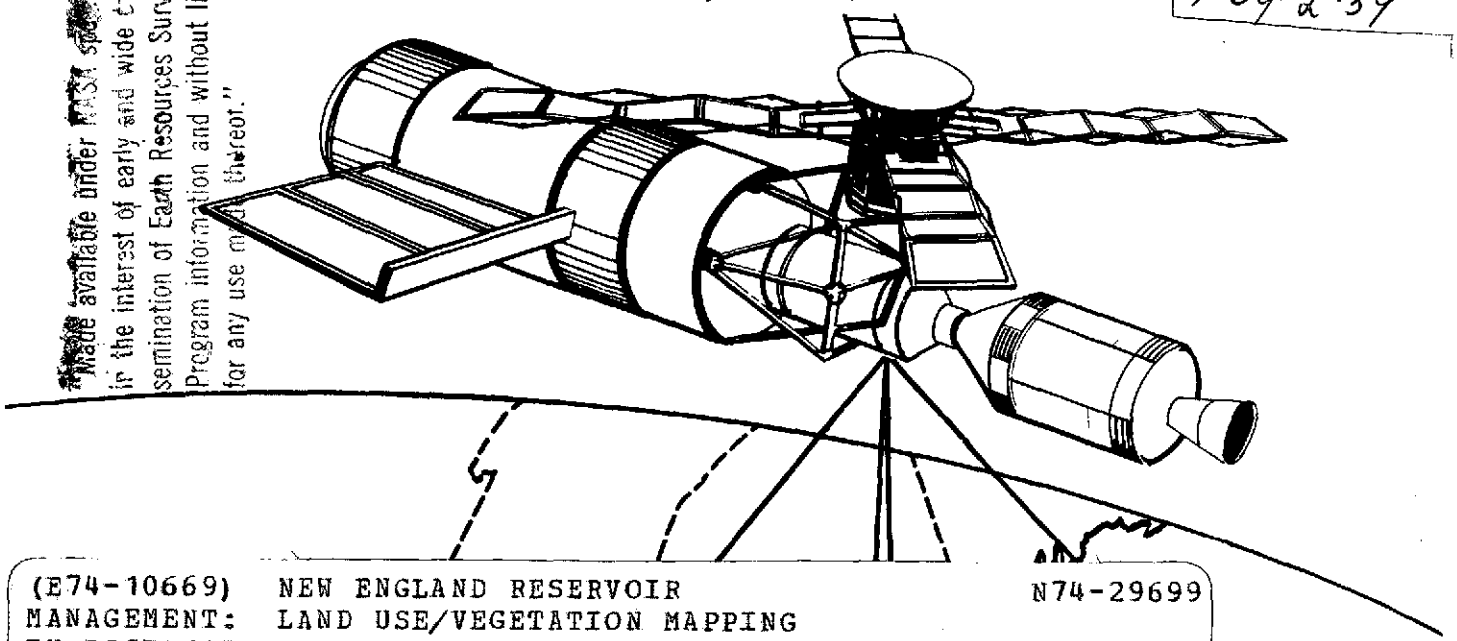
# Land Use / Vegetation Mapping In Reservoir Management

## MERRIMACK RIVER BASIN

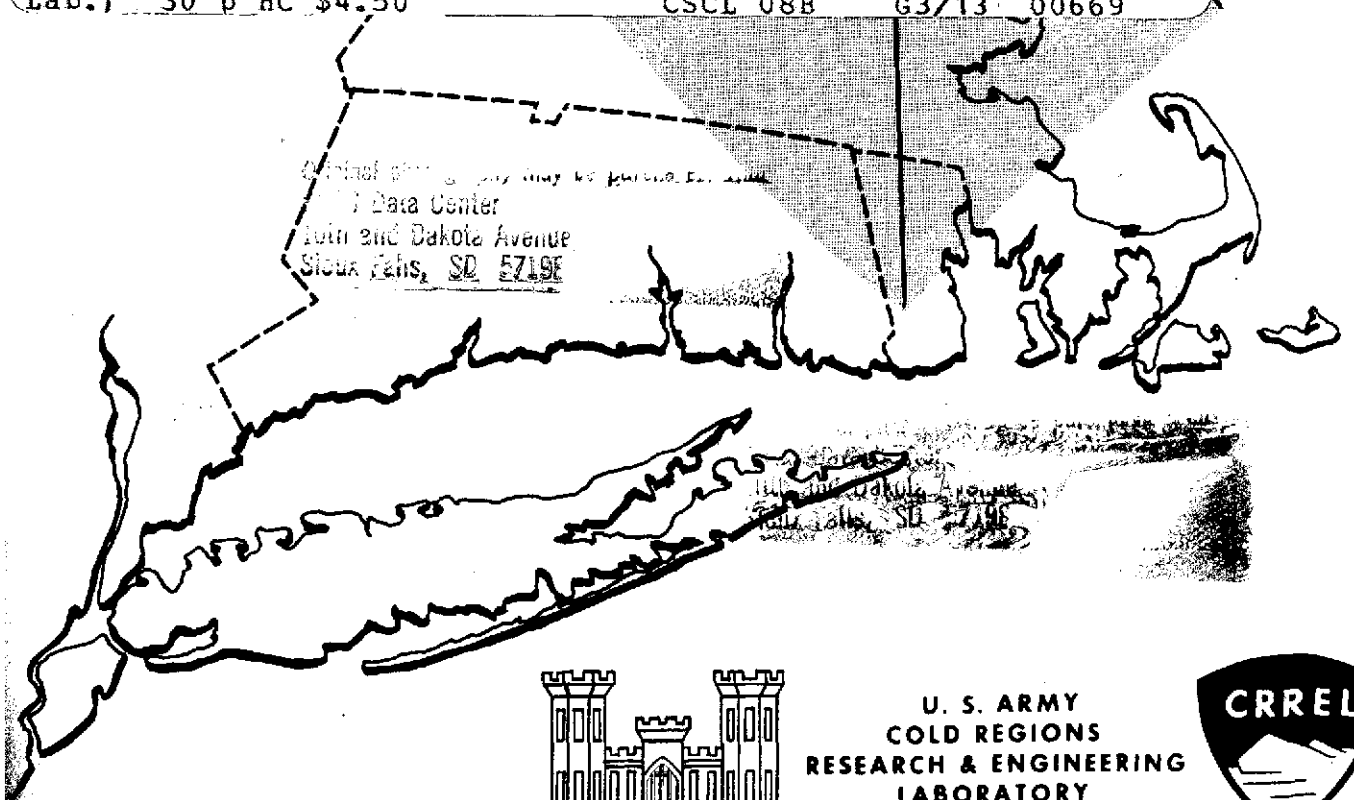


JUNE 14, 1974









U. S. ARMY
COLD REGIONS
RESEARCH & ENGINEERING
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CRREL

# NEW ENGLAND RESERVOIR MANAGEMENT

## INTERIM CONTRACT REPORT

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PREFACE

This report was prepared by H.L. McKim, L.W. Gatto, C.J. Merry and D.M. Anderson, Earth Sciences Branch, Research Division, and T.L. Marlar, Technical Services Division, U.S. Army Cold Regions Research and Engineering Laboratory (USACRREL), Hanover, New Hampshire. The work was funded by the National Aeronautics and Space Administration under Contract ERN089; "New England Reservoir Management," to the New England Division Corps of Engineers; Saul Cooper, Principal Investigator.

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## INTRODUCTION

This report consists of an analysis of: ERTS-1 Multispectral Scanner imagery obtained on 10 August 1973; Skylab 3 S190A and B photography, track 29, taken 21 September 1973; and RB-57 high altitude aircraft photography acquired 26 September 1973. This imagery was acquired on three cloud-free days within a 47-day period. It is known that atmospheric haze and sun angle variations limit the tonal contrast of, and thus the amount of information observable on, satellite and aircraft imagery. It is also evident that these parameters change not only from day to day but continually during image acquisition. Therefore, the interpretations made from imagery acquired on different days when atmospheric conditions are similar are as useful as those made from imagery acquired on the same day. Due to processing delays, receipt of the S190B imagery from NASA was not complete until 24 May 1974.

The objectives of this report are:

(1) To make quantitative comparisons between high altitude aircraft photography and satellite imagery.

(2) To prepare and validate, as a demonstration project, the extent to which high resolution (S190A and B) space-acquired data can be utilized for land use/vegetation mapping and management of drainage basins.

The test site chosen for this investigation was a 124-square-km area of the Merrimack River estuary (Fig. 1). This area contains the largest variety of land use and vegetative classification units to be found in the Merrimack River Basin. In addition, the Merrimack River Basin is a primary test site for the NED-CRREL Skylab Earth Resources Experiment Package (EREP) project.

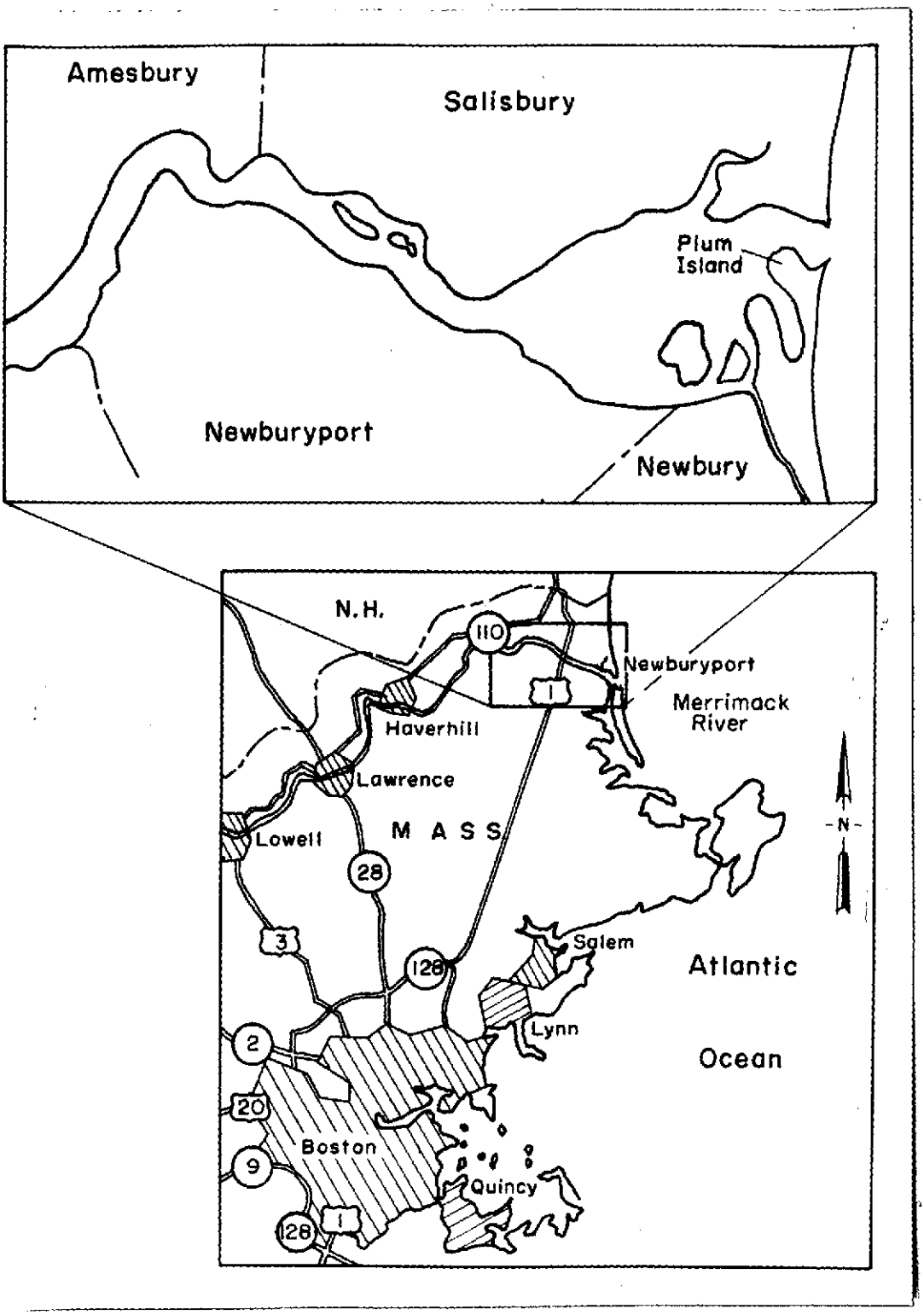


Figure 1. Location map.

## SPECIFIC COMPARISONS OF IMAGERY

### Resolution

The general characteristics of the ERTS-1, Skylab and aircraft imagery received from NASA are described in Table I. Ground resolutions determined by inspection of these various data products are given in Table II. The smallest features that can be recognized on the ERTS-1 imagery are linear features, such as roads, bridges, etc. of about 70 meters in width that contrast sharply with the surrounding terrain (McKim et al., 1972). The minimum size of circular or oblate objects detectable on the Skylab S190A photography is about 4.9 $m^2$, whereas on the ERTS-1 imagery, the area is about 24.3 $m^2$. As might be anticipated, mapping accuracy is found to be superior when using Skylab imagery as compared with the ERTS-1 imagery, increasing as the photographic scale decreases. In line with this, the RB-57 photography at a scale of 1:120,000 offers the best mapping tool of all the data products analyzed when accuracy is considered. This general effect, however, is offset by a reduction in ground coverage.

Table I. Characteristics of NASA data products

| Imagery | Transparency dimension (cm) | Scale | Estimated ground coverage (km) | Area ($km^2$) |
|---|---|---|---|---|
| ERTS-1 Multispectral Scanner (0.6-0.7μ) | 18.6 | 1:1,000,000 | 185 | 34,344 |
| S190A Multispectral Camera (0.6-0.7μ) | 5.7 | 1:2,850,000 | 163 | 26,595 |
| S190B Earth Terrain Camera (CIR 3443) | 11.4 | 1:830,720 | 109 | 11,955 |
| RB-57 RC-8 Camera (CIR 2443) | 22.9 | 1:120,000 | 28 | 773 |

Table II. Ground resolution

| | ERTS-1 | S190A | S190B | RB-57 |
|---|---|---|---|---|
| Linear Features (meters) | 70 | 25 | 12.5 | 5 |
| Circular Features ($m^2 \times 10^3$) | 24.3 | 4.9 | 3.2 | .8 |

Scale

Imagery from the three satellite data products were enlarged to approximately 1:800,000, 1:400,000, 1:200,000, and 1:63,360 to determine the most useful scale for mapping. The detail on the small-scale imagery (1:800,000 - 1:200,000) was sufficient but not practical for level I land use/vegetation mapping. At this scale, all the mapping units detectable on the imagery could not be delineated because the test site was extremely small. However, the units on the 1:63,360 scale were of sufficient dimension to enable accurate mapping and data transfer. Additional reasons for selecting 1" to a mile scale are: this scale corresponds to the 15-minute quadrangle sheets; at larger scales the S190A photographs begin to have a "grainy" appearance; and the scan lines on the ERTS-1 imagery become prominent, reducing image clarity.

## LAND USE/VEGETATION MAPPING

The classification scheme selected for the project is a modified version of a U.S. Geological Survey Land Use Classification System (Anderson et al., 1972). Table III describes the scheme used in this investigation.

Table III. Land use/vegetation classification system
[modified from Anderson et al., (1972)]

| Level I | Level II | Level III |
|---|---|---|
| Urban/Built-up Land (U) | 1. Residential-single | |
| | 2. Residential-multi | |
| | 3. Commercial | Parking lot, $U_{3p}$ |
| | 4. Industrial | |
| | 5. Extractive | |
| | 6. Mixed | |
| | 7. Transportation, Communications, Utilities | |
| | 8. Institutional | School, $U_{8s}$ |
| | 9. Open and Other | Park, $U_{9p}$ |
| | | Cemetery, $U_{9c}$ |
| Agricultural 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, $N_{1a}$ |
| | 2. Bare | |
| Barren Land (B) | 1. Beach | |
| | 2. Bare Exposed Rock | |
| | 3. Other | |

Land use/vegetation maps were prepared from black and white contact prints of ERTS-1 MSS band 5 (0.6-0.7μ wavelength) imagery, S190A (0.6-0.7μ wavelength) photography, S190B color infrared (CIR) photography (Fig. 2) and RB-57 CIR photography. The 0.6-0.7μ wavelength of the ERTS-1 multispectral imagery and the S190A photography was selected because land use and vegetation patterns are most prominently displayed on this band. All imagery was contrast enhanced photographically to portray the maximum number of gray tones.

The maps from the RB-57 and S190B photography were prepared simultaneously by different image analysts; next, the S190A and ERTS-1 maps were compiled. Although mapping from the most detailed photography was actually done first, this information was not a factor in preparing the maps on the less detailed imagery. In all of the analysis unit designations were based strictly on the tone and texture of the photographs. This approach is somewhat different from conventional land use mapping methods; only information extractable from the imagery alone without reference to ancillary data entered into the interpretation of units. This was done to eliminate bias in the comparisons insofar as possible and to insure that the results were derived strictly from interpretations of the various tones and textures intrinsic to the imagery. During the exercise the only references made were to the original color, CIR and false color renditions of the various NASA data products being compared.

ERTS-1 imagery

Four level I, two combined level I, and eight level II units were

Figure 2. Color Infrared (CIR) S190B Photograph (ID 87-305); Scale 1:90000 (Approximate)

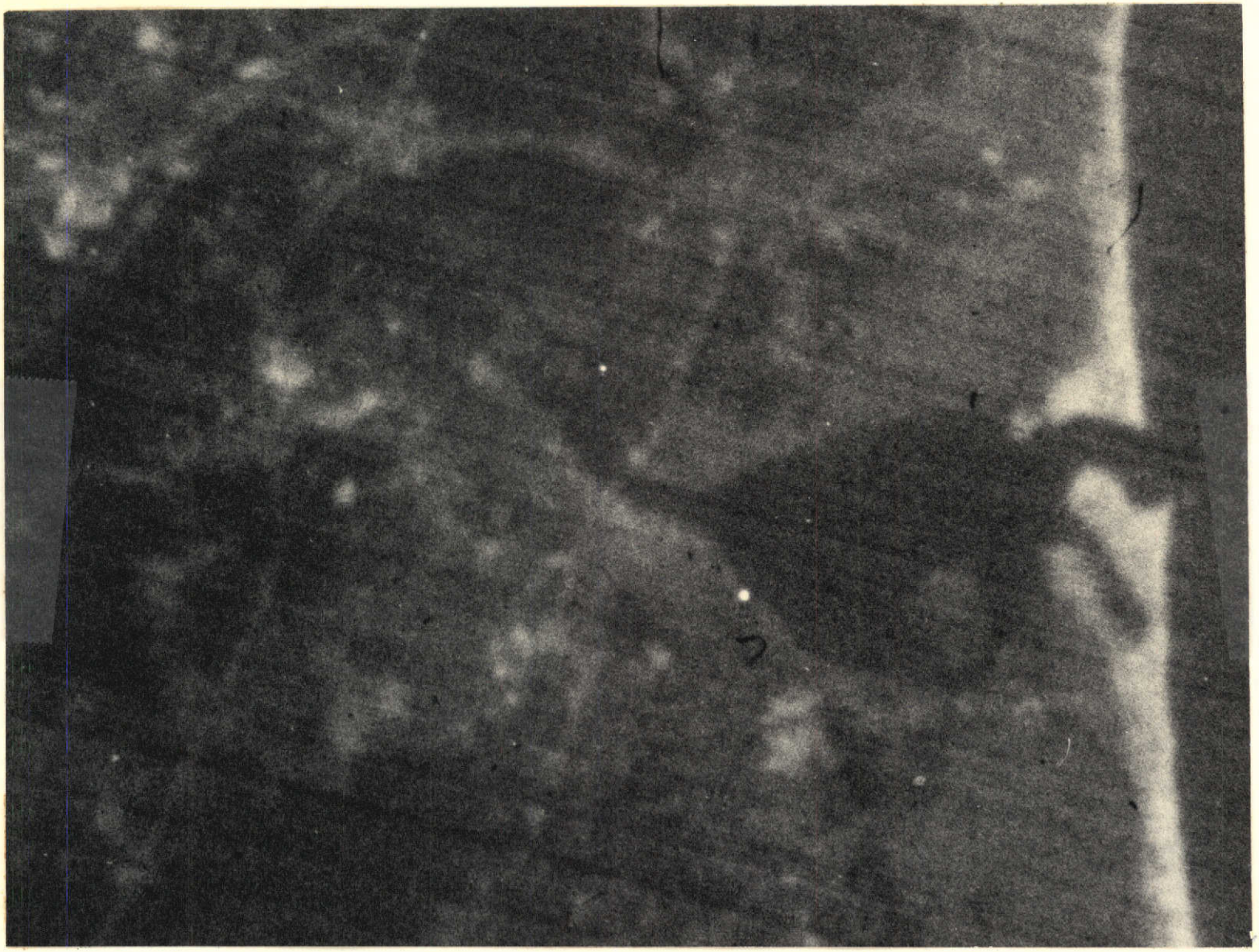

Figure 3a. ERTS-1 MSS Band 5 Image (ID 1383-15003) of Study Area; Scale 1:63360 (Approximate)

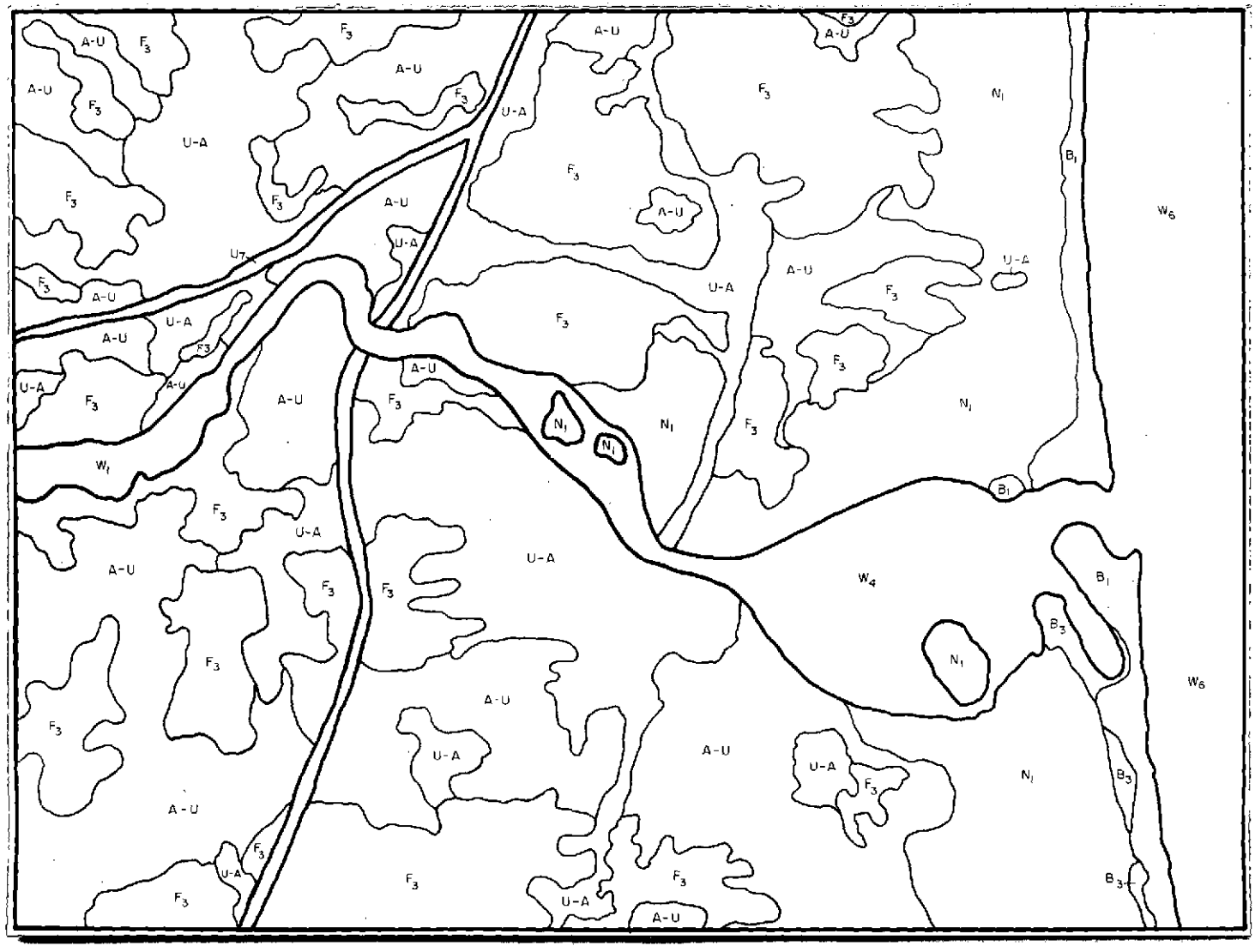


Figure 3b. Land Use/Vegetation Map from ERTS-1 Image

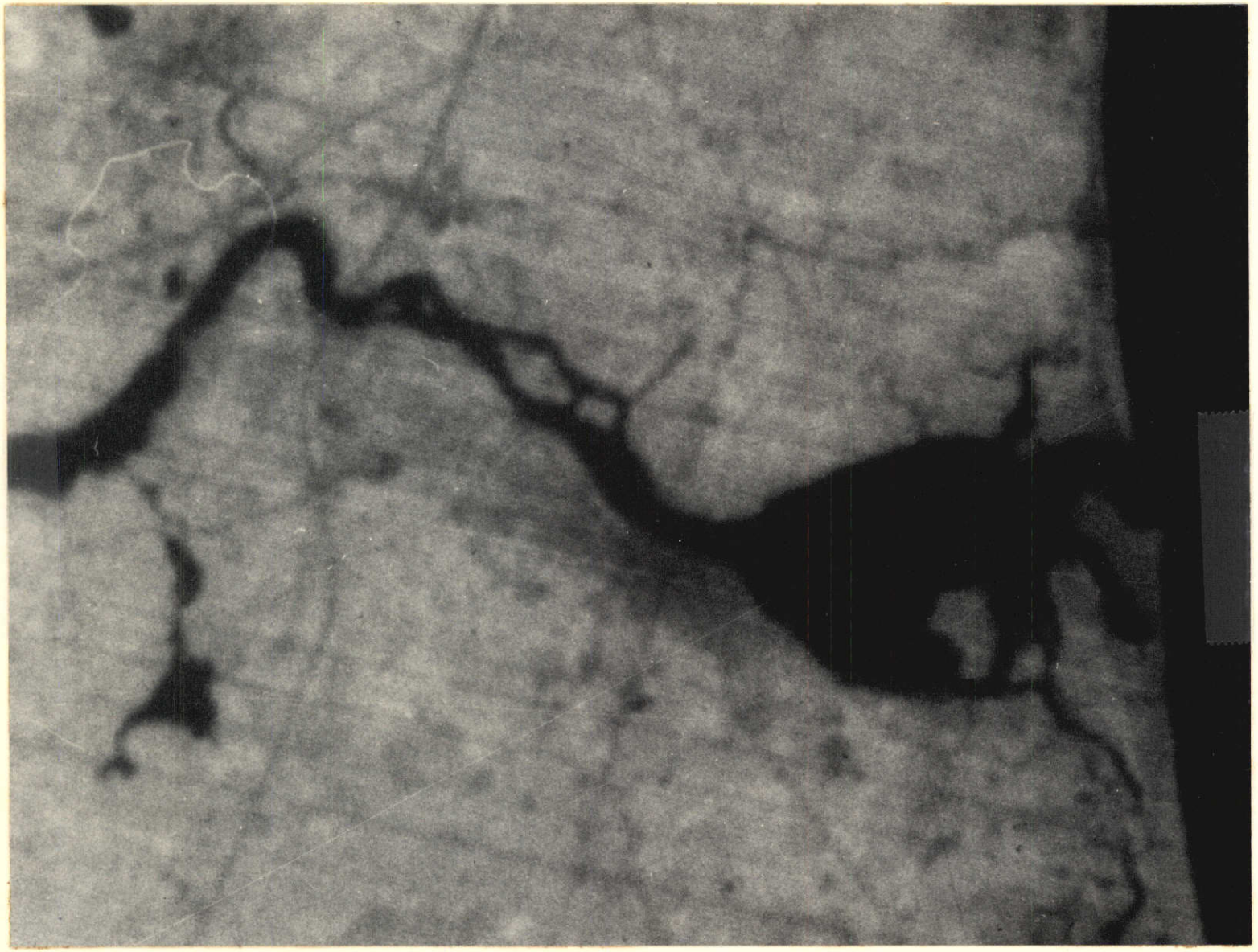

Figure 3c. ERTS-1 MSS band 7 (0.8-1.1μ) Image (ID 1383-15003)
Scale 1:63360 (Approximate)

delineated on the ERTS-1 band 5 image (Fig. 3a, b). It is important to note that open water is also included in the $N_1$ (vegetated, non-forested wetland) and $F_3$ (mixed forest) units on the ERTS-1 map. Tidal channels and intermittent streams also have reflectance characteristics similar to the $N_1$ unit on this band 5 image. These similarities may result from large concentrations of particulates in the water or bottom effects. The boundary between inland water and the $F_3$ unit was also not apparent on the band 5 print because of similar signatures; however, the boundary between these units and water is clearly defined on the band 7, near infrared, scene (Fig. 3c). This clearly illustrates that both ERTS-1 bands 5 and 7 are required for land use/vegetation mapping using conventional photointerpretation techniques.

Since the tonal differences between urban and built-up land (U) and agricultural land (A) were not significant, these units were combined to form either A-U or U-A. The U-A unit was used when light gray tones from highly reflective surfaces (i.e., pavements, buildings, etc.) predominated, whereas the A-U unit was used when the primary tone was dark gray with few scattered light gray tones. The only mappable level II urban unit was $U_7$, the right-of-way for an interstate highway. The coastal area was mapped as $B_1$ and $B_3$ which were interpreted to be a sand beach and an area of drifting sand, respectively.

Skylab S190A photography

Six level I and thirteen level II units were mapped on the S190A image (Fig. 4a, b). Three level II urban units could be easily

Figure 4a. S190A Photograph (ID 47-306) of Study Area;
Scale 1:63360 (Approximate)

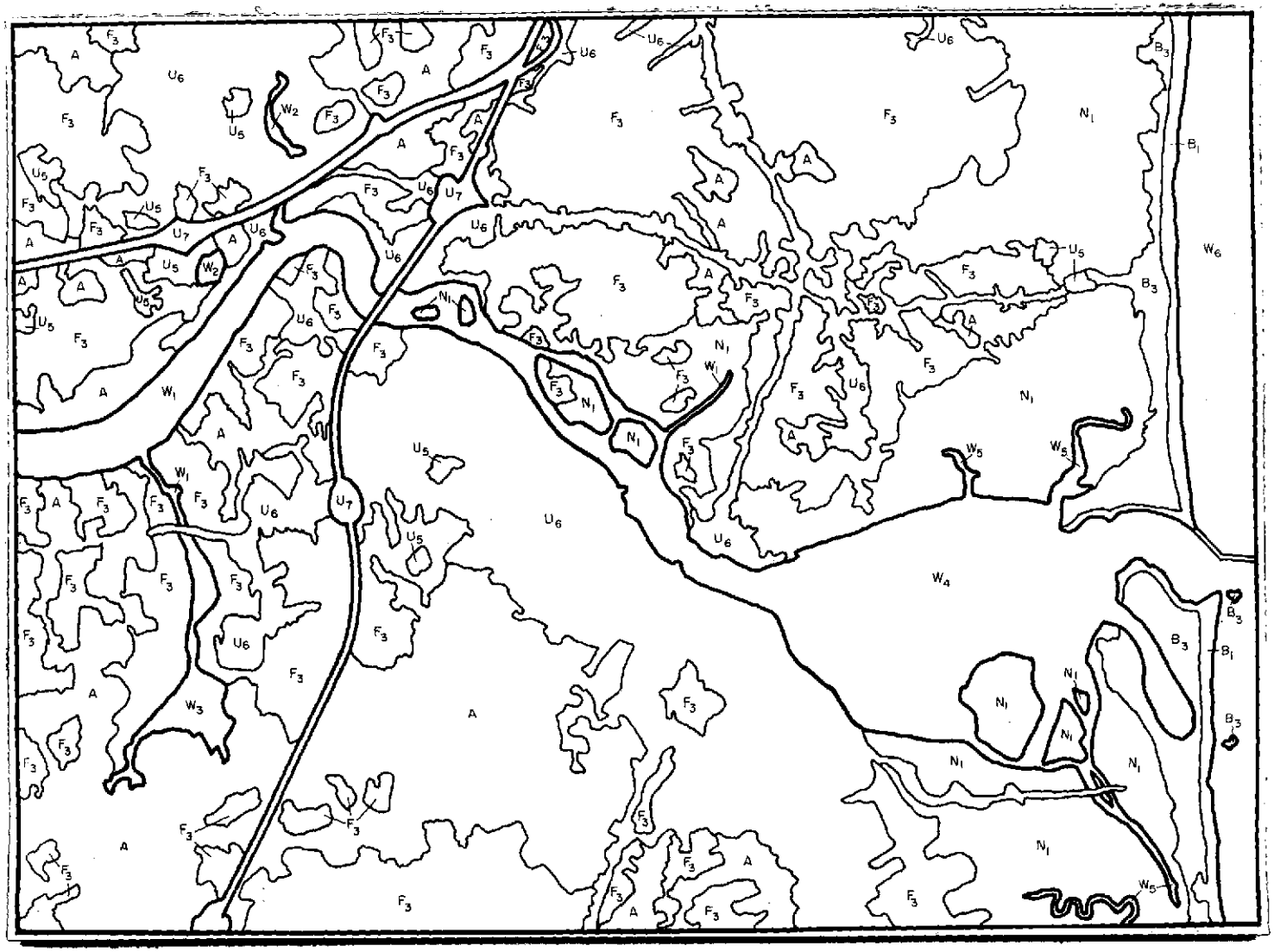


Figure 4b. Land Use/Vegetation Map from S190A Photograph

distinguished from agricultural and forested lands. The agricultural lands, however, could not be defined to the second level because the tonal contrasts of orchards, row crops and pastures were not significant. The $B_3$ unit as previously mapped on the ERTS-1 image was interpreted to be an area where beach sands are encroaching on the tidal marshes. A similar interpretation of this unit was made on the S190A frame, but a more accurate distinction between the $B_1$ and $B_3$ units was possible. The $B_1$ unit is comprised primarily of white to very light gray tones while the $B_3$ unit is comprised of mottled tones with variations from very light gray to dark gray. Small fields and single family residences not visible on the ERTS-1 scene, and surrounded by mixed forests, are included in the $F_3$ unit on the S190A map. Small offshore islands or shoals south of the mouth of the Merrimack River, inland water bodies, and tidal channels not seen on the ERTS-1 band 5 image are apparent on the S190A frame. In all, two additional, discrete level I and five level II units were defined on the S190A photograph.

Skylab S190B photography

Six level I, fifteen level II, and one level III units were mapped on the S190B photograph (Fig. 5a, b). Level II agricultural lands could not be delineated, but two previously unmapped urban units, residential-single ($U_1$) and open and other ($U_9$), were defined. When $U_9$ and A units had similar tones, the unit was designated $U_9$ if it was proximate to urban areas. Marinas not previously recognized were delineated on the S190B image and included in $U_7$. Secondary linear features suggesting

Figure 5a. S190B Photograph (ID 87-305) of Study Area;
Scale 1:63360 (Approximate)

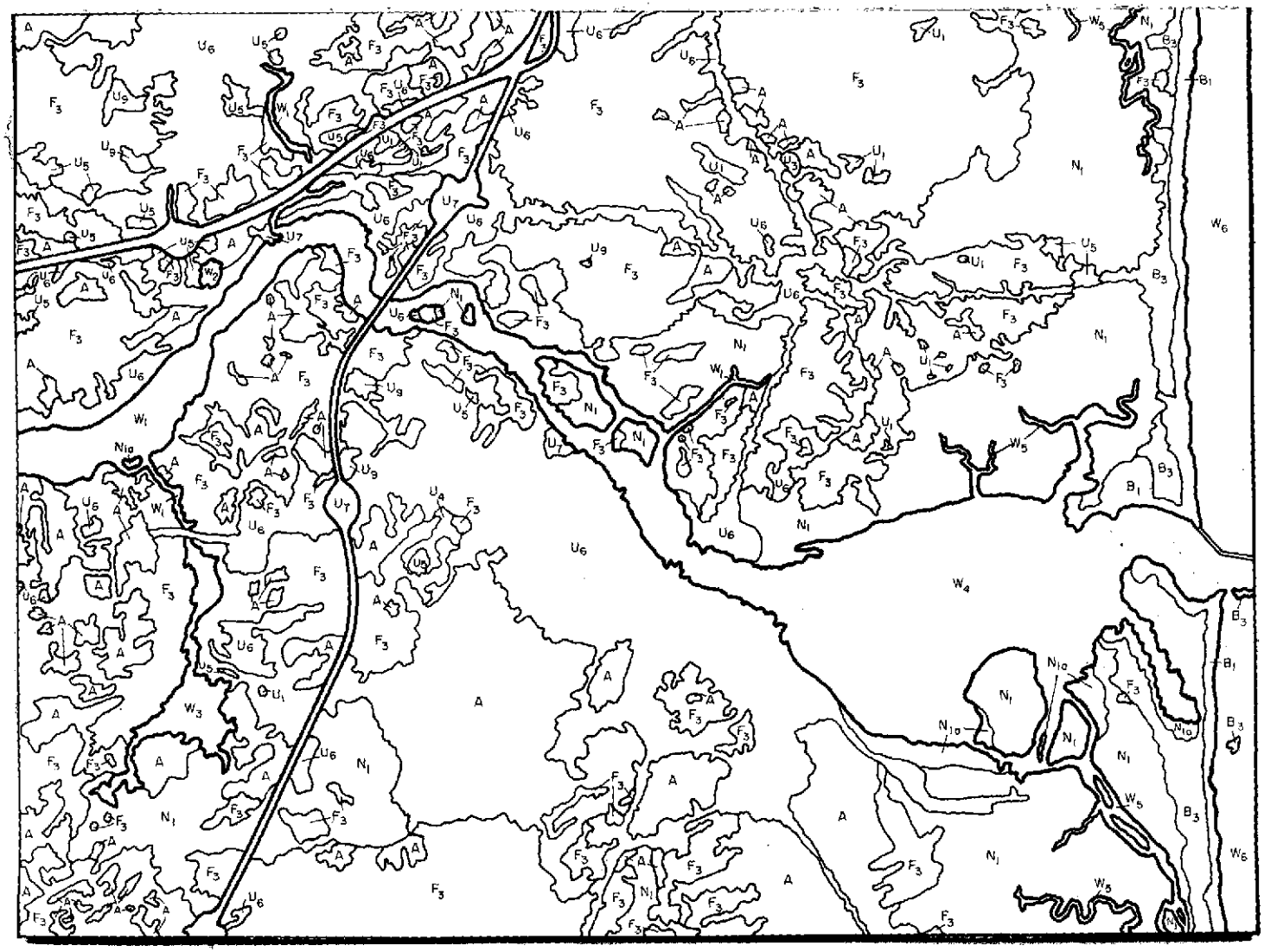

Figure 5b. Land Use/Vegetation Map from S190B Photograph

utility lines, secondary roads and railroads were easily identified. However, they were not mapped because their complex patterns detracted from the clarity of the mapping units.

One level III unit, $N_{1a}$, tidal marshes, could be mapped along the southern shore near the mouth of the estuary. The marshes in the $N_{1a}$ unit differ from those in the $N_1$ unit in that the $N_{1a}$ marshes appear darker and are probably inundated daily. Additional tidal channels not previously distinguished on the S190A print are delineated on the S190B photograph. Many units ($U_1$, A, $U_6$, $N_1$) previously included in $F_3$ and A units of the S190A map are more clearly defined on the S190B image and therefore have been mapped as separate units. In all, on the S190B map, there are two additional level II units and one level III unit above those mapped on the S190A photograph of this area.

RB-57 high altitude aircraft photography

Six level I, twenty level II and five level III units were mapped on the RB-57 photograph (Fig. 6a, b). Four level III units which include schools ($U_{8s}$), parking lots ($U_{3p}$), cemeteries ($U_{9c}$), and parks ($U_{9p}$) were previously mapped in the urban unit ($U_6$) on the S190B; the fifth level III unit, $N_{1a}$, was previously mapped on the S190B photograph. Urban areas included in the level II, mixed urban unit ($U_6$) of the S190B map were separated into the following distinct level II units on the RB-57 map: $U_1$, $U_{1,2}$, $U_3$, $U_4$, $U_8$ and $U_9$. Agricultural lands were easily divided into level II categories, pastures ($A_1$) and orchards ($A_3$). For mapping clarity, trees along fence lines and in small groves were not

Figure 6a. RB-57 High Altitude Aircraft Photograph (ID 151-0085) of Study Area; Scale 1:63360 (Approximate)

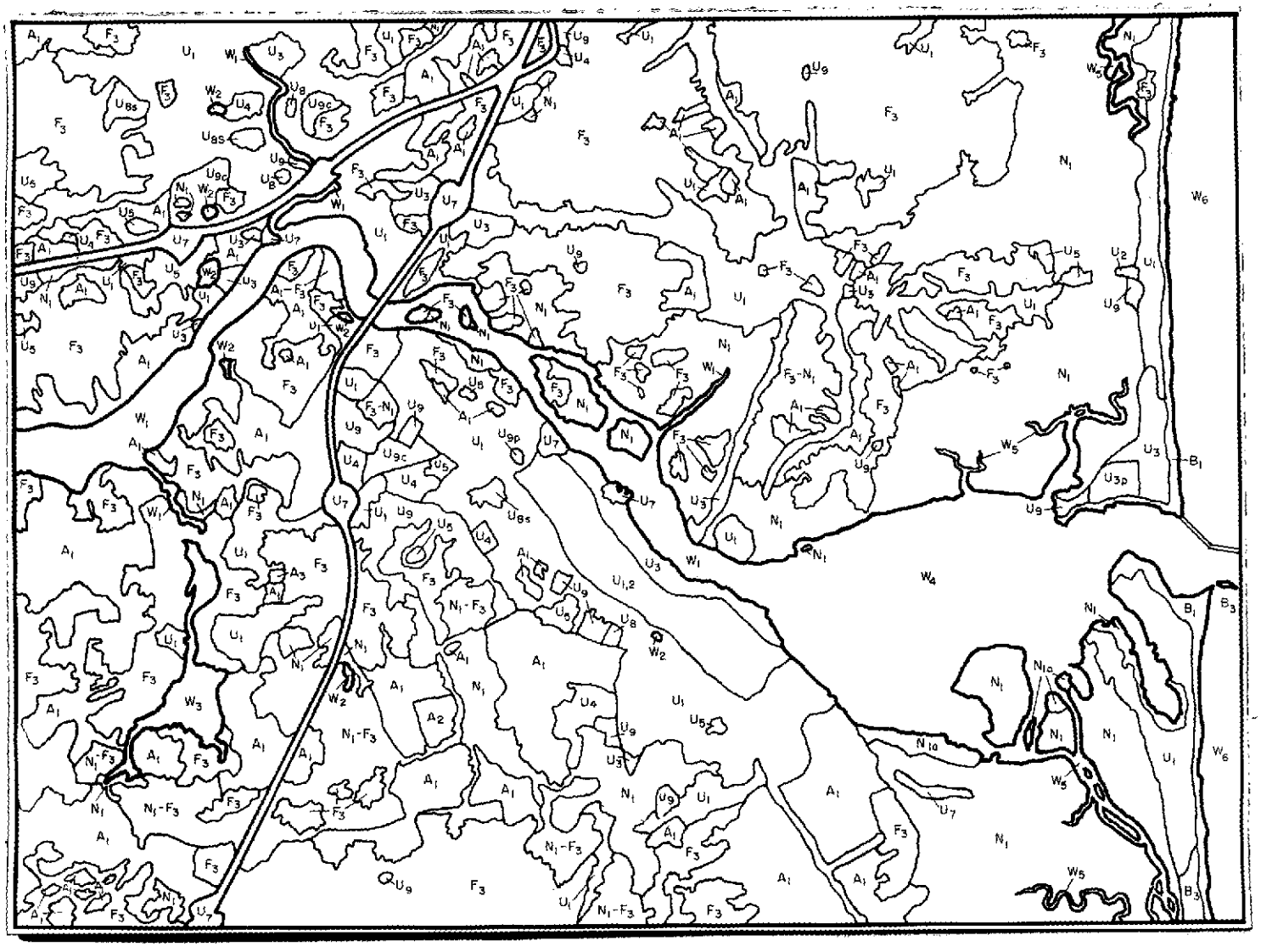

Figure 6b. Land Use/Vegetation Map from RB-57 Photograph

separated but were included in the $A_1$ and $U_1$ mapping units, respectively. Roads, railroads and utility lines could readily be identified. However, they were not drawn on the map because of the difficulty in placement of mapping symbols when these lines crossed individual mapping units. Intermittent streams and man-made drainage ditches not previously recognized in the $N_1$ unit were detected on the RB-57 photograph but were not delineated on the map. Where vegetated, nonforested wetlands ($N_1$) and mixed forests ($F_3$) could not adequately be separated, a combined unit was designated. Where the $N_1$ unit dominated the combined unit $N_1$-$F_3$ was employed, and where mixed forests dominated the unit $F_3$-$N_1$ was used. The same principle was utilized in defining the $A_1$-$F_3$ unit.

It was also possible to observe houses, roads, and developed areas on the RB-57 photography that had been previously mapped 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 ($U_1$, $U_3$, $U_9$). In all, five additional level II and four level III units were mapped on the RB-57 photograph than were found on the S190B.

## DISCUSSION

Earlier experience has shown that the following factors should be considered in providing remote sensing data useful in the management of reservoirs and watersheds: repetitiveness, scale, ground resolution, and interpretation time. ERTS-1 imagery of the study site was available at 18 day intervals. This imagery, however, cannot be enlarged to a

scale greater than approximately 1:63360, and its ground resolution (Table II) is such that only four separate and two combined level I land use/vegetation units could be mapped by conventional methods. Agricultural and urban land could not be easily differentiated; hence the need for combined U-A or A-U units. The eight mappable level II units (Table IV) include water, $W_1$, $W_4$ and $W_6$; barren land, $B_1$ and $B_3$; urban areas, $U_7$; nonforested wetlands, $N_1$; and, forest land, $F_3$. The ERTS-1 map took approximately 1.5 hours to prepare and was the least detailed of all the maps prepared. This imagery can be used effectively for mapping land use/vegetation on a regional scale but is much less useful in the analysis of small watersheds using conventional photointerpretation techniques.

Skylab photography for the site is available for 16 and 21 September 1973 (SL3) and 14 January 1974 (SL4). As in the case with the ERTS-1 imagery, the S190A multispectral photography also begins to lose image quality when enlarged to scales greater than approximately 1:63360. However, the ground resolution is at least three times better than that of the ERTS-1 imagery and thus mapping detail is improved. Six distinct level I units were mapped from the S190A photographs. The two additional units were mapped because urban and agricultural lands not separated on the ERTS-1 imagery were easily differentiated on the S190A image. The thirteen level II units included (Table IV): water, $W_1$, $W_2$, $W_3$, $W_4$, $W_5$, $W_6$; urban areas, $U_5$, $U_6$, $U_7$; barren land, $B_1$, $B_3$; forest land, $F_3$; and nonforested wetlands, $N_1$. The water/land boundary was more apparent on

Table IV. Summary of land use/vegetation units mapped

| Categories | ERTS | S190A | S190B | RB-57 |
|---|---|---|---|---|
| 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 | 22 | 31 |

the S190A photography than on the ERTS-1 image; thus an additional infrared photograph was not required in mapping with S190A data. The mapping time increased to nearly 4 hours with the S190A photography but the product was significantly better than the ERTS-1 map. The S190A photography is sufficient for mapping land use/vegetation in areas where rapid development is not a factor and repetitive coverage is not essential.

S190B color infrared photography has a ground resolution nearly twice that of the S190A and the map prepared from the S190B photography is therefore more detailed. The six level I units, previously mapped with the S190A, were delineated, plus a total of 15 level II units, two more than with the S190A. The level II unit, $U_1$, previously included in the $U_6$ unit, and the $U_9$ unit, previously included in the $U_6$ or A units on the S190A map, were differentiated. Also, the difference between agricultural, urban and forested areas was more apparent on the S190B scene, thus additional and more accurate delineations of these categories were made. The water-land boundary was more apparent on the S190B than on the S190A photography. As a result, additional tidal channels were mapped and many more small streams were detected on the S190B photography. Soil moisture differences were more apparent on the S190B photography, and a previously unmapped level III unit, $N_{1a}$, tidal marshes, was delineated. The distinction in soil moisture also facilitated the differentiation of the agricultural lands, A, and the nonforested wetlands, $N_1$. The time required for mapping was about eight hours but the map is considerably more detailed than either the S190A and the ERTS-1 maps.

The RB57 high-altitude, color infrared photography, has a ground resolution that is at least two times greater than that of the S190B. Thirty-one land use/vegetation units were mapped with the RB57 imagery; six level I previously mapped, twenty level II and five level III. The additional level II units are agricultural land, $A_1$ and $A_3$, and urban land, $U_2$, $U_3$, and $U_4$. These urban areas were delineated from the large urban areas classified as mixed, $U_6$, on the S190B photograph. The four previously unmapped level III units are urban lands, $U_{3p}$ (parking lots), $U_{8s}$ (schools), $U_{9p}$ (parks) and $U_{9c}$ (cemeteries). All the forest land in the area is mixed, $F_3$. The distinction between the $F_3$, $N_1$ and $A_1$ units was more apparent on this photography and more accurate delineations were made. A combined unit, $N_1$-$F_3$ or $F_3$-$N_1$, was used where the mixed forests and vegetated, nonforested wetlands were in proximity to each other. Urban land, $U_1$, along the coast was previously mapped as a $B_3$ unit on the other photographs. Without the high ground resolution of the RB57 photography, this unit ($U_1$) could not have been accurately mapped. Water-land boundaries and nearshore features were very distinctive. There were faint indications of bathymetric features in shallow water. All level III categories as described by Anderson et al. (1972) where applicable can be mapped on the RB57 imagery. The RB57 map required 10 hours to draft and clearly provided the most information. However, it may also be the most costly if aerial coverage, etc. is considered when comparing the imagery and photography of the four sites analyzed in this report.

## SUMMARY

The data products provided were enlarged several times to facilitate land use/vegetation mapping at the accuracy required in reservoir management practices. A scale of approximately 1:63360 was determined to be the most useful because: (1) The maps prepared can be easily referred to 15-minute topographic quadrangles; (2) At larger scales S190A photographs appear "grainy" and the scan lines in the ERTS-1 images become predominant, reducing the utility of the images.

Tonal characteristics of vegetative and agricultural units are more easily distinguished on color than on black and white imagery. Because of this, mapping on black and white prints is facilitated by periodic reference to the original color renditions. Also, when using ERTS-1 MSS imagery in preparing land use/vegetation maps both bands 5 and 7 are required in order to distinguish clear and shallow water from forested and wetland areas, respectively.

The ground resolution of the various satellite and aircraft data products varied with the shape of the feature. As is generally found, linear features were more easily detectable than circular or oblate objects (Table II). Among the various types of imagery, as ground resolution improved, the number of mappable units (Table V) and mapping accuracy increased; this also is as expected.

Table V. Mappable land use/vegetation units

| | ERTS-1 | S190A | S190B | RB-57 |
|---|---|---|---|---|
| Level I | 4+2 Combination | 6 | 6 | 6 |
| Level II | 8 | 13 | 15 | 20 |
| Level III | 0 | 0 | 1 | 5 |
| TOTAL | 14 | 19 | 22 | 31 |

## CONCLUSIONS

It is evident from this comparison that for land use/vegetation mapping the S190B Skylab photography compares favorably with the RB-57 photography and is much superior to the ERTS-1 and Skylab 190A imagery. For most purposes the 12.5 meter resolution of the S190B imagery is sufficient to permit extraction of the information required for rapid land use and vegetation surveys necessary in the management of a reservoir or watershed. The ERTS-1 and S190A data products are not considered adequate for this purpose, although they are useful for rapid regional surveys at the level I category of the land use/vegetation classification system.

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