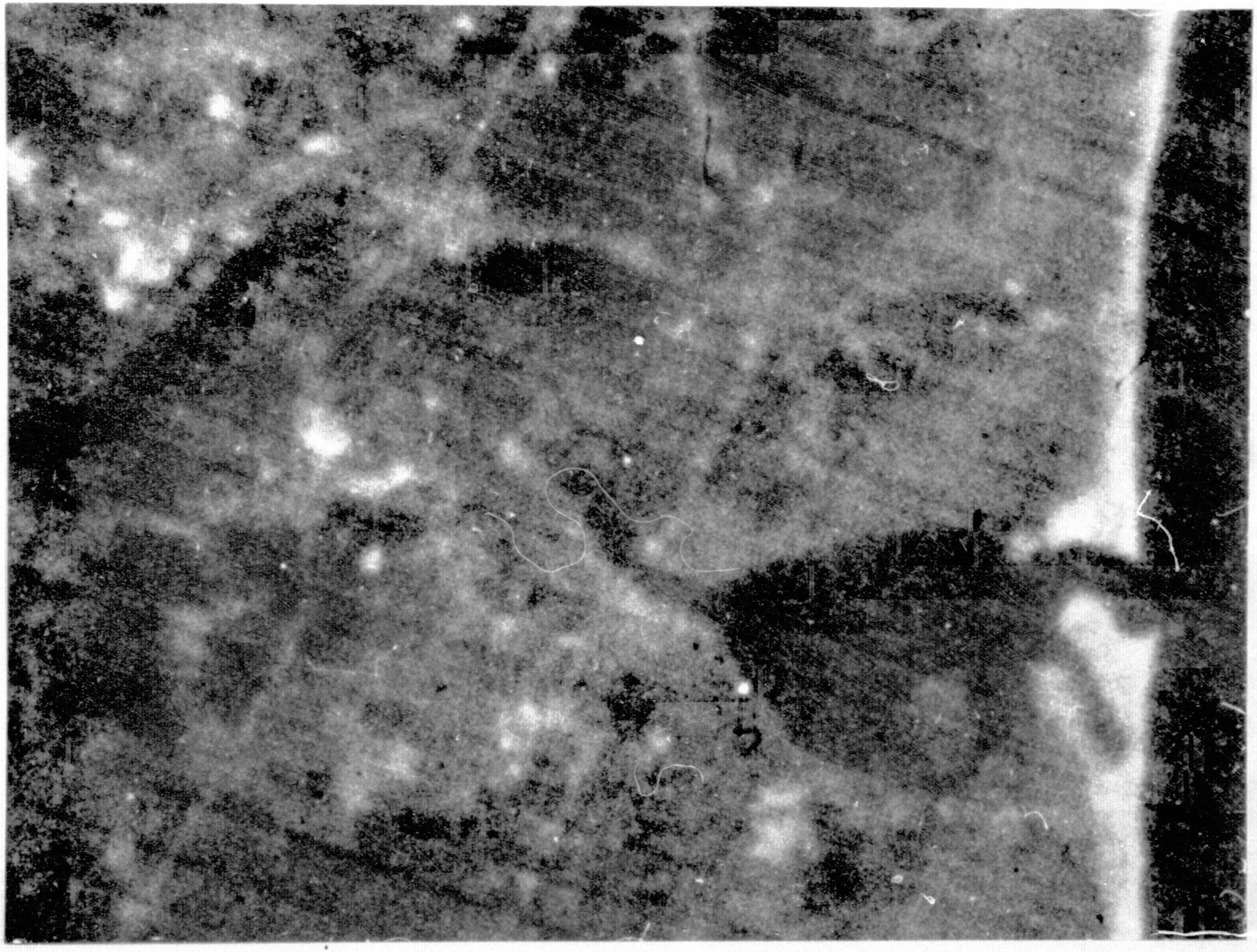

Figure 5a. Enlarged portion of LANDSAT-1 MSS band 5 image (1383-15003) of study area; approximate scale 1:63,360.

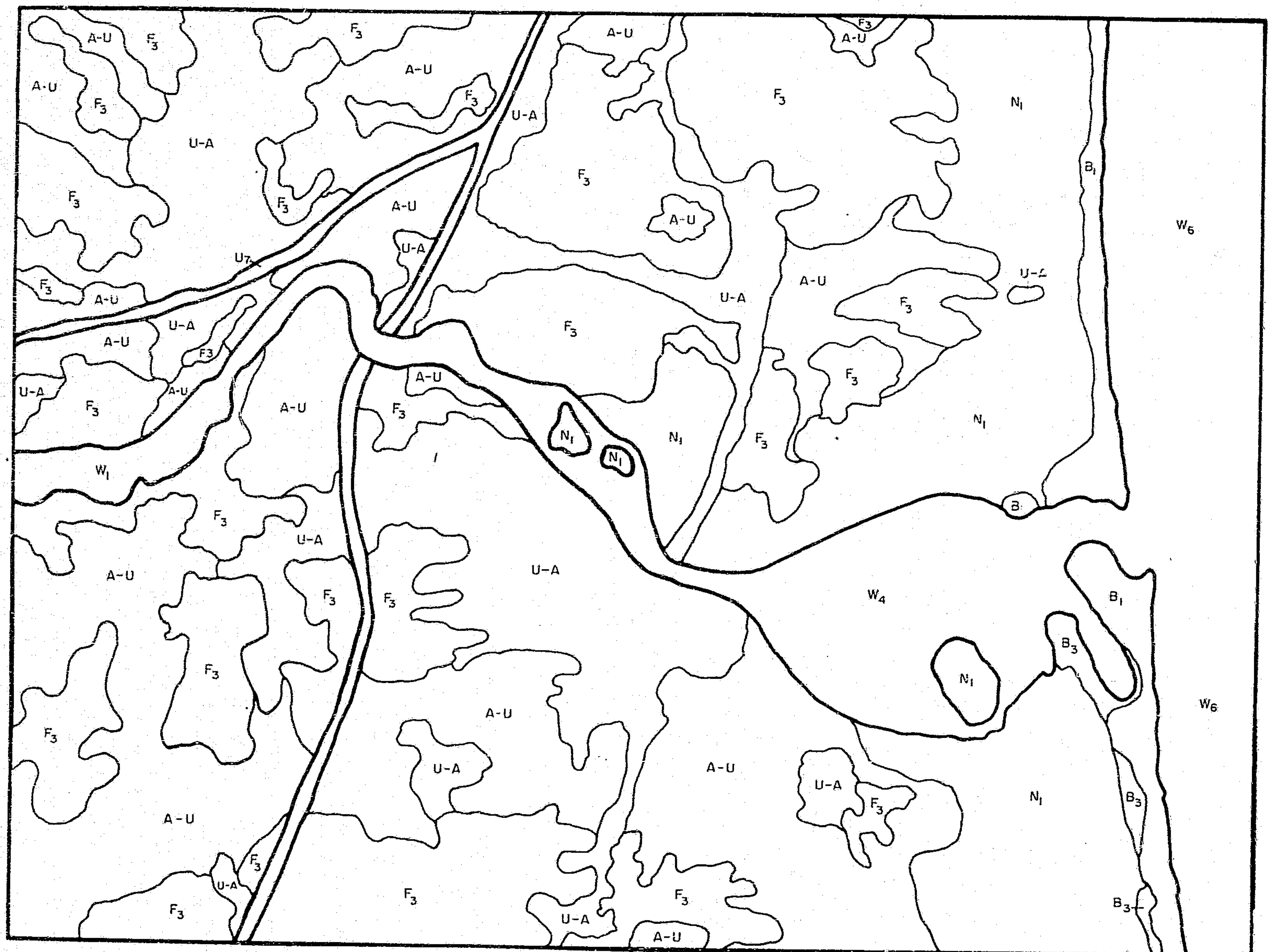

Figure 5b. Land use map from LANDSAT-1 MSS band 5 and false color images.

Table 8. Summary of land use units mapped.

Land use Categories Level I	Level II	Level III	LANDSAT MSS	Skylab *S190A*	Skylab *S190B*	*RB-57 RC8*
U			*	*	*	*
	U_1				*	*
	U_2					*
	U_3				*	*
		U_{3p}				*
	U_4				*	*
	U_5			*	*	*
	U_6			*	*	
	U_7		*	*	*	*
	U_8					*
		U_{8s}				*
	U_9				*	*
		U_{9p}				*
		U_{9c}				*
A			*	*	*	*
	A_1					*
	A_2					*
	A_3					*
F			*	*	*	*
	F_1					
	F_2					
	F_3		*	*	*	*
W			*	*	*	*
	W_1		*	*	*	*
	W_2			*	*	*
	W_3			*	*	*
	W_4		*	*	*	*
	W_5			*	*	*
	W_6		*	*	*	*
N			*	*	*	*
	N_1		*	*	*	*
		N_{1a}			*	*
	N_2					
B			*	*	*	*
	B_1		*	*	*	*
	B_2					
	B_3		*	*	*	*
Total			14	19	24	32

N_1 unit in band 5 and in false color. This was also true in the case of small inland water bodies located within larger F_3 units. However, these boundaries are clearly defined in the band 7 image (Fig. 5c). Tonal differences between urban/built-up land (U) and agricultural land (A) were not significant; these units were combined to form combined A-U or U-A units. The U-A unit was chosen when light gray tones from highly reflective surfaces (i.e., pavements, buildings, etc.) predominated. The A-U unit, on the other hand, was used when the predominant tones were dark gray with few scattered light gray tones.

Only one mappable level II urban unit was recognizable (U_7). In this area it is an interstate highway right-of-way. The coastal area was mapped as either B_1 or B_3, interpreted as beach sand and partially vegetated drifting sand, respectively. The resulting LANDSAT MSS map (Figure 5b) was the least detailed but required only 1.5 hours to prepare. Thus the LANDSAT imagery can be used effectively for mapping land use on a regional scale, but it would not provide the detailed quantification required for reservoir planning, design, operation and maintenance.

Skylab photography was acquired for this site on 16 and 21 September 1973 (SL-3) and for 14 January 1974 (SL-4) on a one time, experimental basis. The quality of S190A multispectral photography is greatly reduced when enlarged to a scale greater than approximately 1:63,360 and is in general comparable to the LANDSAT imagery in this respect. However, the ground resolution is at least three times better and therefore mapping

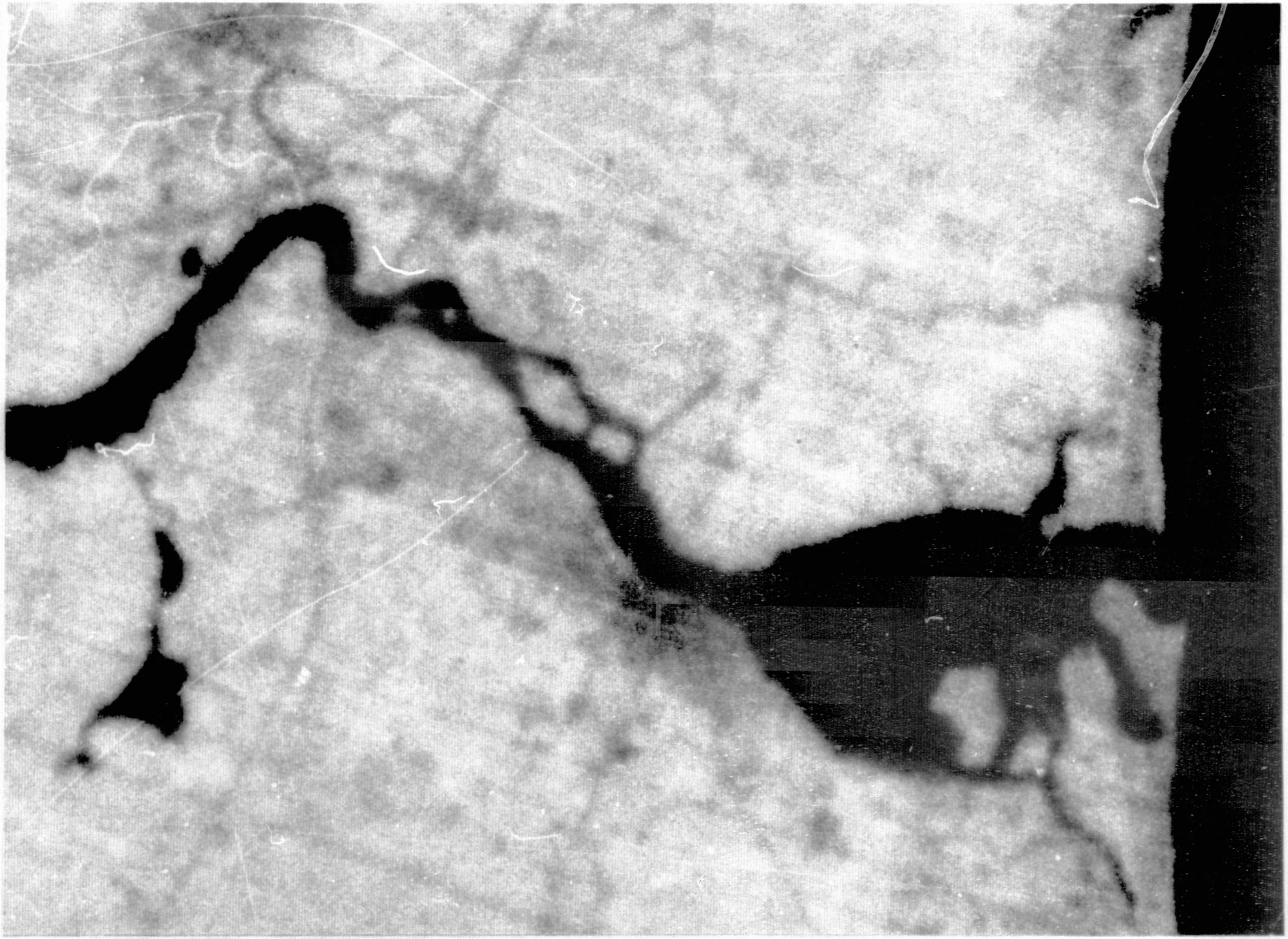

Figure 5c. Enlarged portion of LANDSAT-1 MSS band 7 image (1383-15003); approximate scale 1:63,360.

accuracy is significantly improved. Consequently, six discrete level I and thirteen level II units were mapped (Fig. 6a, b; Table 8). Three level II urban units could be easily distinguished from level I agricultural and forested lands. The level I agricultural lands, however, could not be differentiated at level II. The level II, B_3 unit recognized on the LANDSAT images was interpreted to be partially vegetated beach sands encroaching on tidal marshes. A similar interpretation of this unit resulted from analysis of the LANDSAT image, but a more accurate distinction between the B_1 and B_3 units was possible. Tones of the B_1 unit were primarily white. The B_3 unit had very light to dark gray mottled tones. Small fields and single family residences surrounded by mixed forests were not apparent on the LANDSAT image. These features were distinguishable on the S190A photograph, but were, nevertheless, included in the F_3 unit. Similarly, small offshore islands or shoals south of the mouth of the Merrimack River, inland water bodies and tidal channels sometimes were not recognizable on the LANDSAT images but were easily distinguishable on the S190A photograph. The S190A was significantly better than the LANDSAT map and required nearly 4 hours to prepare. The S190A imagery is sufficient for mapping land use in areas where rapid urbanization is not a factor and repetitive coverage is not essential.

The S190B image had a ground resolution nearly twice that of the S190A. As a result, the S190B map was more detailed with six level I

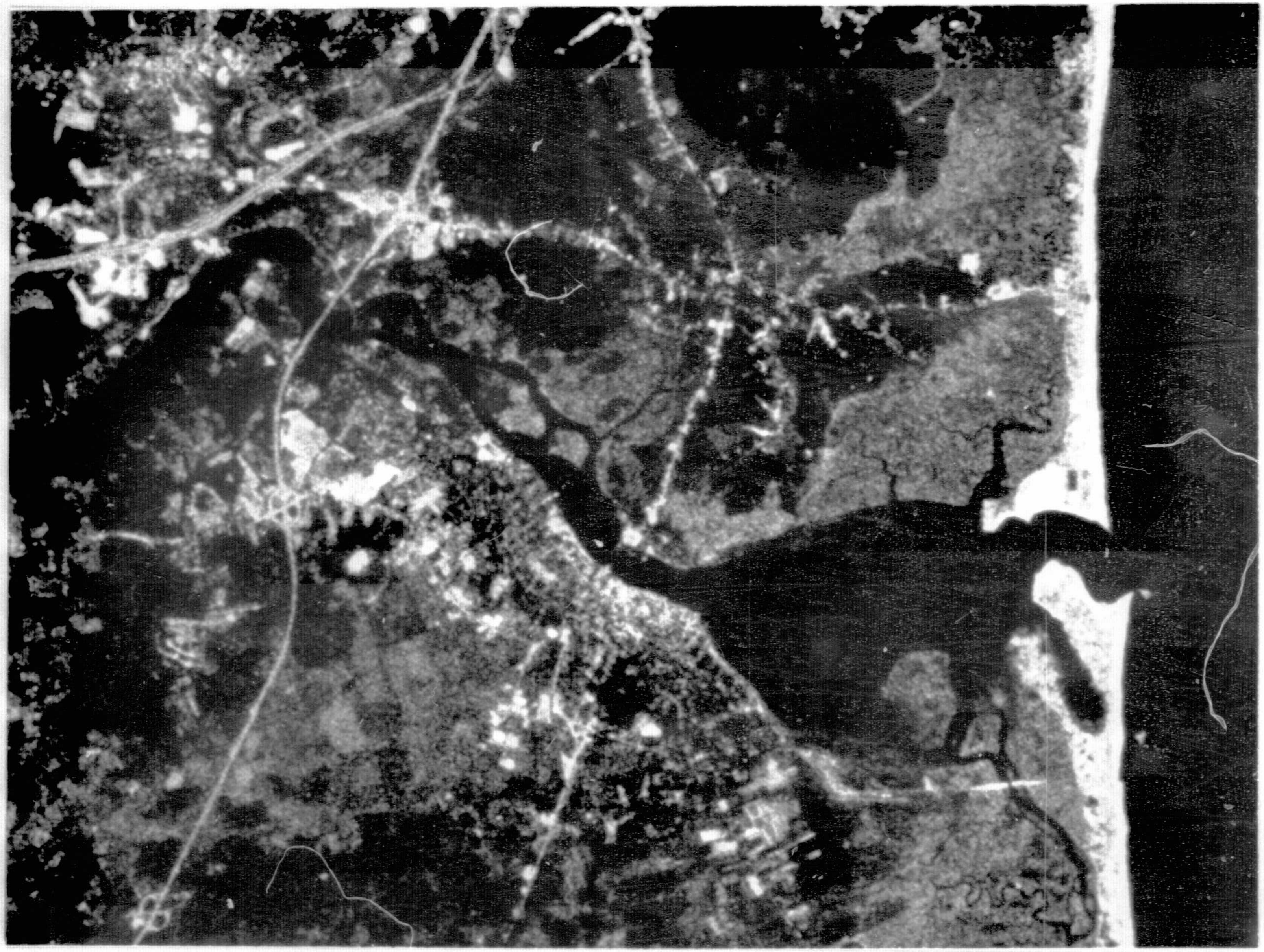

Figure 6a. Enlarged portion of S190A CIR photograph (ID 47-306) of study area; approximate scale 1:63-360.

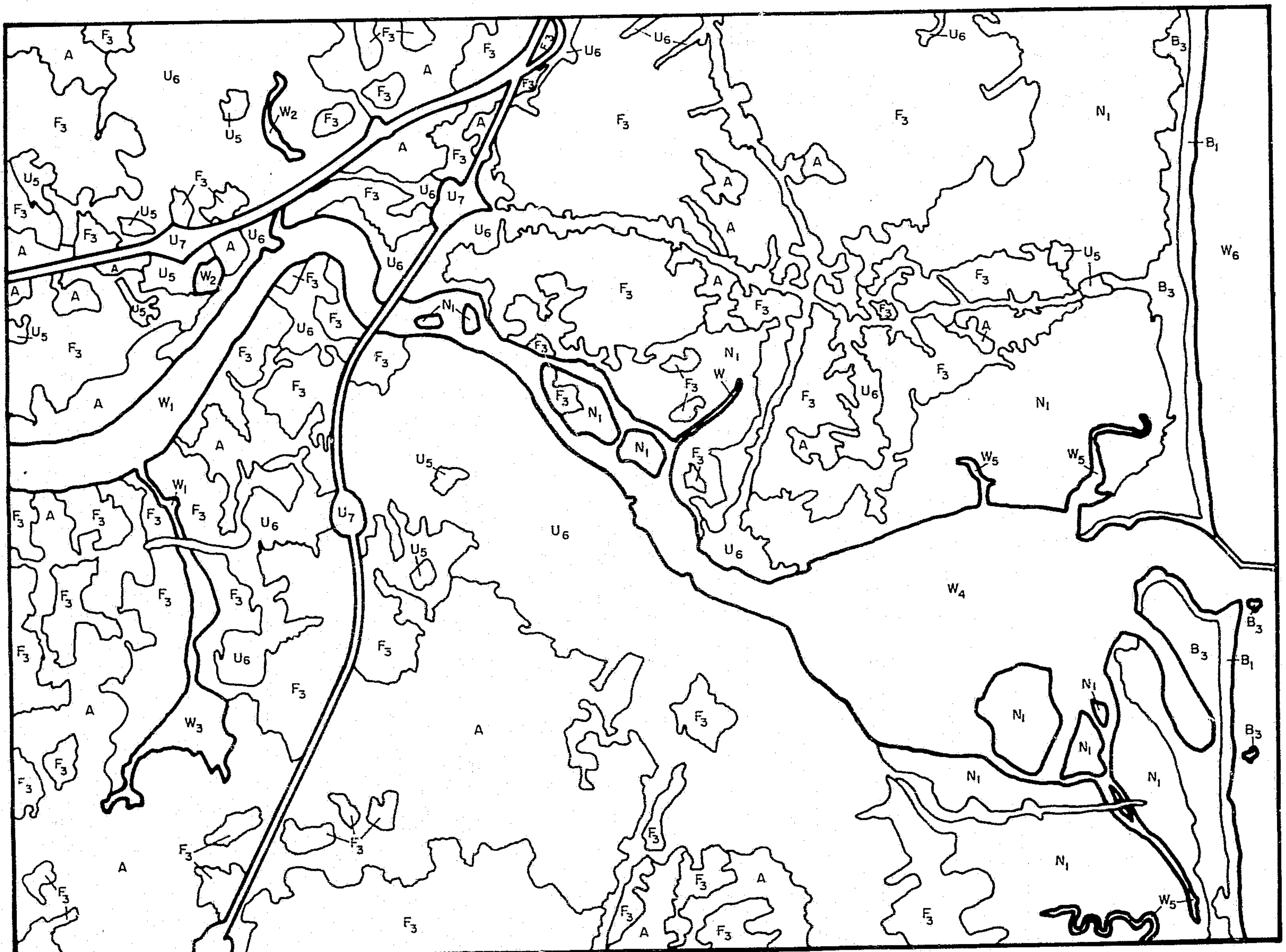

Figure 6b. Land use map from S190A CIR photograph.

units, seventeen level II units and one level III unit (Figure 7a, b; Table 8). This amounts to four level II units and one level III unit not identified on the S190A image. Level II agricultural lands could not be distinguished, although four previously unmapped urban units, residential-single (U_1), commercial (U_3), industrial (U_4) and open and other (U_9), were differentiated. Units with similar tones and considered to be either U_9 or A were designated U_9 when proximate to urban areas. Marinas not previously recognized were delineated as U_7 units on the S190B map. Linear features, such as utility lines, secondary roads and railroads, were easily identified but were not separated because this would have produced confusing patterns.

The only mappable level III unit, N_{1a} (tidal marsh), occurred along the southern shore of the estuary. These marshes appear darker than those in the N_1 unit and are probably inundated daily. Tidal channels not previously distinguished on the S190A image were delineated on the S190B image. U_1, A, U_6 and N_1 units previously included in the F_3 and A units of the S190A map were easily differentiated and therefore were separated. The time required for mapping was about 8 hours, but the map was considerably more detailed than either the S190A or the LANDSAT maps.

The best imagery from the point of view of resolution and tonal differentiation was that obtained from the RC8 camera on the RB-57 aircraft. Resolution was at least two times better than that of the S190B; consequently, six level I, twenty-one level II and five level III

Figure 7a. Enlarged portion of S190B CIR photograph (87-305) of study area; approximate scale 1:63,360.

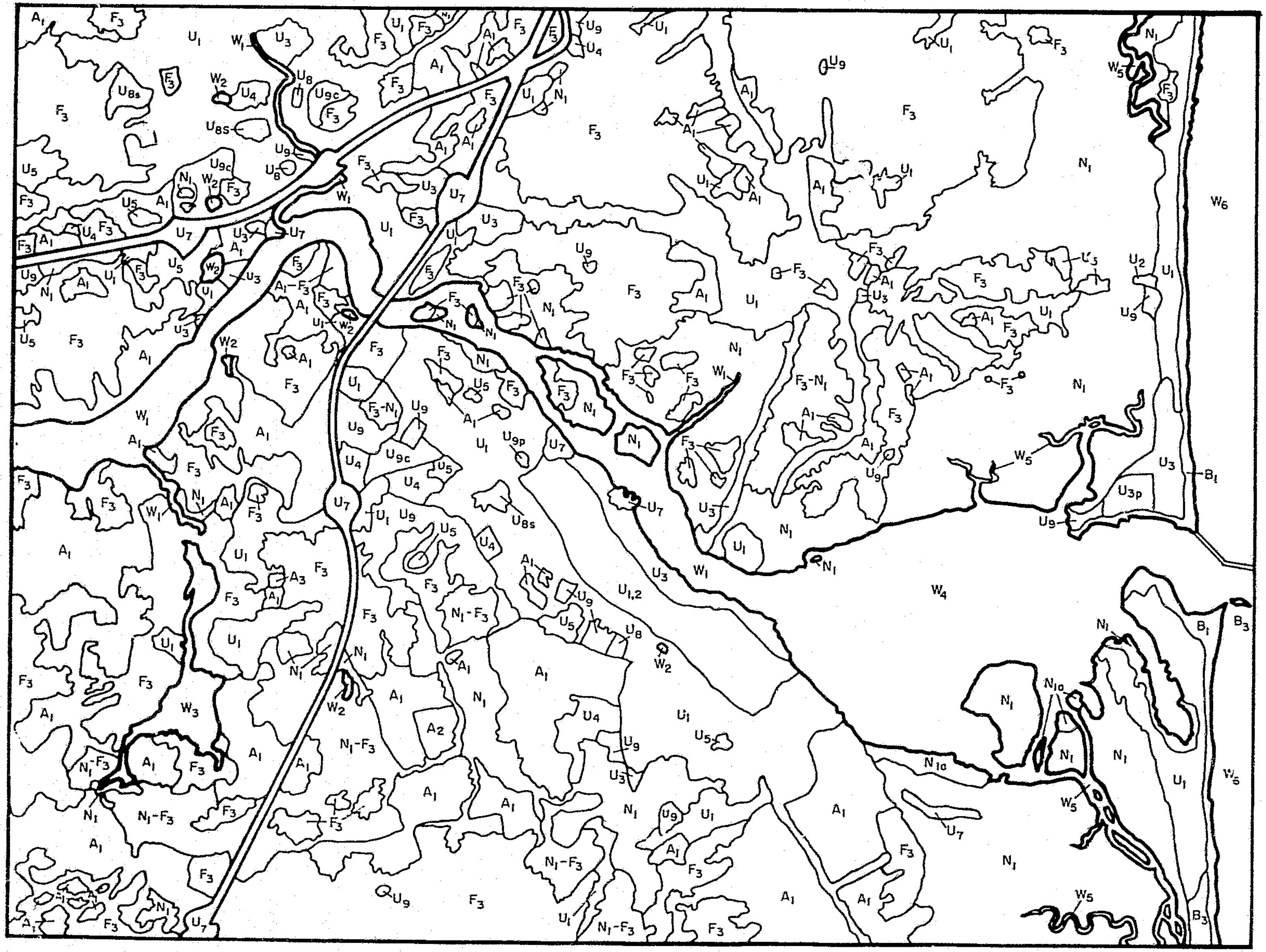

Figure 7b. Land use map from S190B photograph.

units were mapped (Fig. 8a,b; Table 8). Four of the level III units, schools (U_{8s}), parking lots (U_{3p}), cemeteries (U_{9c}), and parks (U_{9p}) were found to have been included in the urban unit (U_6) on the S190B photograph. Urban areas included in the level II, mixed urban unit (U_6) of the S190B map were delineated on the RC8 map as separate level II units U_1, $U_{1,2}$, U_8 and U_9. Level II units, pastures (A_1 and A_2) and orchards (A_3), were easily differentiated from the level I agricultural lands. The following features were identified on the RC8 image but were included in other units to maintain map clarity: trees along fence lines and in small groves, roads, railroads and utility lines, intermittent streams and man-made drainage ditches. Where vegetated, non-forested wetlands (N_1) and mixed forests (F_3) could not be separated adequately, the combined unit N_1-F_3, was used when N_1 dominated; F_3-N_1 was used when mixed forests dominated. Resolution of the RC8 image was required to differentiate houses and commercial buildings in coastal areas that had been mapped previously as B_3 and B_1 on the satellite imagery. Therefore, portions of each of these barren land (B) units were separated into level II urban units (U_1, U_3, U_9). The RB-57/RC8 map required 10 hours to prepare but clearly provided the most information.

CONNECTICUT RIVER BASIN

Test Site Selection

The primary objective of task 4 was to identify and quantify hydrologic factors (Table 6) measurable by remote sensing techniques that

Figure 8a. RB-57/RC8 high-altitude CIR photograph (ID 151-0085) of study area; approximate scale 1:63,360.

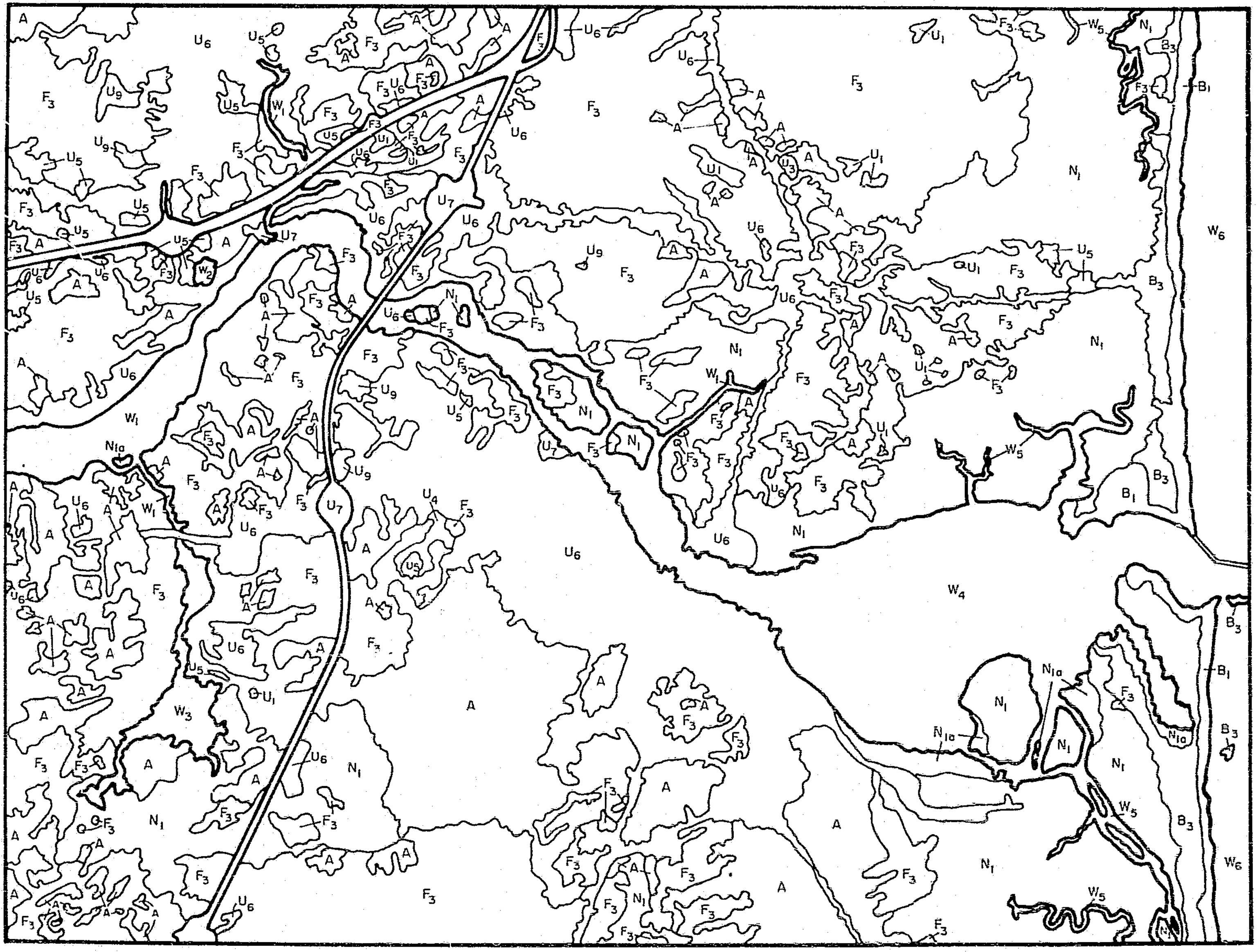

Figure 8b. Land use map from RB-57/RC8 photograph.

significantly influence runoff. Quantification of many of these factors is required in the planning, design and operation of reservoir systems. The Coginchaug River and Broad Brook watersheds in the Connecticut River basin (Figure 9) were selected to determine the utility of the imagery in quantifying land use factors and to relate these factors to runoff characteristics. Ground track 4 (29 September 1973) yielded cloud-free Skylab imagery of this area. LANDSAT and RB-57/RC8 imagery was also available. In addition, extensive hydrologic data were available in U.S. Geological Survey hydrologic reports. The Coginchaug River watershed is located in south central Connecticut near Middletown and is approximately 34.7 mi^2 (89.9 km^2) in size. Many steep slopes occur in the southern portion of the watershed while gently sloping hills predominate in central and northern sections. The mean annual precipitation is 44.9 in (114 cm) measured 4.0 mi (6.4 km) west of Middletown.[15] Stream discharges averaged 57.2 ft^3/sec (1.62 m^3/s) from 1962-1973 at the Rockford, Connecticut gaging station.[16]

The Broad Brook watershed is located in north central Connecticut near the town of Broad Brook. It is approximately 15.6 mi^2 (40.4 km^2) in size. The dominant landforms in this watershed are gently rolling hills. The mean annual precipitation measured at the Weather Service Office at the Hartford Airport, 7.5 mi (12 km) west of Broad Brook, is 41.7 in (106 cm).[15] Stream discharges from 1962-1973 averaged 21.1 ft^3/s (0.598 m^3/s) at the Broad Brook gaging station.[16]

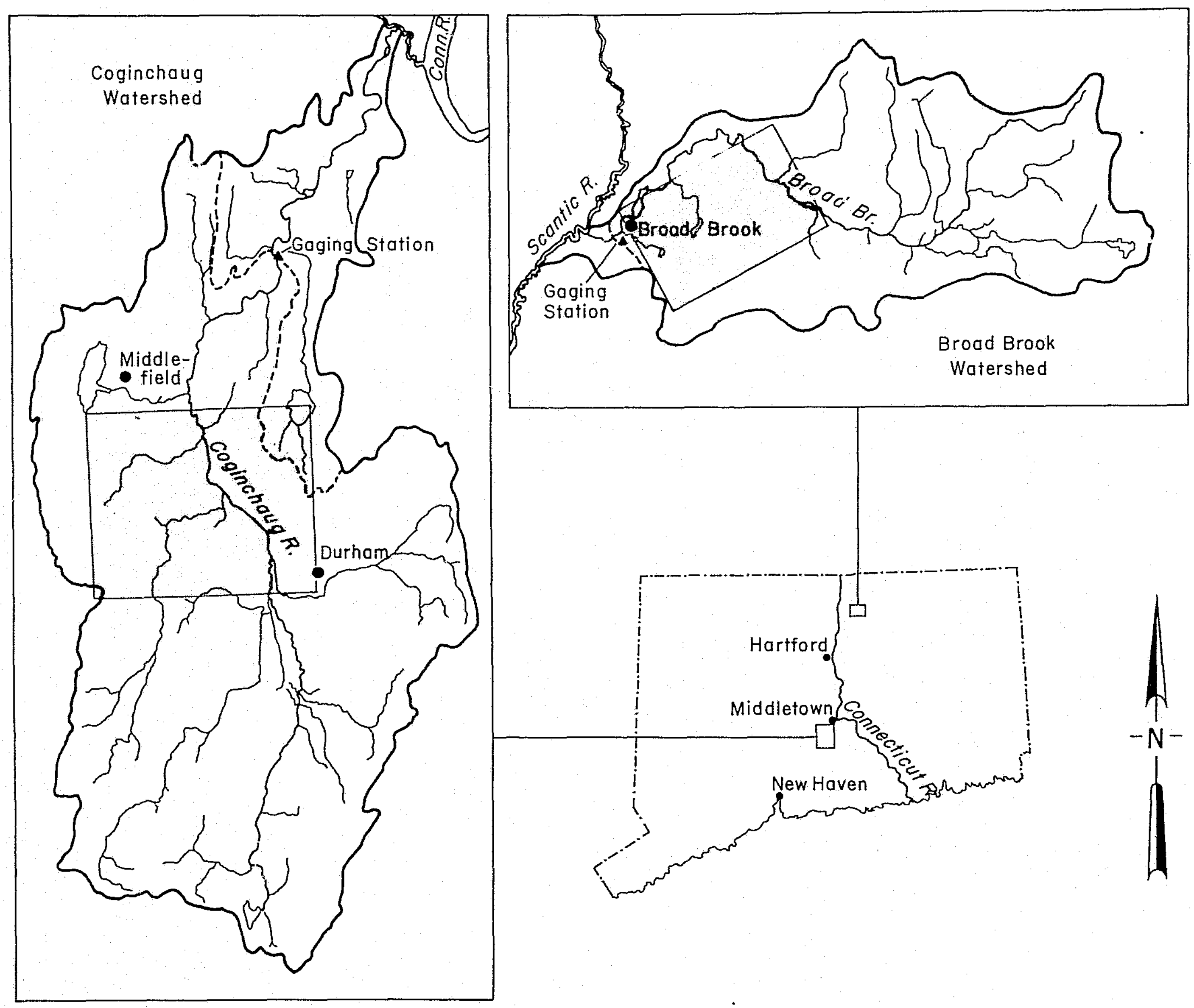

Figure 9. Test site locations in the Connecticut River Basin; shaded areas are mapped sites; entire watersheds delineated by solid line; dashed line is downstream boundary of the watershed monitored by the stream gauge.

Analytical Procedures

Factors that significantly effect runoff which can be directly or indirectly extracted and quantified from satellite or aircraft imagery are listed in Table 6. A number of these factors are required as inputs to water quality/quantity models, e.g. Storage, Treatment, Overflow and Runoff Model ("STORM")[17], Hydrologic Engineering Center models, National Weather Service flood forecasting models[18], etc.

For this portion of the investigation, land use categories were considered only as they pertain to probable influences on runoff. Level I units shown in Table 7 were adopted except that the nonforested wetlands unit was enlarged to include all wetlands regardless of vegetation cover. Agricultural land (A) included croplands, pastures, orchards and rural and farm homes. Forest land (F) included deciduous, coniferous and mixed forest types. The urban/built-up land (U) included residential and commercial areas, industrial, extractive, transportation and open land within cities and towns. Water (W) included lakes, ponds and reservoirs. Because they could not be differentiated clearly, the wetlands unit was combined with the forest land unit when mapping from the LANDSAT and S190A imagery. Wetlands were easily distinguishable on the S190B and RB-57/RC8 imagery; therefore, they were delineated as individual units on maps made from these data products. While water was easily delineated on the S190A, S190B and RC8 photography, bands 5 and 7 were required as mentioned in the preceding section in the case of LANDSAT-1 imagery.

These Level I categories were mapped in test sites covering about 20% of each of the two watersheds (see shaded areas in Figure 9). The following data products were used: 18.6 cm x 18.6 cm transparencies of LANDSAT MSS image 1402-15062 bands 5 and 7, 22.8 cm x 22.8 cm transparency of Skylab 3 S190A color infrared frame 45-304, 22.8 cm x 22.8 cm transparencies of Skylab 3 S190B color infrared frames 87-301 (Coginchaug River) and 87-302 (Broad Brook), 22.8 cm x 22.8 cm transparencies of RB-57/RC8 color infrared frames 151-175 (Coginchaug River) and 151-177 (Broad Brook). As before, the mapping was accomplished without reference to ancillary information. Black and white prints enlarged to 1:63,360 from the original NASA transparencies were used as base maps in preparing the LANDSAT and S190A maps. The S190B and RB-57/RC8 maps were prepared directly from CIR transparencies projected with a Bausch and Lomb Zoom Transfer Scope (ZTS) to 1:63360. Each level I category was mapped on a separate overlay. In all cases, the areal extent of each unit was then measured as a percentage of the test site using an Antech Inc. Densitometer/Planimeter (Model A-12). The S190B maps shown as examples are presented in Figures 10 and 11.

An analysis was made to establish that the distribution of land use units in the 20% sampling area in each watershed was representative of the entire watershed. Forest lands and wetlands in both watersheds are the most easily identifiable land use units on the S190A photographs. Thus, differences between the areal distribution of the forest lands and wetlands were measured within the test sites and the entire watershed. These units were measured on the S190A image because of its more uniform

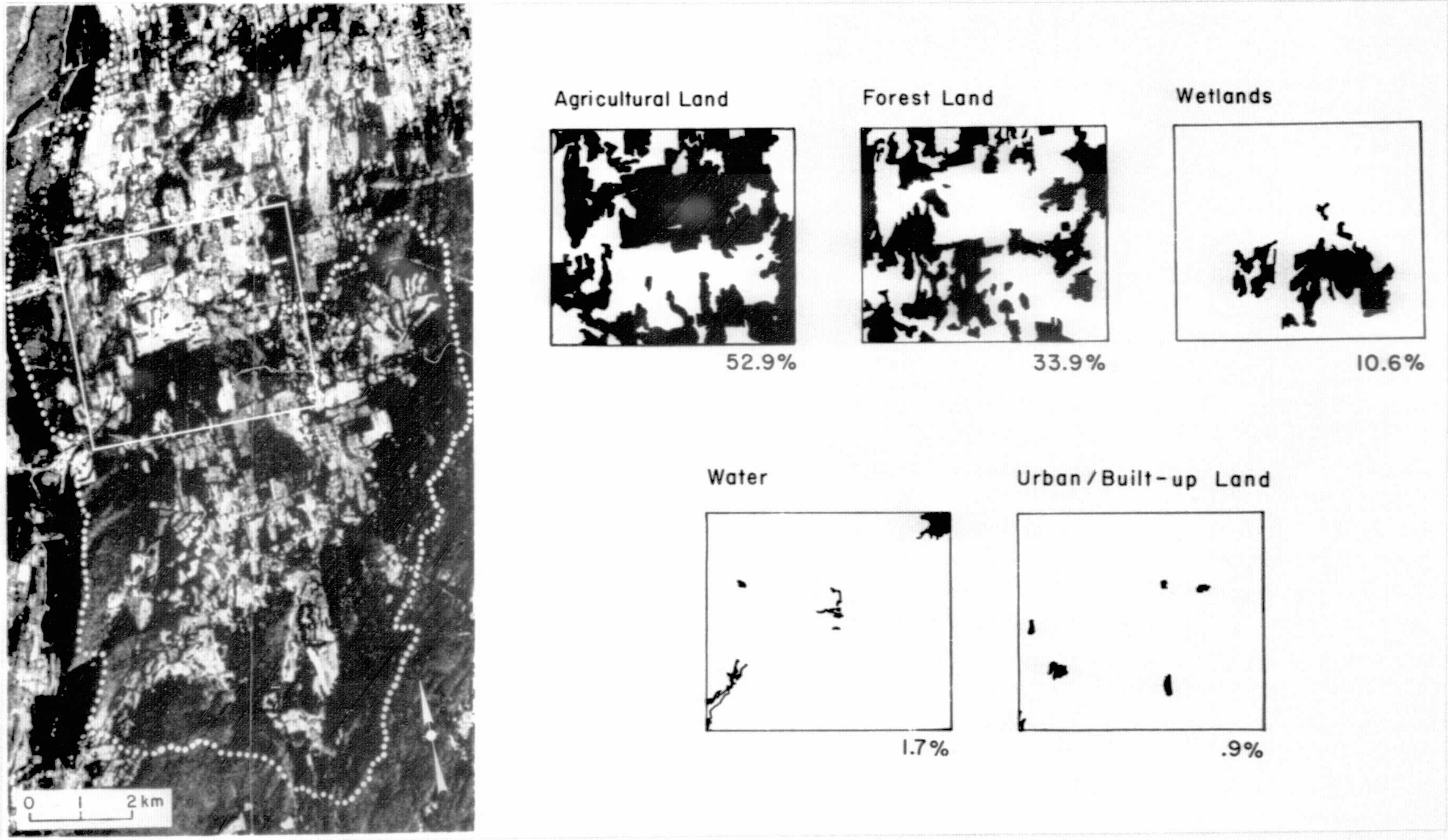

Figure 10. Coginchaug River watershed; portion of S190B CIR photograph (ID 87-301) showing mapped area with percentages of land use.

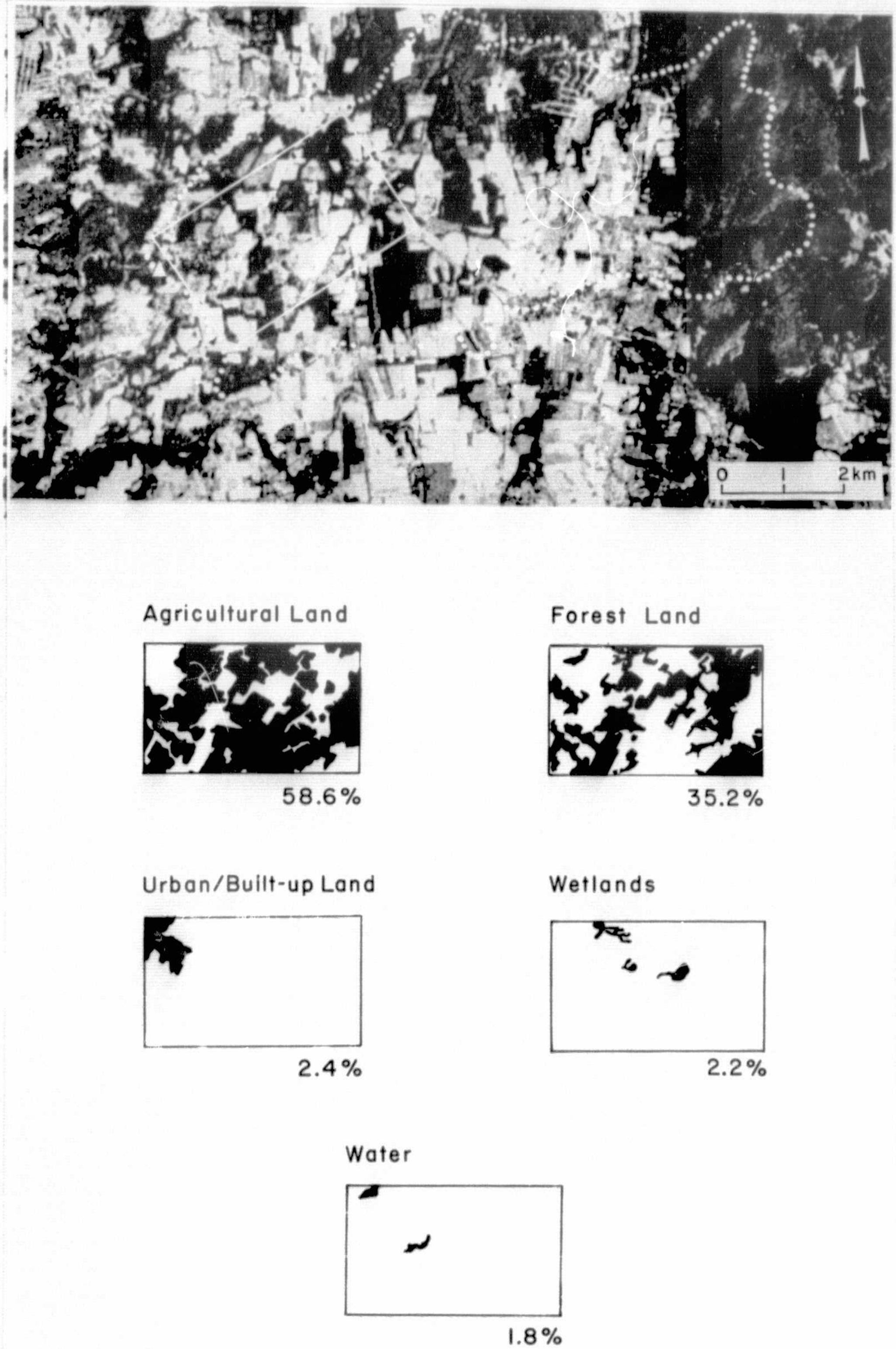

Figure 11. Broad Brook watershed; portion of S190B CIR photograph (ID 87-302) showing mapped area with percentages of land use.

tonal and density characteristics. These units comprised 42.7% of the entire Coginchaug River watershed and 42.1% of the test area. In the Broad Brook watershed, these percentages were 38.2 and 37.8%, respectively. The two values did not vary by more than ± 0.5%; therefore, the value obtained from each test area was considered representative.

Results and Discussion

The land use percentages obtained for the Coginchaug River and Broad Brook watersheds are given in Table 9. The values represent the percentage of each land use category normalized to a total of 100%. The LANDSAT and S190A land use percentages are comparable but, as can be seen in Table 9, these values do not compare favorably to those obtained from either the S190B or the RC8 photography. This indicates that the resolution of either the LANDSAT or S190A imagery is not sufficient to accurately quantify the land use categories required as inputs to peak or volume runoff prediction equations. The areal distribution of the land use units could be most accurately defined on the RC8 image. The RC8 and S190B results (Table 9) compare favorably, indicating that the S190B photography is as useful as the RC8 products for differentiating and measuring areas of land use that influence total volume of runoff.

Of the other factors important in determining land use-runoff relationships, the components of basin morphology (Table 6) are especially important. Topographic relief characteristics of a watershed can be generally identified but measurement would be limited to areas with stereo coverage. LANDSAT imagery provides stereo coverage in the sidelap

Table 9. Comparison of normalized land use percentages for the Coginchaug River and Broad Brook watersheds.

	COGINCHAUG RIVER				BROAD BROOK			
	LANDSAT/MSS	S190A	S190B	RB-57/RC8	LANDSAT/MSS	S190A	S190B	RB-57/RC8
Agricultural Land	52.6	52.9	52.9	57.6	64.0	58.9	58.6	58.7
Forest Land/Wetlands	40.9	42.1	---	---	33.5	37.8	---	---
Forest Land	---	---	33.9	30.4	---	---	35.0	29.9
Wetlands	---	---	10.6	10.0	---	---	2.2	3.7
Water	2.0	5.0	1.7	1.1	2.5	1.8	1.8	2.3
Urban/Built-up Land	---	---	.9	.9	---	1.5	2.4	4.8
Clouds	4.5	---	---	---	---	---	---	.6
TOTAL	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

portion of images acquired on adjacent orbits. This sidelap increases from 14% at 0° latitude to 85% at 80° latitude. The New England test site extends from approximately 40° to 45° north latitude; the stereo sidelap varies from 34.1% to 39.5%[9]. Stereo overlap on the S190A/B photographs varies from 10 to 70%; that on the RB-57/RC8 photographs is generally 60% and stereo sidelap is usually 30%.

In watersheds with low relief, such as the Coginchaug and Broad Brook, many of the components of basin morphology are not as apparent as in areas of greater relief (Table 6). Consequently, the imagery with the best resolution, that is, the S190B and RB-57/RC8, is required to adequately quantify basin morphology where topography is subdued.

To compare level I land use categories mapped and summarized in Table 9 with runoff characteristics, the precipitation and runoff data available were collected and reduced. The results are shown in Tables 10 and 11. As shown in Table 9, the only significant difference in land use between the two watersheds is in the category of wetlands. As determined by the S190B CIR image, the Coginchaug River watershed contains 8.4% more wetlands area than does the Broad Brook watershed (Figures 10 and 11). As shown in Table 11, runoff expressed as $m^3/sec/km^2$, from the Coginchaug River watershed is 20% greater than that from the Broad Brook watershed. Usually wetlands reduce runoff because of increased evapotranspiration and infiltration.[19,20]

There are several factors which may explain the unexpected precipitation/runoff ratios shown in Table 11. The Coginchaug River

Table 10. Total annual precipitation (cm)[15] and the amount resulting in runoff[16] for the Coginchaug River and Broad Brook watersheds, 1961-1972. Precipitation data obtained from Middletown and Hartford, Connecticut, meteorological stations.

Year	Coginchaug River (from Middletown station)				Broad Brook (from Hartford WSO-AP station)			
	Precipitation		Runoff		Precipitation		Runoff	
	in.	cm	in.	cm	in.	cm	in.	cm
1961	47.07	119.56	2.22*	5.63*	40.65	103.25	5.02**	12.75**
1962	41.11	104.42	19.68	49.98	40.40	102.62	16.45	41.78
1963	42.18	107.14	17.51	44.47	33.29	84.56	14.77	37.51
1964	39.20	99.57	19.38	49.22	34.53	87.71	13.74	34.89
1965	36.51	92.74	11.34	28.80	29.45	74.80	9.85	25.01
1966	38.12	96.82	12.13	30.81	41.27	104.83	10.64	27.02
1967	45.31	115.09	24.12	61.26	45.05	114.43	24.12	61.26
1968	45.38	115.27	22.59	57.37	40.63	103.20	18.75	47.62
1969	51.44	130.66	24.66	62.63	47.63	120.98	19.06	48.41
1970	39.89	101.32	21.73	55.19	38.43	97.61	21.69	55.09
1971	49.55	125.86	25.35	64.38	44.75	113.67	16.71	42.44
1972	64.93	164.92	42.75	108.58	64.55	163.96	29.41	74.70
1961-72 Annual Mean	45.1	114.45	21.9	55.62 (48.6%)	41.7	105.97	17.7	44.95(42.4%)
Annual Mean Less 1972	43.3	109.98	19.8	50.29 (45.7%)	39.6	100.58	16.5	41.91(41.7%)

* October - December only

** August - December only

Runoff from:

Coginchaug River at Rockfall, Conn.
Broad Brook at Broad Brook, Conn.

Table 11. Precipitation-runoff relationships for Coginchaug River and Broad Brook watersheds, 1961-1972.

Parameter	Coginchaug River	Broad Brook
Area, mi^2 (km^2)	34.7 (89.9)	15.6 (40.4)
Average runoff, ft^3/s (m^3/s)[16]	57.2 (1.62)	21.1 (0.598)
Average runoff, $ft^3/s/mi^2$ ($m^3/s/km^2$)	1.65 (0.018)	1.35 (0.015)
Annual mean precipitation, in (cm)	45.1 (114.45)	41.7 (105.97)
Predicted runoff as 100% of precipitation, ft^3/s (m^3/s)	115.11 (3.26)	48.0 (1.36)
Precipitation lost or retained, storage and vapor return, etc., ft^3s (m^3/s)	57.9 (1.64)	26.8 (0.76)
Actual runoff, % of precipitation	50	44

watershed had steeper slopes than the Broad Brook watershed which would result in less time for infiltration or evaporation and thereby increasing the amount of runoff. A second factor is the nature of the runoff. The monthly runoff data for Broad Brook are more uniform than similar data for the Coginchaug River.[16] During the 1962-63 water year, a year with greater than normal precipitation, the differences in this respect were particularly dramatic. The standard deviation of monthly runoff data[16] from Broad Brook was 42.2% of the mean; for the Coginchaug River watershed it was 71.7%. The long term averages confirm the difference. The uniformity of the monthly runoff data for the Broad Brook watershed indicates that, in general, the water moves less rapidly through its interior drainage system, increasing the time for evaporation and infiltration.

SUMMARY AND CONCLUSIONS

The primary objective of this investigation was to test the utility of Skylab imagery in the acquisition of data required in the planning, design and operation of reservior systems. The tasks addressed in fulfilling this objective were: 1) the preparation of land use maps from LANDSAT, Skylab S190A and S190B and RB-57/RC8 imagery, and 2) a determination of the utility of imagery in quantifying environmental factors that effect runoff. The quality of the original NASA data products enlarged to various scales was compared. It was found that the S190A imagery corresponded most closely to the LANDSAT multispectral imagery. The S190B imagery corresponded most closely to the RB-57/RC8 high altitude aircraft imagery in resolution and general utility for land use mapping. Land use maps were made from 1:63,360 scale, black and white enlargements of each using a modified version of the U.S. Geological Survey Land Use Classification System. Referance was made to the original color transparencies to verify the discrimination between tonal characteristics used to differentiate between similar mapping units.

As summarized in Table 12, five level I units and eight level II units could be mapped from the LANDSAT multispectral imagery. All six level I units and thirteen level II units could be mapped from the S190A photography. The six level I units, seventeen level II units and one level III unit could be mapped from the S190B photograph. This is very nearly as good as the high altitude aircraft photograph from which six level I, twenty one level II and five level III units could be differentiated. For the purpose of this investigation the Skylab S190B photographs were fully adequate.

Table 12. Mappable land use units.

	LANDSAT	S190A	S190B	RB-57
Level I	5	6	6	6
Level II	8	13	17	21
Level III	0	0	1	5
Total	13	19	24	32

It has been suggested that one of the most important factors determining the relationship between watershed characteristics and runoff is the extent of wetlands.[19,20] Two closely proximate watersheds in Connecticut for which all four image types were available were selected to investigate the degree to which land use could be quantified. Analysis of the available runoff data suggested that these two watersheds were similar in many respects. The discharges on a unit area basis were similar although the areal extent of wetlands, on a percentage basis, differed in each by a small but significant amount. The map made from the S190B photographs was used to investigate this point. It showed that the Coginchaug River watershed test site was 10.6% wetlands and that the Broad Brook watershed test site was 2.2% wetlands. These findings were confirmed by the analysis of the RB-57/RC8 photographs as shown in Table 9. The U.S. Geological Survey eleven year stream gaging records showed that average runoff in $m^3/sec/km^2$ was 0.018 in the Coginchaug River watershed and 0.015 in the Broad Creek watershed. The greater relief and steep slopes in the Coginchaug River watershed must be more important factors in effecting runoff than is the amount of wetlands.

The Skylab S190A photographs were not adequate for the detailed land use mapping required in the planning, design and operation of reservoir systems. They are adequate, however, for land use mapping on a regional scale. The Skylab S190B photographs, on the other hand, provide adequate detail for land use mapping that can be used in reservoir management. It compares favorably with the best high altitude aerial imagery available for this purpose.

SIGNIFICANT FINDINGS AND UNIQUE RESULTS

1. S190B imagery is superior to the LANDSAT imagery for land use mapping and is as useful for Level I and II land use mapping as the RB-57/RC8 high altitude imagery. Detailed land use mapping at levels III and finer from satellite imagery requires better resolution. However, the larger areal coverage available from the S190B imagery is a great advantage. Thus the S190B imagery was found to be nearly ideal for detailed, regional land use mapping.

2. For evaluating factors that are required to determine volume runoff potentials in a watershed the S190B imagery was found to be as useful as the RB-57/RC8 high altitude aircraft imagery.

3. In areas where regional hydrologic surveys and land use mapping are critical requirements in urban planning and planning for natural resource development, the S190B imagery obtainable from satellite orbits is of great potential value.

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APPENDIX 1. Reports prepared and presentations made during the project.

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APPENDIX 2. Metric/English equivalents

1 cm = .032 ft.; .39 in.
1 m = 1.09 yds; 3.28 ft.; 39.37 in.
1 km = 0.62 stat. mi.