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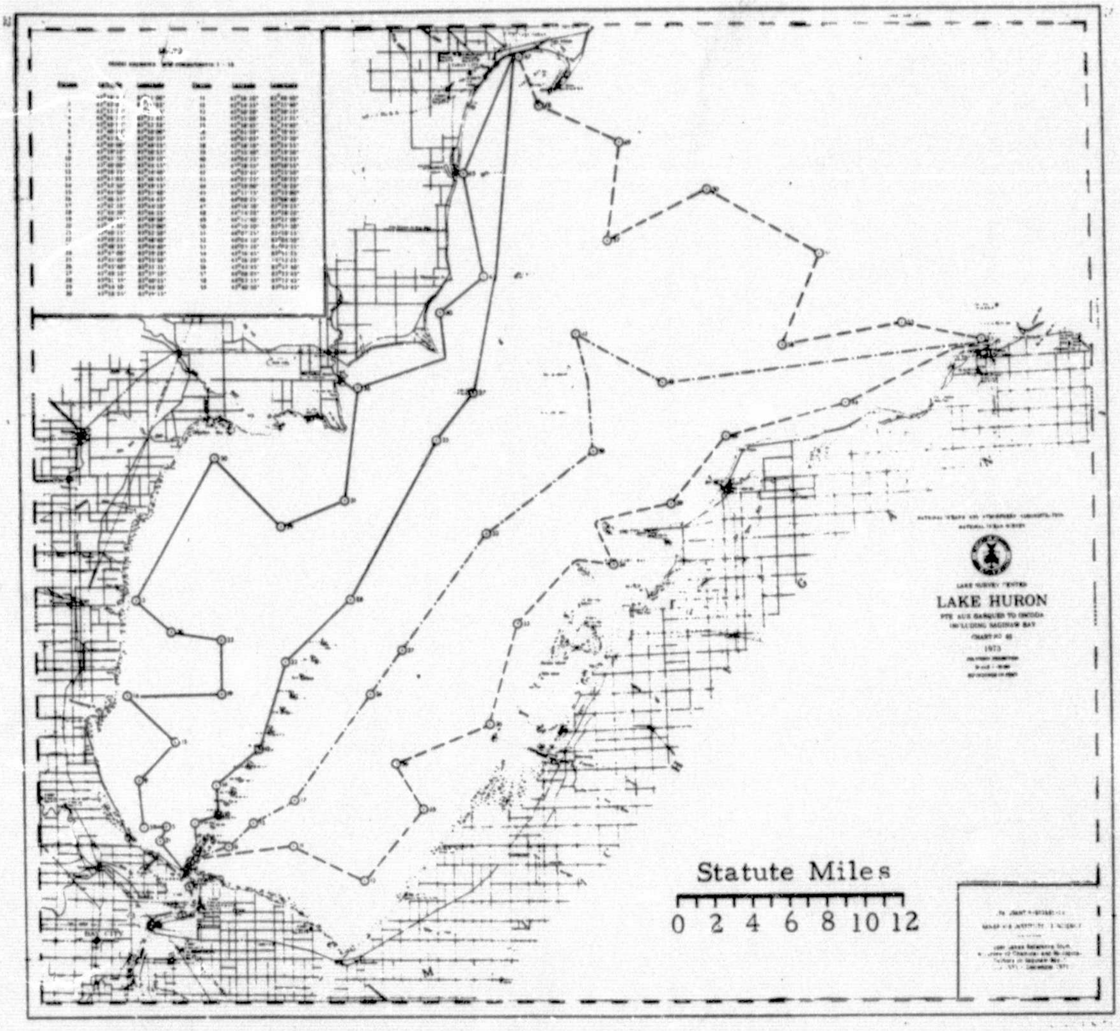
Application of LANDSAT to the Surveillance and Control of Eutrophication in Saginaw Bay



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APPLICATION OF LANDSAT TO THE SURVEILLANCE AND CONTROL OF EUTROPHICATION IN SAGINAW BAY

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16. Abstract

Computer techniques developed for mapping water quality parameters from LANDSAT data are demonstrated, using ground truth collected in an ongoing survey of water quality in Saginaw Bay (Lake Huron), Michigan sponsored by the US Environmental Protection Agency. Chemical and biological parameters were collected at 27 bay stations in concert with LANDSAT overflights. Application on stepwise linear regression to 12 of these parameters and corresponding LANDSAT measurements resulted in relationships that can be applied to map any one of the 12 water quality parameters over the entire bay. The regression correlation coefficients varied from 0.99 for total phosphorus to 0.72 for chlorophyll $\bar{a}$ corrected. Five of the water quality parameters are best correlated with LANDSAT Band 6 alone. One parameter, temperature, relates to Band 5 alone and only two bands are justified for mapping the remaining six parameters.

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Several institutions and federal agencies in the United States and Canada are conducting a comprehensive survey of water quality and circulation in Lakes Huron and Superior (the Upper Lakes Reference Study, a part of the United States/Canadian Great Lakes Water Quality Agreement of 1972). In Saginaw Bay (Lake Huron), EPA is sponsoring a 36-month modeling study of water quality. EPA's program will develop a deterministic model that will describe water quality changes within the bay and their relationship to enrichment and pollution caused by man. The resulting model will be used to evaluate various strategies to control nutrient flow into the bay. Important goals in this project are to describe, on a seasonal basis, the circulation and water quality in Saginaw Bay, to monitor inputs of nutrients from its watershed, and, ultimately, to develop and evaluate models for predicting water quality in the bay as a function of various control strategies.

A number of investigators have recently reported on the feasibility of determining various water quality parameters from LANDSAT data. Klemas (Ref. 1)* has used Secchi depth and suspended sediment measurements as correlated with Band 5 image radiance to map turbidity and circulation patterns in Delaware Bay. Yarger (Ref. 2) has processed multidate digital data for reservoirs in Kansas to study the effects of sun angle change, and the 5/4, 6/4, and 7/4 band ratios to predict suspended solids (ppm) at unsampled areas from ground truth samples. Johnson (Ref. 3) has applied the equations for predicting suspended sediment derived from stepwise regression analysis of ground truth data from Delaware Bay to image data for Chesapeake Bay, and has found reasonable agreement with ground truth measurements for Chesapeake Bay.

This LANDSAT-2 investigation has reported (Ref. 4) on the applications of a supervised computer processing technique to produce geometrically corrected color-coded imagery of Saginaw Bay where the imagery shows nine discrete categories of turbidity, as indicated by nine Secchi depths between 0.3 and 3.3 meters. This work was limited to the consideration of the Secchi depth parameter as an indicator of turbidity and the application of the supervised processing technique to correlate the Secchi depth parameter to the LANDSAT measurements. This paper considers Secchi depth and 11 additional water quality parameters and their relationships to LANDSAT measurements as established by a "stepwise linear regression" program (Ref. 5).

Mapping nine Secchi depth ranges or any other water quality parameter by a supervised technique requires: subdividing the parameter of interest into discrete categories (i.e., nine Secchi depth ranges), locating and editing LANDSAT measurements (training measurements) corresponding to each category and applying the training measurements to categorize other LANDSAT picture elements ("pixels"). This technique is well established and is by far the most efficient procedure for mapping land-cover categories, i.e., urban, grassland, bare soil, water, etc., where the spectral characteristics of the categories are very different (uncorrelated). The application of this same processing technique to mapping the amount or concentration of a continuous water quality parameter, i.e., temperature, Secchi depth, chlorophyll concentration, etc., may not be justified as better estimates of the parameter may be obtained with less effort by a simpler technique. If a continuous equation can be established between the parameter and LANDSAT, e.g., the equation of a straight line with one independent and one dependent variable, then its solution would provide many more estimates of the desired parameter than would be practical by the supervised technique, which requires a training set for each discrete value of the parameter. This paper investigates this possibility by applying a stepwise linear regression program to 12 water quality parameters (Table 1) and LANDSAT measurements (Table 1) observed on 3 June 1974 at 27 stations in Saginaw Bay.

2. TEST AREA

Saginaw Bay is a shallow extension of Lake Huron and is bounded by five counties of southeastern Michigan (Figures 1 and 2). The bay has an area of some 2,960 km^2 and a maximum length and width of 82 km and 42 km, respectively. The mean depths are 4.6 m for the inner bay and 14.6 m for the outer bay. The Saginaw River enters the bay at its extreme southwestern end

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*References, tables, and figures are located at the end of this paper.

and contributes approximately 90% of the pollutants found in the bay (Ref. 6). This river and its tributaries drain a watershed of more than 16,060 km^2, which contains four major cities and much agricultural land. Consequently, inputs of salts, nutrients, and pollutants to the bay have been increasing for many years. Levels of turbidity and algal production are consistently high, especially within the inner bay. Major declines in commercial fish yields, wildfowl populations, and esthetic values have resulted from this eutrophication. The natural movement of pollutants from the bay into southern Lake Huron may reduce water quality throughout the lower Great Lakes as well. While circulation within the bay is highly wind-dependent, the pattern is generally counterclockwise. Clear Lake Huron water enters mainly along the western shore; turbid bay water exists along the eastern shore. Significant but unknown quantities of sediment are resuspended regularly by wave action. The lower two-thirds of Saginaw Bay usually freezes over during January and February. These and other characteristics of Saginaw Bay have been documented by Freedman (Ref. 6).

3. GROUND TRUTH PROGRAM

The EPA measurement program in Saginaw Bay is creating a data bank of water quality information that will be used to develop and test models of circulation, nutrient loadings, and algal productivity. Since April 1974, surface and subsurface measurements have been obtained at the 59 bay stations shown in Figure 2, at 18-day intervals coinciding with LANDSAT overflights.

The first clear LANDSAT scene of the bay, coincident with surface measurements at the bay stations, was the 3 June 1974 scene in Figure 1. On both the day of the survey and the preceding day, water conditions such as circulation within the bay were stable, i.e., not wind-driven. The corresponding cruise tracks of the survey vessels obtaining measurements at the bay stations are shown in Figure 2. Typically, as in this 3 June mission, the western half of the bay (containing 31 stations) is sampled within a period of 3 hours before and 8 hours after a LANDSAT overflight. The remaining 28 stations are sampled on the following 2 days. LANDSAT measurements from 27 of the 31 bay stations monitored on 3 June were used in this investigation.

On-site measurements at each bay station include: temperature, pH, dissolved oxygen, conductivity, alkalinity, and water clarity. Clarity is indicated by Secchi depth and percent transmittance measurements. Variables measured in the laboratory include: soluble nutrients (nitrate-nitrite, orthophosphate, sulfate, silicate, and ammonia), organic materials (nitrogen, phosphorus, carbon, and chlorophylls), chloride and metals (sodium, potassium, calcium, magnesium, and six trace metals), and total suspended solids. Enumerations of phytoplankton and zooplankton are also made. Coordinated studies of current patterns, nutrient inputs, and bottom fauna are also underway by EPA.

4. COMPUTER PROCESSING OF LANDSAT DATA

The LANDSAT Computer-Compatible Tapes (CCTs) for this investigation were processed on the Bendix Multispectral Data Analysis System, M-DAS (Ref. 4). Three major processing steps were involved: (1) transforming the locations of the bay stations from navigation charts to LANDSAT CCT coordinates, (2) extracting the LANDSAT digital measurements from the CCTs for each of 27 bay station areas, and (3) applying stepwise regression to the water quality parameters and LANDSAT measurements derived from each bay station area.

Earth-to-LANDSAT Coordinate Transformation

Three basic steps were involved in the automatic referencing of ground coordinates to LANDSAT coordinates. The first step consisted of automatic retrieval of the latitude and longitude of carefully selected ground control points (GCPs) from a map through a digitizing process. The criteria for selecting these GCPs is that they can be easily and accurately identified on LANDSAT imagery. The second step consisted of converting the latitude and longitude of these GCPs to LANDSAT coordinates by using a theoretical transformation derived from known and assumed spacecraft parameters including: heading, scan rate, altitude, and a knowledge of earth rotation parameters. The LANDSAT coordinates and transformation matrices thus obtained are approximate, based on the use of the nominal spacecraft parameters. The approximately derived

LANDSAT coordinates and transformation are used, however, to identify the actual LANDSAT coordinates associated with the GCPs. To accomplish this, the coordinates of a GCP are input to the Bendix M-DAS. The approximate transformation computes the LANDSAT coordinates and displays the area on the TV monitor. Positional errors of the GCPs displayed to the operator are designated by a cursor to the computer, which uses the error measurement to derive an improved set of coefficients for the transformation matrix. This procedure is repeated on additional GCPs until the desired geometric accuracy is achieved. This investigation used 20 GCPs within the LANDSAT scene. The resulting bay station coordinates were transformed to LANDSAT coordinates with an accuracy of better than one picture element (pixel). A LANDSAT pixel corresponds to an area of 57 m x 79 m (0.44 hectares).

Extraction of Station Area Digital Characteristics

The M-DAS TV monitor was used to display the single pixel best corresponding to each bay station location. A cursor was then positioned, expanded, and shaped by the operator about each station site to designate a station area of 40 to 50 pixels in size. For some stations near coastal features, piers, or jetties, considerably fewer pixels were designated (Table 1). Once the station areas were designated, the M-DAS computer extracted the measurements from all pixels defined by the cursor and calculated the mean digital count in each band (Table 1). For the table shown, the digital counts from the standard LANDSAT CCT have been multiplied by two in Bands 4, 5, and 6 and by four in Band 7. The mean values of the digital counts in each LANDSAT band for each bay station were then stored in a disk file for use in the regression analysis.

Stepwise Regression Analysis

The LANDSAT measurements stored on the disk file were used in a stepwise linear regression program (Ref. 5) to investigate relationships between the LANDSAT measurements and each of 12 water quality parameters. The stepwise regression procedure first determined which single independent variable (one of the four LANDSAT bands) provided the best statistical correlation with the dependent variable (one of the water quality parameters). In successive steps, a second independent variable was added, if necessary, to improve the multiple correlation.

5. STATISTICAL RESULTS

The statistical results of the stepwise regression analyses are summarized in both tabular and graphical form at the end of the paper.

Part of the results of the regression analyses are presented in Table 2, which is best explained by reviewing the first row. If temperature in °C is considered as the dependent variable, then the best single independent variable is LANDSAT Band 5. The results for only one step of the regression are reported in this case, indicating that the correlation coefficient is not significantly improved by the addition of other bands. The regression correlation coefficient is a measure of the fit of the regression equation to the data with a maximum value of unity. The standard error of estimate has the same units as the dependent variable, in this example °C, and is the statistical standard deviation. Approximately 68% of the measurements are expected to be within one standard deviation of the mean. The estimated percent inaccuracy of the regression equation is 3.8% (standard error of estimate of 0.6759°C divided by mean temperature of 17.73°C).

The constants and coefficients for each of the 12 regression equations are shown in Table 3. For example, temperature may be predicted as follows:

$$\text{Temperature } (^{\circ}\text{C}) = 13.186 + 0.157 \text{ (Band 5 digital count)}$$

It should be pointed out that LANDSAT is not measuring temperature directly as temperature does not change the color or volume reflectance of the water, which LANDSAT measures directly. In June, however, Saginaw River water is effectively labeled by temperature as well as by turbidity and other chemical and biological factors.

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Figure 3 presents graphs for six water quality parameters that have been determined to be best predicted by only one independent variable or LANDSAT band. Each plot shows the N sample points, the regression line and equation, and the regression correlation coefficient.

Figure 4 includes six examples of the 12 possible graphs which permit a visual evaluation of the overall fit of the regression equations. The regression equations and the appropriate samples and band(s) counts shown in Table 1 were used to arrive at predicted values of each water quality parameter. These predicted values were in turn plotted versus the measured values. If the regression equation resulted in a perfect correlation, then all points would fall on the 1:1 line.

6. DISCUSSION

Perhaps the most significant finding of this investigation is that Band 6, rather than either Band 4 or 5, is the single most important band for the prediction of almost all of the water quality parameters. Both Yarger (Ref. 2) and Johnson (Ref. 3) also found this to be true in Kansas reservoirs and Chesapeake Bay, respectively. It is suggested that atmospheric haze degrades the correlations in the two visible bands, 4 and 5.

Five of the six graphs shown in Figure 3 show a fairly even scatter of points both above and below the regression line. This suggests that, for these variables, a linear regression is sufficient to predict the water quality parameter plotted. The plot of temperature versus Band 5 counts shows a systematic departure of points from the straight line. If the straight line were used to estimate temperature from Band 5 counts, a large error would be incurred for temperatures below 17°C. Thus, it appears that a curve rather than a straight line should be used for this parameter.

Figure 4 permits a somewhat improved comparison between variables. It should be noted that both temperature and Secchi depth depart from the 1:1 line in a noticeably curvilinear pattern as explained above. Furthermore, the plot for chlorophyll $\bar{a}$ (corrected) has been included as an example of the poorest correlation fit of all 12 parameters, as is also indicated in Table 2.

Although the water quality parameters investigated here have been treated individually so far, there are apparent correlations between the parameters themselves. Table 4 presents the correlation coefficients for all parameters at 59 stations in Saginaw Bay during the second quarter of 1974. Although these relationships vary seasonally, some pairs of parameters consistently are well correlated. For example, distributions of the four major metals with chloride are highly correlated throughout the year. Thus, with a table such as this one, it may be possible to isolate the subset of water quality parameters whose distribution may be mapped or modeled as a unit.

The significance to water quality of each parameter measured in Saginaw Bay varies with the location and season. In general terms, however, the following applies to the June 1974 data. Temperature (also chemical and biological) gradients in the bay during the spring reflect the mixing of eutrophic Saginaw River water with oligotophic (and cooler) Lake Huron water. Thus, temperature may be used coincidentally to discriminate between waters of markedly different quality. Secchi depth estimates are used to approximate water transparency as affected by suspended particles and solutes. Chlorophyll $\bar{a}$ is also an approximate indicator of living algal biomass. Conductivity, which varies directly with the concentration of dissolved ions, is generally high in eutrophic or polluted waters. Similarly, chloride is used here as a conservative tracer of enriched Saginaw River water. The major metals (sodium, potassium, calcium, magnesium) are also important as principal ions derived partly from urban and agricultural pollution. Finally, the organic forms of phosphorus and nitrogen (TP, TDP, and KN) are major nutrients, derived largely from pollution, that stimulate algal productivity in Saginaw Bay.

As this investigation proceeds, it will seek to: (1) determine if data on suspended solids, which were lacking in 1974 but have been collected since April 1975, provide a better basis than Secchi depth for categorizing water masses using LANDSAT data, (2) determine if the use of a nonlinear regression analysis improves the correlations, (3) determine if the correlations can be improved by the use of one or more of the six nonredundant band ratios (such as 6/4, or 7/6, etc.) as the independent variables in the stepwise regression analysis, rather than single bands, so as to correct for local gradients in atmospheric haze, (4) analyze data from the remaining stations taken during the 2 days following the overpass to see how well they correlate, (5) determine the feasibility of using the regression equations as a means to produce color-categorized maps of the bay where each map would show a different water quality parameter and the color would denote its concentration or level, and (6) to determine if the regression equations can be applied to analyze LANDSAT data acquired at a different date to predict water quality parameters that agree with those obtained by boat on the same day.

7. CONCLUSIONS

LANDSAT digital data and ground truth measurements for Saginaw Bay (Lake Huron), Michigan, for 3 June 1974 can be correlated by stepwise linear regression technique and the resulting equations used to estimate "invisible" water quality parameters in nonsampled areas. The correlation of these parameters with each other indicates that the transport of Saginaw River water can now be traced by a number of water quality features, one or more of which are directly detected by LANDSAT. Five of the 12 water quality parameters studied are best correlated with LANDSAT Band 6 measurements alone. One parameter (temperature) relates to Band 5 alone and the remaining six may be predicted with varying degrees of accuracy from a combination of two bands (first Band 6 and generally Band 4 second).

Water quality parameters mapped from the linear regression equations should indicate which water quality parameter(s) is most reliable as a tracer to identify Saginaw River water as it circulates throughout the bay and is diluted by Lake Huron water. The resulting regression equations can be used to predict the levels of water quality parameters throughout the bay, given the appropriate LANDSAT measurements. These parameters need not be directly detectable by LANDSAT, provided their distribution is correlated with some water characteristic that is detectable. The predicted values for each water quality parameter could be displayed on a TV monitor and color-coded and mapped onto film. Thus, LANDSAT monitoring, as an adjunct to conventional point-sampling, would provide an economical basis for extrapolating water quality parameters from point samples to unsampled areas and provide a synoptic view of water mass boundaries that no amount of point sampling could provide.

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TABLE 1. WATER QUALITY AND LANDSAT DATA. For Saginaw Bay, 03 June 1974, Cruise 8. Measurements Made at Water Depth of One Meter.

On-Site Measurements					Laboratory Analysis								Computer Processing of CCTs				
						Major Metals				Nutrients			LANDSAT Digital Data				
													Mean Reflectance for Station Area				
Station Number	Temperature °C	Secchi Depth m	Conductivity Micromhos	Chloride mg/l	Chlorophyll ā (Corrected) µg/l	Sodium, Na mg/l	Potassium, K mg/l	Magnesium, Mg mg/l	Calcium, Ca mg/l	Total Dissolved Phosphorus P mg/l	Total Kjeldahl Nitrogen mg/l	Total Phosphorus P mg/1	Bands: 4 Max: 254	5 254	6 254	7 252	Number of Pixels to Station Area
41	18.8	0.4	764.	950.	55.50					0.043	1.00	0.186	46.8	32.1	21.9	7.1	17
9	19.0	0.3	827.	1070.	38.20								46.5	32.5	19.9	4.1	27
6	18.7	0.4	828.		27.90	42.	5.2	19.	104.	0.070	0.52	0.145	46.1	32.3	19.6	4.3	81
7	17.0	0.6	425.	364.	50.80								43.1	25.8	15.3	2.7	90
10	18.0	0.7	381.	287.	53.90	12.	2.1	13.	55.				42.8	25.3	15.0	3.6	67
14	18.4	0.8	309.	195.	29.00								45.1	27.4	14.0	2.9	63
18	17.7	1.3	293.	170.	9.46	9.	1.5	10.	45.	0.006	0.19	0.029	47.0	26.3	12.8	2.7	56
23	17.0	1.7	286.	172.	5.93								44.1	23.4	11.9	3.1	64
28	15.4	1.7	329.	194.	5.85								43.6	23.7	11.6	3.0	64
35	15.8	2.2	283.	147.	5.13					0.004	0.20	0.018	44.8	23.8	13.4	4.7	80
55	19.2	0.3	659.	759.	22.80	33.	4.0	19.	93.	0.071	0.73	0.195	53.7	41.3	27.3	8.3	12
54	19.0	0.3	736.	882.	26.80					0.071	0.94	0.213	53.0	40.7	27.2	9.0	8
1	19.8	0.3	772.	1118.	36.20	41.	5.3	19.	101.	0.054	0.81	0.200	50.2	38.0	23.8	6.8	10
21	17.8	0.5	466.	465.	69.30								44.9	29.5	18.5	5.0	72
5	18.0	0.6	492.	485.	59.70	20.	2.9	16.	70.				43.6	27.4	17.1	4.7	81
59	18.0	0.8	359.	265.	36.60	12.	2.1	12.	52.				46.8	29.5	16.7	3.9	64
2	17.5	1.0	320.	200.	17.00	10.	1.7	10.	44.	0.010	0.27	0.029	47.0	27.2	14.2	3.2	49
15	17.0	1.3	323.	160.	6.17	7.	1.2	9.	39.				46.7	25.8	13.0	2.8	42
16	18.2	0.8	315.	190.	12.10	9.	1.7	10.	46.				56.9	37.2	17.5	4.2	49
19	16.2	1.7	303.	157.	2.73								45.9	25.0	12.5	2.8	72
22	16.3	1.4	283.	163.	4.41								44.1	23.1	11.3	2.3	42
20	17.5	1.5	268.	159.	5.93					0.004	0.24	0.016	45.8	23.5	12.4	2.4	49
3	19.2	0.6	330.	207.	3.74	11.	1.8	11.	50.				62.8	42.0	18.6	4.3	56
30	18.7	1.2	285.	153.	6.74	8.	1.5	10.	42.				52.5	29.1	15.8	5.4	64
29	16.6	1.8	269.	140.	5.69					0.010	0.23	0.014	43.5	22.7	11.3	2.2	42
31	16.2	2.2	274.	137.	3.93								43.5	22.2	11.5	2.2	49
36	17.8	1.8	262.	124.	6.17								48.2	27.1	16.3	5.7	64
Mean	17.73	1.04	423.7	358.2	22.507	17.83	2.58	13.17	61.75	0.0343	0.513	0.1045	47.37	29.03	16.31	4.20	
Standard Dev.	1.15	0.62	196.0	316.6	20.651	13.15	1.45	3.97	24.12	0.0303	0.328	0.0896	4.73	6.03	4.61	1.85	
No. of Samples	27	27	27	26	27	12	12	12	12	10	10	10	27	27	27	27	

TABLE 2. RESULTS OF STEPWISE REGRESSION ANALYSIS

Dependent Variable	Units	Regression Step	Independent Variable Added (LANDSAT Band)	Regression Variables (LANDSAT Bands)	Standard Error of Estimate	Percent Inaccuracy	Regression Correlation Coefficient
Temperature	°C	1	5	5	0.6759	3.8	0.819
Secchi Depth	m	1	6	6	0.3839	36.9	0.791
		2	7	6, 7	0.2890	27.7	0.892
Conductivity	Micromhos	1	6	6	115.130	27.2	0.817
Chloride	mg/l	1	6	6	180.578	50.4	0.829
Chlorophyll ā, (Corrected)	μg/l	1	6	6	18.715	83.2	0.459
		2	4	6, 4	14.905	66.2	0.721
Sodium	mg/l	1	6	6	8.5521	48.0	0.785
Potassium	mg/l	1	6	6	0.9696	37.6	0.772
		2	4	6, 4	0.7737	30.0	0.876
Magnesium	mg/l	1	6	6	2.4170	18.4	0.815
		2	4	6, 4	1.4331	10.9	0.945
Calcium	mg/l	1	6	6	14.9092	24.1	0.808
		2	4	6, 4	11.0980	18.0	0.909
Total Dissolved Phosphorus	mg/l	1	6	6	0.0121	35.3	0.926
Total Kjeldahl Nitrogen	mg/l	1	6	6	0.1429	27.9	0.912
Total Phosphorus	mg/l	1	6	6	0.0225	21.5	0.972
		2	4	6, 4	0.0155	14.8	0.988

TABLE 3. CONSTANTS AND COEFFICIENTS FOR REGRESSION EQUATIONS

Dependent Variable	Units	Constant	LANDSAT Coefficients			
			Band 4	Band 5	Band 6	Band 7
Temperature	°C	13.186		0.157		
Secchi Depth	m	3.370			-0.230	0.339
Conductivity	Micromhos	-143.269			34.762	
Chloride	mg/l	-555.378			56.450	
Chlorophyll	μg/l	99.388	-2.873		3.631	
Sodium	mg/l	-24.324			2.393	
Potassium	mg/l	2.534	-0.111		0.315	
Magnesium	mg/l	14.240	-0.350		0.925	
Calcium	mg/l	57.658	-1.847		5.439	
Total Dissolved Phosphorus	mg/l	-0.0472			0.0044	
Total Kjeldahl Nitrogen	mg/l	-0.358			0.047	
Total Phosphorus	mg/l	0.246	-0.010		0.019	

TABLE 4. CORRELATION COEFFICIENT MATRIX OF WATER QUALITY PARAMETERS FOR SAGINAW BAY, APRIL 1 - JUNE 30, 1974 (REF. 7)

Temperature (T)	1.000											
Secchi Depth (SD)	-.179	1.000										
Conductivity (CON)	.304	-.470	1.000									
Chloride (Cl)	.251	-.465	.958	1.000								
Chlorophyll ā (CH-ā)	.223	-.446	.733	.784	1.000							
Sodium (Na)	.324	-.468	.962	.973	.689	1.000						
Potassium (K)	.301	-.500	.960	.940	.752	.933	1.000					
Magnesium (Mg)	.372	-.586	.921	.920	.760	.879	.917	1.000				
Calcium (Ca)	.326	-.534	.942	.927	.751	.900	.940	.916	1.000			
Total Dissolved Phosphorus (TDP)	.214	-.158	.558	.077	.206	.663	.593	.509	.611	1.000		
Total Kjeldahl Nitrogen (TKN)	.285	-.484	.604	.617	.680	.683	.745	.736	.725	.275	1.000	
Total Phosphorus (TP)	.289	-.506	.609	.523	.531	.617	.649	.677	.689	.515	.485	1.000
	T	SD	CON	Cl	CH-ā	Na	K	Mg	Ca	TDP	TKN	TP

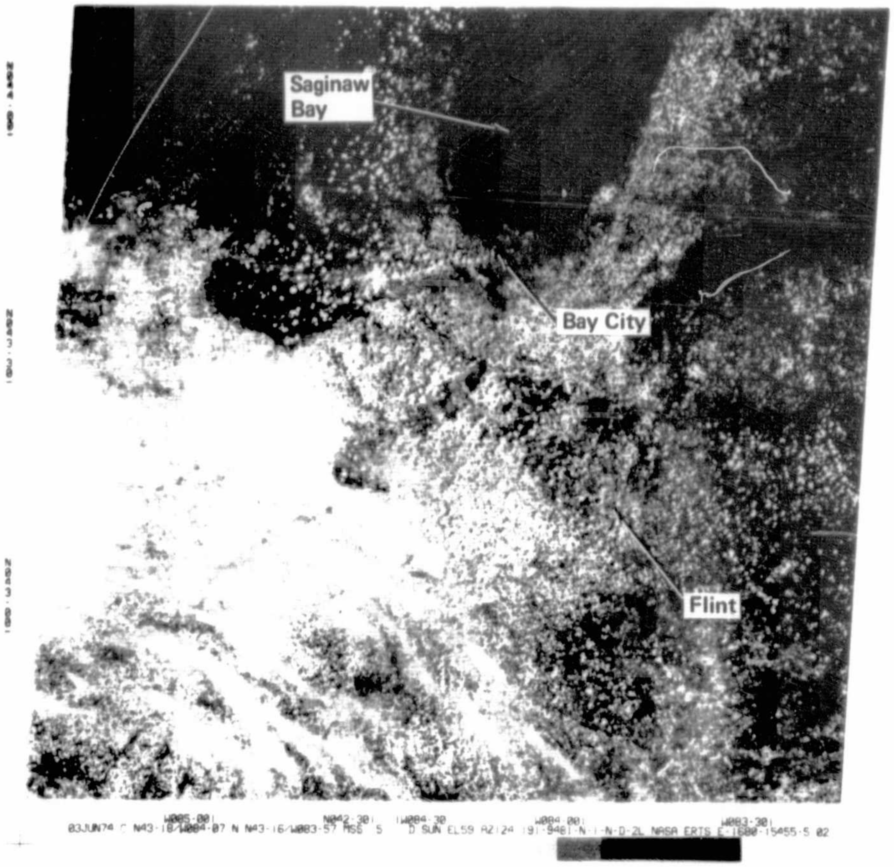

Figure 1.
LANDSAT Image (1680-15455, Band 5) of Lower Saginaw Bay Area for June 3, 1974

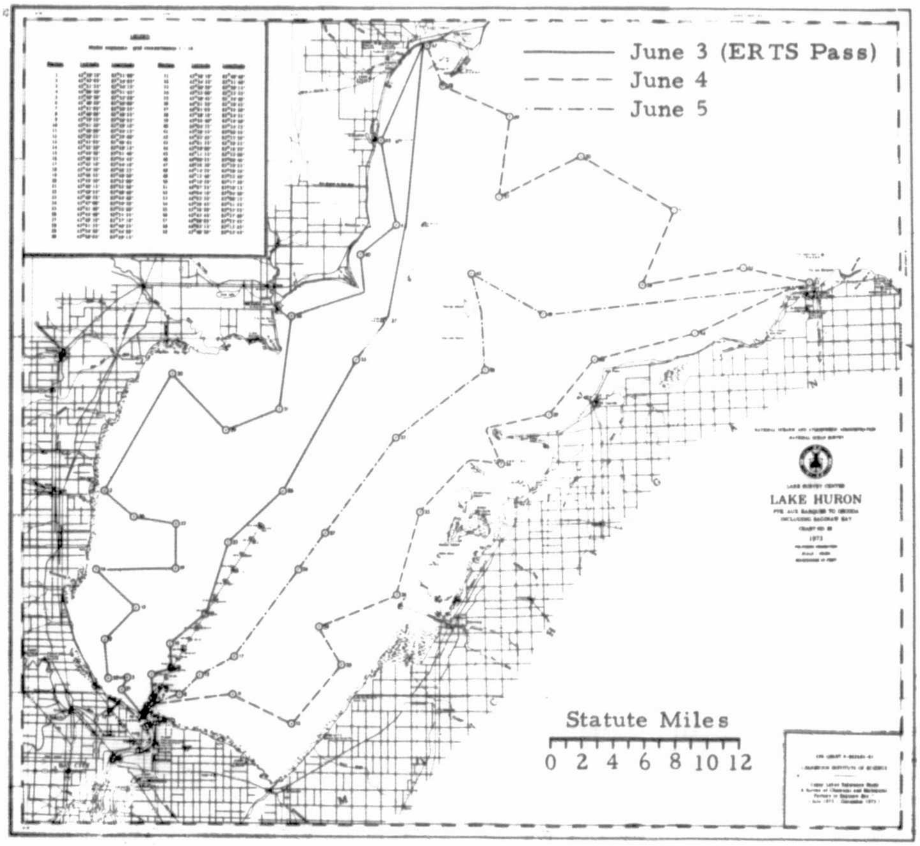

Figure 2.
Map of Saginaw Bay with Location of the 59 Bay Stations Denoted by ☉ .

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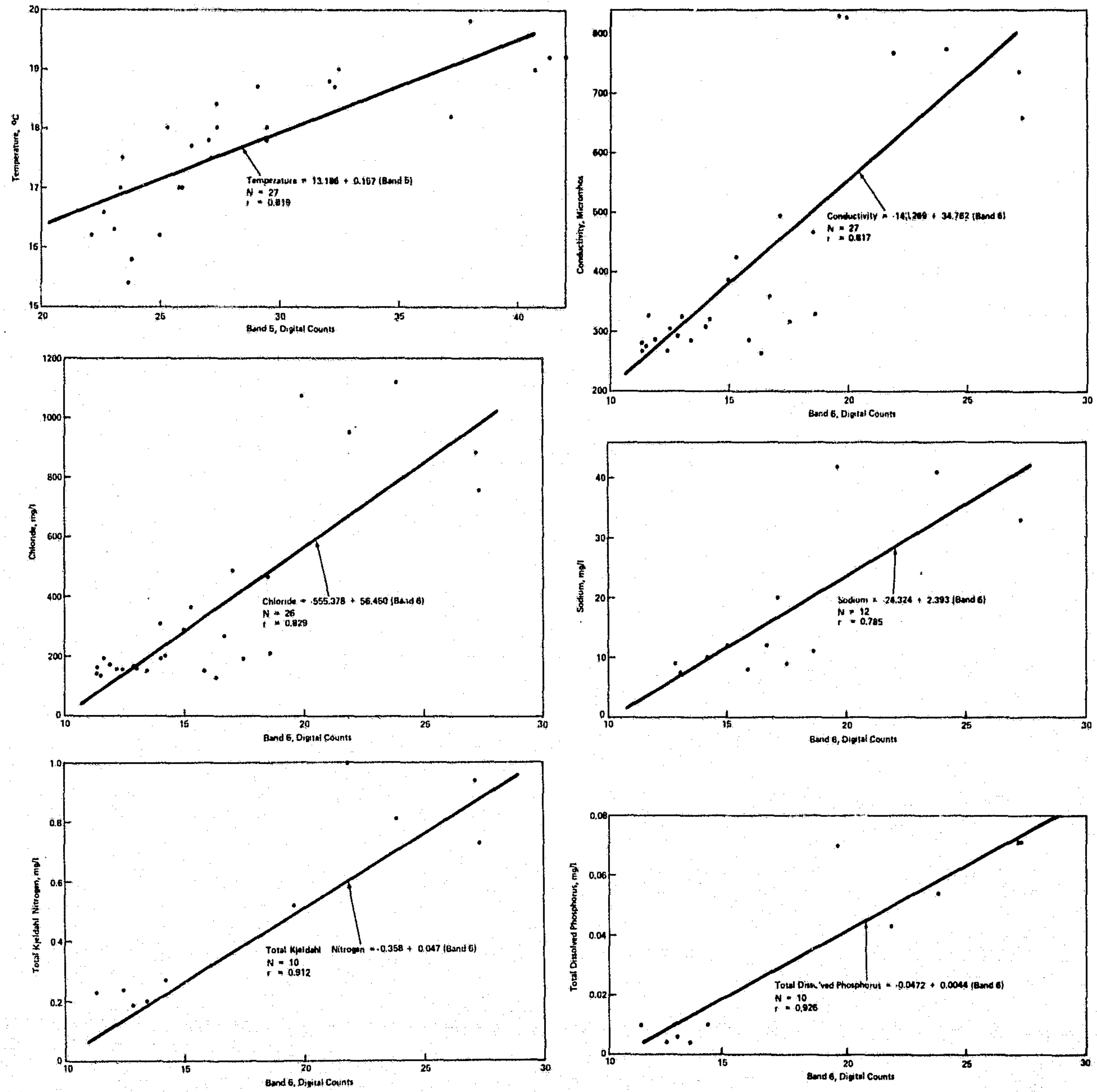

Figure 3. Water Quality Parameter Versus LANDSAT Measurements with Regression Line for Most Significant Single LANDSAT Band.

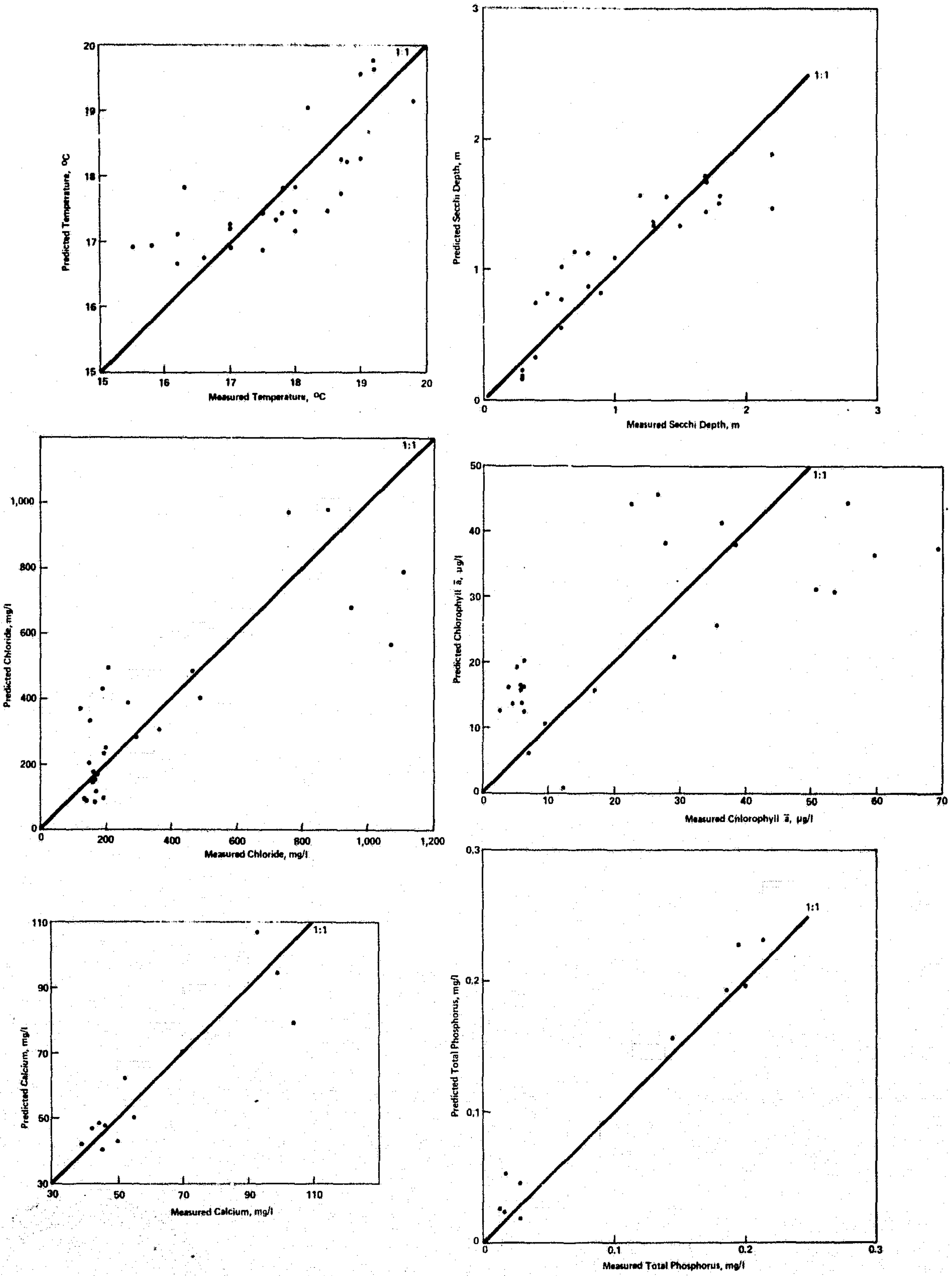

Figure 4. Predicted Versus Measured Values of Water Quality Parameters.