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MULTIDATE MAPPING OF MOSQUITO HABITAT

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ABSTRACT

LANDSAT data from three overpasses in 1975 (25 June, 13 July, 9 August) formed the data base for a multidate classification of 15 ground cover categories in the margins of Lewis and Clark Lake, a fresh water impoundment between South Dakota and Nebraska. When scaled to match topographic maps of the area, the ground cover classification maps were used as a general indicator of potential mosquito-breeding habitat by distinguishing productive wetlands areas from non-productive non-wetlands areas. More specifically, the interpretation of the Consolidated Wetlands, Flooded and Transitional classes as permanently-flooded, frequently-flooded and intermittently-flooded, respectively, permitted a breeding potential to be assigned to each class vis-a-vis the preferred breeding habitat of Culex tarsalis, a permanent pool species and Aedes vexans, a floodwater species. The 12 channel multidate classification was found to have an accuracy 23% higher than the average of the three single date 4 channel classifications. By assuming that the 1.1 acre LANDSAT resolution reflects the dominant tendency within each pixel, the multidate classification map of ground cover categories can be considered a broadbrush indicator of potential mosquito-production and used to plan control programs.

1. INTRODUCTION

The association of certain species of mosquitoes with certain types of vegetation has been recognized for a long time; the association is usually explained in terms of shared ecological niches. For example, in coastal areas the association of Aedes sollicitans breeding areas with the salt marsh grasses Distichlis spicata and Spartina patens has been reported by a number of investigators (Elmore and Fay, 1958; Ferringo, 1953) and exploited to plan mosquito control strategies by mapping the location of the salt marsh grass.

Lewis and Clark Lake, the locale of the present study, is a 50 km long, freshwater, mid-continental impoundment which was created in 1957 when Gavins Point Dam was constructed on theMissouri River between South Dakota and Nebraska. As figure 1 indicates, the portion of the lake between Niobrara, Nebraska and Springfield, South Dakota is narrower and consequently shares the relict floodplain with wetlands, crops and mixed deciduous stands, whereas the wider portion of the lake between Springfield and Gavins Point Dam extends over the floodplain to the bluffs with very few wetlands margins. The location of the study areas reflects this marginal difference and, to some extent, documents it.

In our study areas we were concerned primarily with 2 species of mosquitoes, Aedes vexans, a floodwater species, and Culex tarsalis which prefers more permanent water habitats. Our principal objective was to define relationships

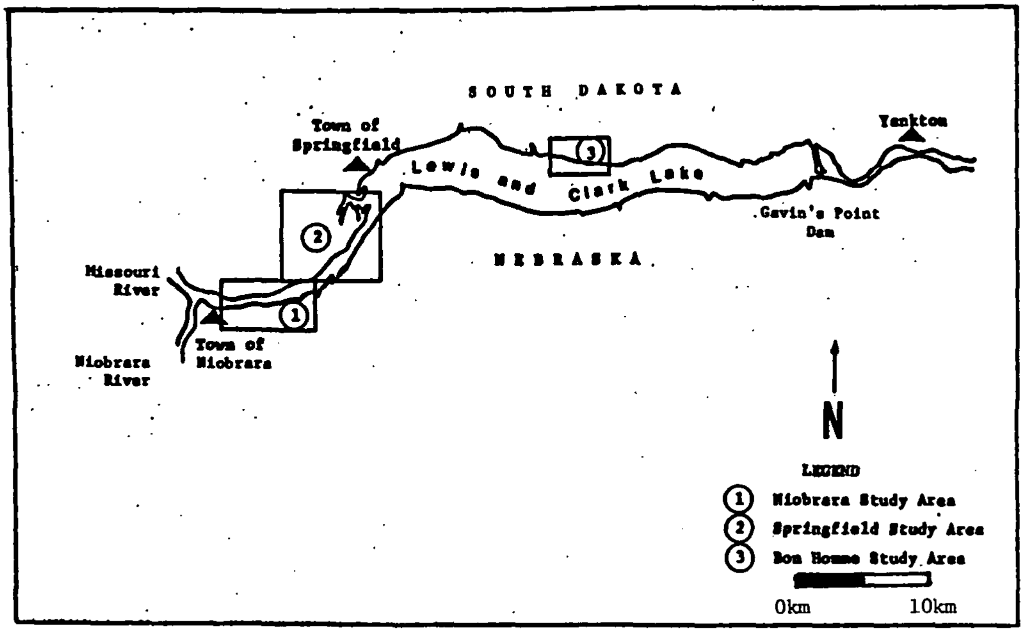

Figure 1. Lewis and Clark Lake and features of interest.

between the breeding habitats of these species and specific plant associations such that a mapping of the vegetative ground cover would serve as an indication of the location of specific mosquito-breeding habitat areas. Mosquito larvae data from collections made by the Water Resources Branch of the Center for Disease Control during the summer of 1975 were used as the reference for the distribution of mosquito-breeding habitat in the study areas. To delineate the vegetation patterns, we could have used conventional mapping techniques such as field transects (Küchler, 1967), interpretations based on black and white aerial photography (Rioux et al., 1968), or interpretations based on aerial color infrared photography (Rohe, 1970); we used multispectral data obtained from LANDSAT for this purpose because of the advantages it offered in terms of availability and repeated coverage of a given area.

LANDSAT data from three dates coincident with the period of larvae collection in the summer of 1975 (25 June, 13 July, 9 August) were digitally-processed to produce single-date land cover classification maps. They were also combined to form a multidate-multispectral land cover classification map of the study areas representative of ground conditions for the entire summer.

What follows is a more detailed description of the attempt to map mosquito-breeding habitat by mapping associated fresh-water wetlands as depicted through a digital, supervised, multidate analysis of LANDSAT data. Application of the remote sensing technique to mosquito habitat mapping over extensive areas such as that surrounding Lewis and Clark Lake should provide a tool for water resources planners and managers to more effectively prevent mosquito problems from developing in impoundment margins.

2. METHODOLOGY

A. Procedures. Computer compatible tapes from LANDSAT-1 and LANDSAT-2 were obtained for three dates in 1975 that coincided with the collection of mosquito larvae. The dates obtained were June 25, July 13, and August 9.

The images for these three dates were rectified, rotated and adjusted to a scale of 1:24,000. A visual fit was made (on a light table) between the images and 7 1/2' quadrangle maps for the area, and all three images were thus registered to each other. Once registration was accomplished, the data from all three dates, for the Lewis and Clark Lake area, were combined onto a single file such that each pixel was represented by a 12 variable vector (4 LANDSAT bands for 3 dates).

The processing of this combined data tape was accomplished with Colorado State University's LANDSAT Mapping System (LMS). The LMS employs supervised classification using a maximum likelihood algorithm. This system permits the selection of any of the variables on a data tape, so we had the option of classification with data from any one date, or we could use all 12 variables in a multidate mode.

Three sources of information were used to select vegetation types for classification and the training fields to represent these classes. Initially the data obtained during the 1975 larvae collection program was used to select areas around the lake and vegetation characteristics which were related to mosquito production. Then, color infrared aerial photographs for the area were obtained from the Corps of Engineers, Omaha. We were most fortunate to have photographs taken within two days of the August 9, 1975 LANDSAT overpass. These CIR images were used to select areas having similar radiance characteristics. Finally, three field trips during 1976 (close to the 1975 image dates) were used to obtain on the ground knowledge of vegetation conditions. Using all of this information, and the LANDSAT images themselves, training fields were selected to represent the vegetation and water classes given on Table 1.

Fortunately, the LMS permits the use of irregularly shaped masks to define training fields. This was extremely important for the intermixed, irregularly bounded, natural areas of this project. Of equal importance was the provision of the LMS to delete individual pixels, using statistical criteria, from training data sets. In this way, viable class signatures for the vegetation types noted were obtained. These signatures consisted, of course, of a 12 variable mean vector and covariance matrix.

B. Lewis and Clark Ground Cover Classification Scheme. Colwell (undated) observed that a suitable classification scheme is generally developed as a compromise between what the user considers ideal for his purposes and what the remote sensing analyst finds is consistently identifiable on the imagery he has to work with. Ideally, then, each of the cover types in Table 1, found in the margins of Lewis and Clark Lake, would be identifiable at the species level by means of remote sensing and would have attached to it a coefficient of mosquito breeding potential for the major mosquito species observable in the area. Gabinaud (1975) in fact used ground and aerial surveys to map vegetation species which served as biotic indicators in establishing an ecological chart for studying the distribution of the breeding habitat of two species of *Aedes* in the French Mediterranean lowlands. However, given the resolution of the LANDSAT system, 1.1 acres arranged in a regular rectilinear grid, and the complex, heterogeneous, irregular growth pattern of many of the Lewis and Clark wetlands vegetative species, the ideal solution is not immediately achievable. On the other hand, if the differentiation scale is modified so as to accomodate communities of somewhat larger units than one species, as Gabinaud (1975) occasionally did and Küchler (1967) recommended, a classification scheme whose vegetation components are consistently differentiable in terms of LANDSAT reflectance is possible.

Table 1 contains the raw material from which such a classification system was ultimately derived for the Niobrara and Springfield areas. The floodplain, in this reach of the river, is the site of wetland units encroaching into areas formerly covered by domestic units and dryland wild flora. In this successional context, transitional units mark the leading edge of the encroaching wetlands whereas flooded units specifically indicate areas where moist ground was observable on the August 9, 1975 color-infrared aerial photos. Figure 2 serves to illustrate these relationships in terms of elevation.

Following the selection of training data, initial tests of class separability resulted in modifications to Table 1 in the form of deletions and combinations of classes. The final set of classes (see Table 2 in the next section) were consistently identifiable from the LANDSAT data, and their areal distribution was indicative of the relative level of the water table. In this manner, mosquito breeding habitat potential could be mapped at a scale consistent with the 1.1 acre resolution of LANDSAT.

C. Single date vs. multidate analysis. Vegetated areas change their characteristic reflectance through time because of phenological or other developments, e.g., the soil component of a corn field's reflectance progressively diminishes from June to August as the plants grow. Several remote sensing investigators have demonstrated that sequential or multidate coverage yields more information, and therefore better identification, than single date coverage (Steiner, 1970; Richardson et al., 1972).

Table 1. Ground cover in margins of Lewis and Clark Lake arranged according to elevation.

H	W	F	T	D	U
WATER	WETLANDS	FLOODED	TRANSITIONAL	DOMESTIC	UPLAND
River	Duckweed	Cattails	Polygonum	Corn	Mixed Decid.
Standing	Cattails -bleaches -dead trees	Polygonum	Johnson Grass	Alfalfa	Bluff Grass
		Corn	Kochia	Oats	
		Unknown	Reed Canary	Wheat	
			Bog Marshcress	Wheatgrass	
			Foxtail Barley		
			Ragweed		
			Young willow		

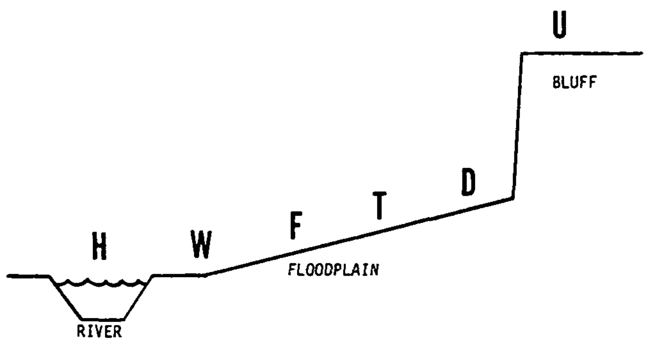

Figure 2. Generalized cross-section across Lewis and Clark Lake and Missouri River floodplain in Niobrara - Springfield areas. Not drawn to scale. Bluff tops are 250 feet (76.2 meters) above river at some locations.

In a wetlands area such as the margins of Lewis and Clark Lake, where the influx of water from upstream dams and the outflow at Gavins Point Dam are the dominant factors affecting water level, it was expected that the multidate approach might be even more effective. For example, a mosquito site which is slightly flooded in June, dry in July, and severely flooded in August would be expected to have a different signature than a site that had a fairly constant water level over the 3 months. A check of reservoir level records and precipitation records at Niobrara, Springfield and Gavins Point Dam indicated a common pattern through the summer of 1975; the reservoir level was not greatly affected by local precipitation and July was a time in which the reservoir level steadily rose to a point where the August impoundment was approximately 0.6 meters higher than in June. Hayes (1977) cited unusual discharges from upstream dams as the reason for the abnormally high reservoir level in August of 1975. Hayes also reported that mosquito larvae collections in the Niobrara-Springfield area reflected the unusual influx of water in the form of increased Culex production (permanent pool species) and decreased Aedes production (periodically-flooded species) as the summer progressed.

3. LANDSAT Classification Results

A. Niobrara. Figures 3, 4 and 5 are ground cover classification maps of the Niobrara study area based on 4 channels of reflectance data from LANDSAT overpasses made on June 25, July 13, August 9, 1975, respectively. Table 2 contains a brief description of the classes which are keyed to the symbols used on these single date classification maps. Noteworthy features on the June map include one area of wetlands north of the river, two areas of wetlands south of the river, a stand of mature mixed deciduous at the eastern border, and apparently, corn-covered islands in the river. On the July map, still water has taken over the islands and much of the wetlands area north of the river, while the two wetlands areas south of the river and the mixed deciduous stand to the east are again evident. In August, the two wetlands

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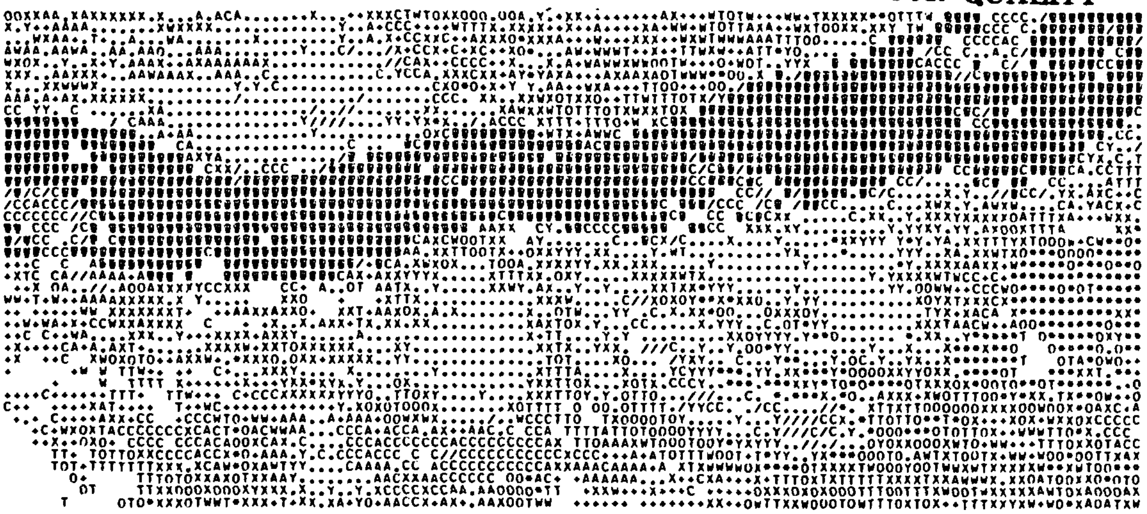

Figure 3. Niobrara ground cover, 25 June 1975.

Figure 4. Niobrara ground cover, 13 July 1975.

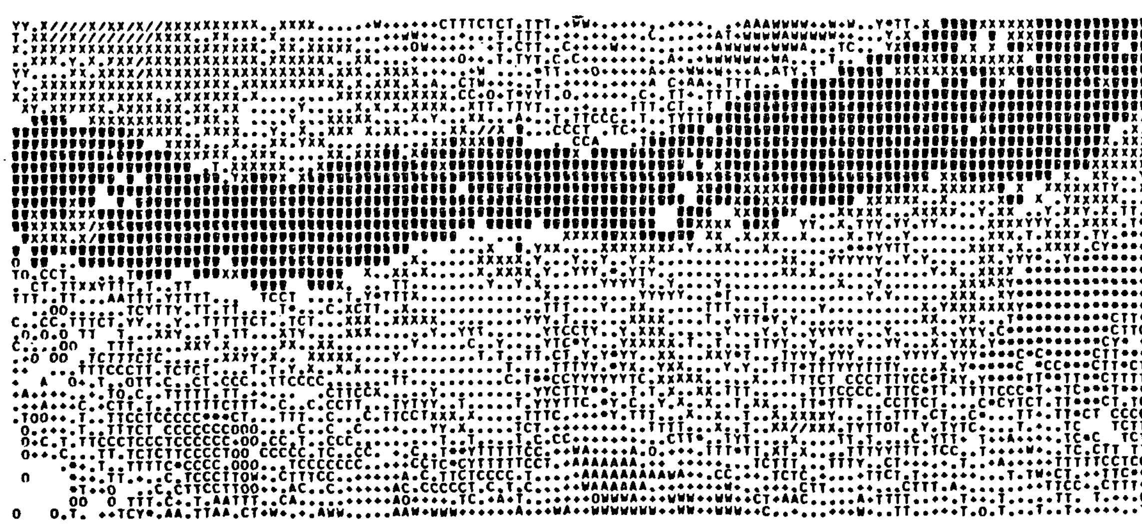

Figure 5. Niobrara ground cover, 9 August 1975.

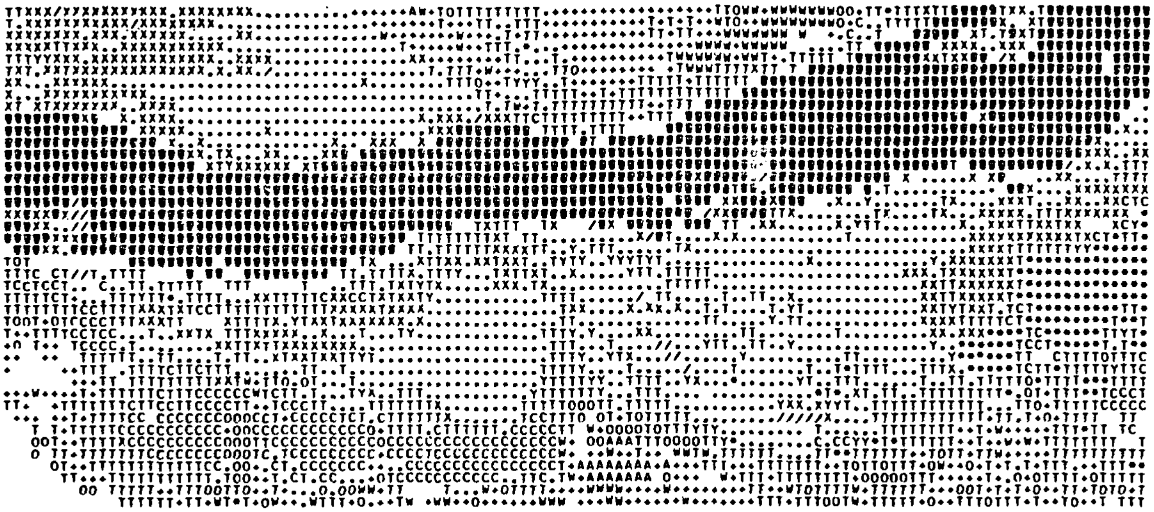

Figure 6. Niobrara ground cover, multidate classification

areas south of the river and the mixed deciduous stand are still in evidence as contiguous units, whereas the wetlands north of the river and the islands are largely classified as flooded. Many of the variations are explainable in terms of a rising reservoir level and a plant canopy expanding with time.

Figure 6 is a multidate ground cover classification map of the Niobrara study area based on 12 channels of reflectance data, four channels from each of the three dates. Very noticeably, the patchiness of the single date classifications has disappeared, and well-defined areas of river, wetlands, flooded, transitional, croplands, mixed deciduous and bluff-grass can be discerned. The 12 channel multidate classification yields a map with better definition than any of the single-date 4 channel maps.

TABLE 2. Legend of symbols used on classification maps of the Springfield and Niobrara study areas.

SYMBOL	CLASS	DESCRIPTION	
W	RVRH	River water	
/	STLH	Still water	
.	CXTW	Cattails	consolidated wetlands
.	BCTW	Cattails with bleached areas	
.	DWDW	Duckweed	
X	LXGF	Flooded, <u>Polygonum</u> and cattails	frequently flooded
X	XXCF	Flooded, corn	
T	PXXT	Transitional, <u>Polygonum</u>, ragweed and wild grasses	intermittently flooded
Y	YWLT	Young willow and cottonwood	
A	ALFD	Alfalfa	
C	QQQD	Corn	
O	OATD	Oats	
W	WHTD	Wheat and wheatgrass	
*	ZZZU	Mature mixed deciduous	
+	FLBU	Bluff grass	
		Blank areas are ground cover types different from classes above	

In Table 3, areal percentages of selected classes are compared for the June, July, August and Multidate classifications. Noteworthy features are the constancy of River Water and Bluff Grass, the increasing percentages of the Wetlands, Flooded, and Transitional classes through the single date sequence at the expense of the crops and Mixed Deciduous classes, and the averaging effect of the multidate percentages with respect to the single date sequences. The high percentage of Transitional is the one major exception to the Multidate averaging effect and can be explained in part by the large variance in reflectances for the Transitional class.

Table 3. Areal percentages of selected ground cover classes on the June, July, August and Multidate Classifications.

	June	July	August	Multidate
River Water	20.8	20.3	21.5	21.9
Still Water	1.8	9.1	.5	.6
Consolidated Wetlands	18.4	20.8	25.7	22.3
Flooded	11.3	8.0	12.6	9.1
Transitional	5.5	10.5	10.3	21.2
Corn	7.1	3.1	6.1	4.9
Oats/Alf/Wht	14.4	8.5	3.8	4.2
Mixed Decid.	5.4	6.0	4.9	3.7
Bluff Grass	6.5	6.9	6.6	7.1
Other	8.8	6.8	8.0	5.0

Table 4 is a comparison of the accuracy of the single date and the multidate classifications. Seven categories were selected from those used in the classifications and fifteen pixels from each were compared to what was actually found on the ground; the number of each category correctly classified appears in the columns for June, July, August and Multidate. Before discussing the results, certain qualifications need to be mentioned. The fifteen pixels selected were not included in the original training fields. Such a constraint, while yielding an unbiased sample in one sense, often leads to the choice of verification pixels which are not as representative of the category as they could be. Particularly with the complexly-structured wild species this can be a problem because large contiguous non-training groups of pixels are difficult to find. This also limited the classes which could be used for verification. Also, the ground truth, with the exception of the color-infrared aerial photos of August 7, 1975, was gathered in 1976, one year after the period of the LANDSAT imagery. Slight changes, particularly in the complexly-structured categories over the period of a year are a possibility. Finally, a sample size of 15 pixels does not portend great statistical rigor. Table 4, therefore, should be considered a qualified comparison of the accuracy of the single date and multidate comparison.

Table 4 indicates an overall accuracy of classification of 72% for June, 60% for July, 83% for August and 95% for multidate. Thus, August was the most accurate single date classification for the Niobrara study area and the multidate classification was 23% better than the average single date classification. In terms of utility, the results indicate that one single date classification provides an acceptable instantaneous view of ground cover classes with an accuracy as high as 83%, whereas sequential viewing of three single dates permits seasonal changes to be appreciated. The comprehensive multidate classification with an accuracy of 95% provides the best rendition of ground cover in terms of mapping categories and can be used to delineate mosquito-breeding potential in the Niobrara study area.

Table 4. Accuracy of June, July, August and Multidate classifications based on a sample of 15 non-training pixels for each selected ground cover class.

	June	July	August	Multidate
River Water	15	15	15	15
Cattails	15	9	13	15
Flooded	6	4	13	13
Transitional	8	7	7	14
Corn	12	5	10	15
Mixed Deciduous	13	14	14	14
Bluff Grass	4	7	13	14
TOTAL	73	61	85	100
% Correct	72%	60%	83%	95%

AVERAGE SINGLE DATE % CORRECT: 72%

B. Springfield. Figure 7 is the multidate classification map for the Springfield study area. Its data base also was 12 channels, four channels from each of the 3 LANDSAT overpasses selected for the summer of 1975. The ground cover symbols indicate that in this area, the wetlands occupy the northwest margin of the reservoir. Besides pointing out the contrast between the lower river and wetlands areas and the higher bluff areas which are occupied by bluff grass and crops, a distinction is made between river water and the less turbid still water.

C. Bon Homme negative study area. A classification map of the Bon Homme study area on the north margin of the wider portion of Lewis and Clark Lake (see figure 1 for relative location) is shown in Figure 8. This area is in contrast to the Springfield-Niobrara study areas with their significant regions of wetlands cover between the reservoir and the bluffs. Here the transition from reservoir to bluff occurs much more quickly than it did in the Springfield-Niobrara area because the rise in elevation from the reservoir edge is accomplished over a much shorter distance; a slope of 1% is representative of some portions of the Springfield floodplain whereas 30% slopes are typical and near-verticality can be found at the Bon Homme margins of the reservoir. The symbols on the Bon Homme map reflect the rapid transition from reservoir to bluff. Center-pivot irrigation in the form of a circular pattern and a staircase-shaped blank area due to parity errors in the original data tape are evident. Figure 8 was generated only from the four bands of the August 9 LANDSAT overpass. It was felt that in an elevated, stable, agricultural situation, a single-date classification would produce results almost comparable to a multidate classification of a wetlands area. Table 5 is the legend that explains the symbols used in the Bon Homme classification map. Compared to the Niobrara-Springfield areas, the absence of cattails, both flooded classes, still water and young willow classes generally indicates the non-wetland and dominantly upland-agricultural character of the Bon Homme study area.

4. DISCUSSION

In a general sense, the absence of wetlands cover characterizes an area as having a very low percentage of mosquito-breeding habitat sites. A comparison of figures 6, 7, and 8 indicates that the Niobrara and Springfield study areas have abundant potenital mosquito breeding sites (the · , X and T symbols stand for the consolidated wetlands, flooded and transitional categories) whereas Bon Homme has very few. In this respect the LANDSAT ground cover classification can be used as a broadbrush indicator of the mosquito breeding potential of an area.

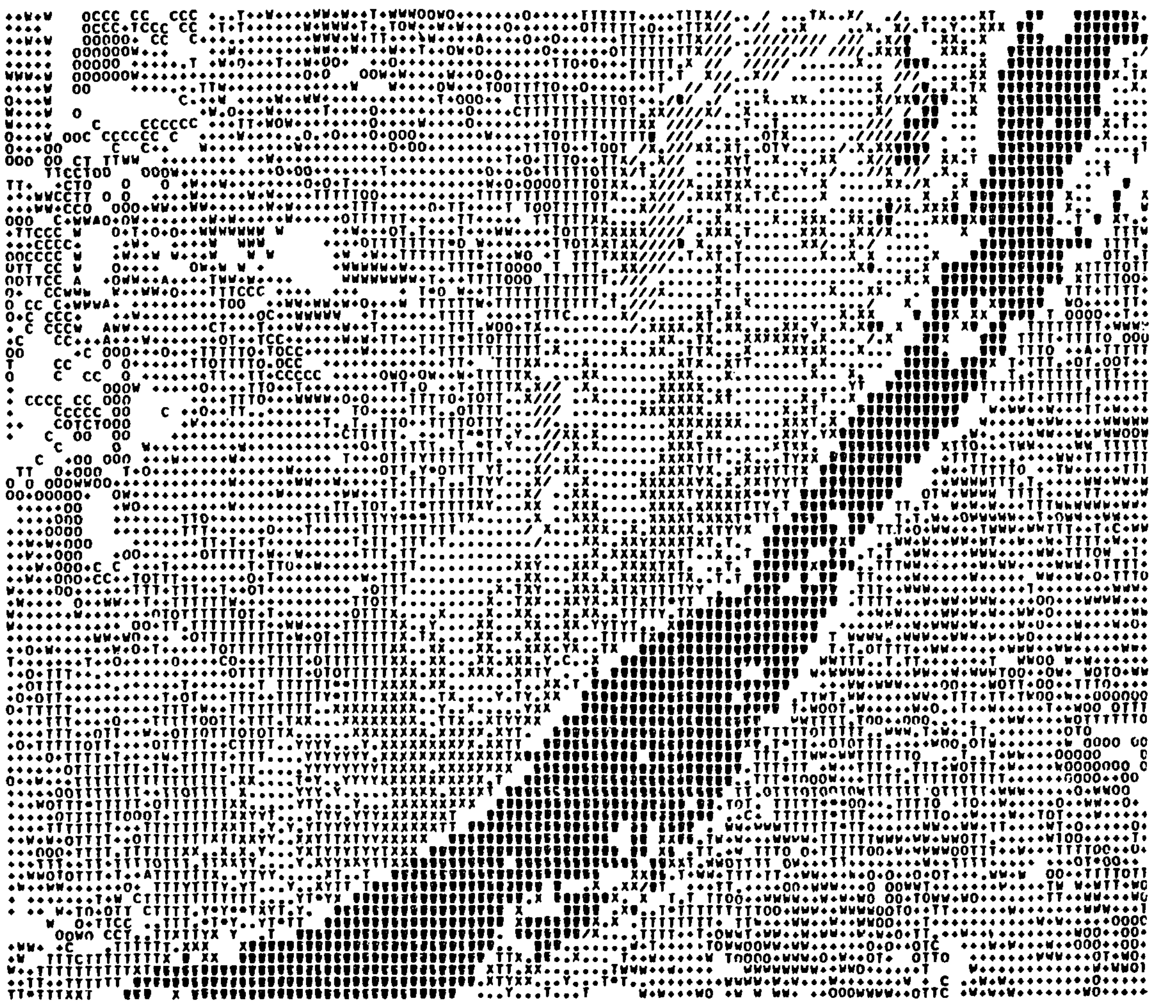

Figure 7. Springfield ground cover, multidate classification.

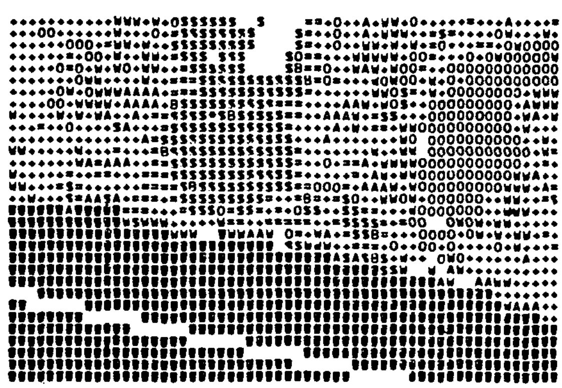

Figure 8. Bon Homme ground cover, 9 August 1975.

Table 5. Legend of symbols used on classification map of the Bon *Homme* study area.

SYMBOL	CLASS	DESCRIPTION
W	RVRH	River water
B	PMST	Patchy mixed shrubs
A	ALFD	Alfalfa
O	OATD	Oats
W	WHTD	Wheat and wheatgrass
$	ISGD	Irrigated sorghum
=	PSGD	Poorly-irrigated sorghum
+	FLBU	Bluff grass
		Blank areas are ground cover types different from classes above

It should be noted that other marginal areas of Lewis and Clark Lake are characterized by consistently higher elevations and even steeper reservoir to bluff transitions than at the Bon Homme study area. They have widespread mixed deciduous cover and almost complete absence of wetlands cover classes, except where a few larger streams, with their associated wider valley/lowlands, discharge into the reservoir. Although not shown here, such conditions could also be detected by LANDSAT-derived ground cover classification and used in a preliminary assessment of the mosquito breeding potential over a large region.

The mosquito larvae collection data from 1975 confirm the characterization of the Niobrara and Springfield areas as highly productive and Bon Homme as less productive in terms of mosquito breeding. Table 6 contains the Niobrara, Springfield and Bon Homme collection data for 1975.

Table 6. Fourth instar larvae collections during summer of 1975 at selected study areas in the margins of Lewis and Clark Lake.

	Culex tarsalis	*Aedes vexans*	TOTAL	Number of collections
Niobrara	8072	5636	13,708	6
Springfield Bottoms	2797	808	3,605	5
Bon Homme	242	21	263	2

Whereas the absence of wetlands cover generally characterizes an area as having a very low mosquito-breeding potential, it is possible within a recognized wetlands area to assign varying degrees of breeding-potential to the constituent wetlands and wetlands-marginal cover types. In the elevational model proposed in Figure 2 for the Niobrara and Springfield floodplains, the three cover types that appear to be located at the levels most conducive to *Aedes* and *Culex* larvae production are, in increasing topographic order, the consolidated wetlands (·), flooded (X), and transitional (T) categories which correspond to permanently-flooded, frequently-flooded and intermittently-flooded areas respectively. Given the 1.1 acre resolution of the present LANDSAT system and the view that each pixel classification represents the dominant tendency within the 1.1 acres, it is considered appropriate to use the qualitative terms *slight*, *moderate* and *problematic* to characterize the cover types for mosquito-breeding potential. Because *Culex* is a permanent pool breeder, we feel that the consolidated wetlands category would be problematic, the flooded category moderate, and the transitional category slight with respect to breeding potential. Because *Aedes* prefers to breed in periodically flooded areas we would describe the flooded category as problematic, the transitional category as moderate, and the consolidated wetlands category as slight. Control programs aimed at eliminating either *Aedes* or *Culex* could therefore use the ground cover classification maps (Figures 6 and 7) as guides to the location of potentially problematic breeding sites. With limited funds and the objective of eliminating both Aedes and Culex, the flooded category (X), would be the prime target.

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