QUANTITATIVE WATER QUALITY WITH ERTS-1

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1.0   ABSTRACT

Analyses of ERTS-1 MSS computer compatible tapes of reservoir scenes in Kansas along with ground truth show that MSS bands and band ratios can be used for reliable prediction of suspended loads up to at least 900 ppm.

The major reservoirs in Kansas, as well as in other Great Plains states, are playing increasingly important roles in flood control, recreation, agriculture, and urban water supply. Satellite imagery is proving useful for acquiring timely low cost water quality data required for optimum management of these fresh water resources.

2.0   INTRODUCTION

The dominant limnological feature of the Great Plains today takes the form of reservoirs constructed by the U.S. Army Corps of Engineers and the U.S. Bureau of Reclamation. The primary influence on the reservoir ecosystem is the suspended material and chemicals carried in by streams and rivers. The authors are studying ERTS images of Kansas reservoirs to determine the feasibility of monitoring these water quality indicators by satellite. The reservoirs throughout the state (Figure 1) which should be representative of most Great Plains reservoirs, are located in a variety of physiographic regions such as the glaciated region in the northeast, the valleys and scarps in the southeast, the dissected plateau and alluvial plains areas in central Kansas, and the high planes in the west.

Two reservoirs, Perry and Tuttle Creek, have been singled out for close study. Approximately ten water samples from each reservoir are collected during each cloud-free ERTS overpass and analyzed for concentrations of inorganic suspended and dissolved solids, organic suspended and dissolved solids, chlorophyll, potassium, phosphate, and nitrate ions. In addition, secchi disc and temperature measurements are taken at each sampling station. The two reservoirs are distinct in terms of adjacent outcropping rocks and land use. Perry drains

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a recently glaciated region in the cornbelt of eastern Kansas.
Tuttle Creek drains the Flint Hills area to the west which is
outcropping Cretaceous and Permian rock. The dominant land
use is seasonal grazing and small grains. A later phase of
this project will be to test any predictive relations derived
from Perry and Tuttle Creek on other reservoirs in Kansas.

Kansas reservoirs are typically shallow and thus are susceptible
to mixing by strong winds which are a characteristic climatic
feature of this region. Wind generated currents are of suf-
ficently high velocity to maintain a sizable fraction of the
silts and clays in suspension and the result is turbid water
(mean light extinction coefficient $\sim$ 2.5 meters^{-1}). Accord-
ingly, reflected energy detected by ERTS is primarily influ-
enced by the suspended load (the predominant fraction of which
is inorganic material).

Figure 2 summarizes imagery and ground truth acquisitions for
Perry and Tuttle Creek reservoirs during the first 25 ERTS
passes over the state of Kansas, which covers the period July
25, 1972 to Oct. 2, 1973.

Water samples were collected for 16 of the 23 cloud free re-
servoir passes. Conditions such as ice cover, high wind and
mechanical failure prevented sample collection for the re-
maining 7 cloud free passes. This report is based primarily
on the analysis of computer compatible tapes (CCT's) from 11
reservoir passes with ground truth which includes sun angles
above the horizon of 25° to 62° (Figure 3). Qualitative analy-
ses of ERTS-1 9.5" positive transparencies appear in earlier
presentations (Yarger, 1972 and 1973).

3.0   Sun Angle Effects

The multispectral scanner (MSS) in ERTS records light reflected
from a scene illuminated by an admixture of sunlight and sky-
light (Figure 4). On relatively clear days the spectral shape
of the illumination remains fairly constant throughout the year.
However, the intensity, angle of incidence, and path length
through the atmosphere depend on sun angle (angle above horizon).
The reflectance levels from the concrete dam at Tuttle Creek
Reservoir, a target with constant spectral reflectance, demonstrate
a strong sun angle dependence in all MSS bands (Figure 5). As
has been suggested by Vincent (1972), the sun angle dependence
is suppressed by plotting band ratios instead of absolute levels
(Figure 6). The three other possible ratios, not plotted in
figure 6, also show a flat response to change in sun angle.
Ratioing essentially removes the effect of unequal illuminating
intensities caused by the continuously changing sun angle from
one ERTS pass to the next. Since the ratio curves for the dam
are flat, the angle of incidence and atmospheric scattering of

reflected light are not important factors, at least for a concrete target.

Water reflectance levels do not exhibit as strong a dependence on sun angle, but there is a significant measureable effect (see Figure 7 for band 5 example). As for concrete, the absolute, reflectance levels for water decrease with lower sun angle. In addition, the correlation (or slope) between reflectance level and suspended solids, in the range 0-90 ppm, appears to depend on sun angle. On the other hand, the magnitudes of MSS5/MSS4 ratios are indistinguishable for the three different sun angle passes (Figure 8). The slopes (ratio vs. suspended solids) for the two low sun angle passes remain fairly flat. A dark object subtraction on each band before ratioing, as suggested by Vincent (1972), does not significantly change the slopes of the three passes. Dark object subtraction, which is the absolute level detected by ERTS minus level of darkest object in scene, should suppress atmospheric scattering effects present in the ratios. These results indicate that the slope dependence on sun angle is probably not due to atmospheric scattering. It is perhaps due to water column reflectance dependence on illuminator angle of incidence.

There were no obvious anomalous conditions during the low sun angle passes such as high wind or chemical concentration. Lower temperatures should not significantly effect water volume reflectance (Scherz, 1971). Reflectance levels from the 8 passes with sun angle $\geq 45°$ exhibit much weaker dependence on sun angle, but ratioing neverless improves correlation with suspended load, particularly for bands 4 and 5. The 3 passes with sun angle $\leq 40°$ exhibit lower correlation with suspended load, but the suspended load range 20 to 60 ppm is small compared to the range 0 to 900 ppm for all the data. More points at higher suspended load and low sun angle are needed to statistically confirm a band ratio-suspended solids correlation dependence on sun angle. For the remaining discussion it is assumed that, after ratioing, sun angle dependence is relatively unimportant.

4.0   CCT Correlations with Ground Truth

Digital levels for each water sample were extracted from the CCT by locating the sample station coordinates on a CCT generated gray level map, then averaging 9 pixels centered around the coordinate which corresponds to a 240 x 240 meter square area on the water surface.

Band 4 shows no correlation beyond ~50 ppm and is useful only for relatively clear water (Figure 9). This green band penetrates the water column more than the other bands (Figure 4), but as a consequence encounters a large amount of scattering material which

produces saturation or maximum scattering at levels ⪆ 50 ppm. Band 5 is correlated with somewhat higher turbidites (⪅ 80 ppm) but its response to suspended load is quite similar to band 4 (Figure 10). Band 5 ratioed with band 4 (Figure 11) improves suspended load correlation and is roughly linear in the range of 0 to 80 ppm with RMS residual of 12 ppm (Figure 12). All regression analysis in this report was done with horizontal axis as the dependent variable and vertical axis as the independent variable.

Band 6 and the ratio band 6/band 4 display good correlation with suspended load over the entire range of 0 to 900 ppm (Figure 13 and 14). A smoothly varying polynomial fit yields an RMS residual of 31 ppm. A similar fit (not shown) to the non-ratioed curve in figure 13 yields an RMS residual of 48 ppm, so that a significantly better fit was achieved by ratioing. As is the MSS5/MSS4 ratio, the MSS6/ MSS4 is linearly related to suspended solids in the region ≤ 100 ppm. The response of band 7 (not shown) and band 7/band 4 (Figure 16) to suspended load is somewhat weaker than the other bands but is definitely correlated with accuracy level ~50 ppm.

Figure 17 is an example of a suspended solids contour map of Tuttle Creek Reservoir (August 14,1972) which was produced using a correlation curve between band 5 and suspended solids. The curve (not shown) was derived from four high sun angle passes which yielded an RMS residual of 5 ppm.

Band ratio correlations with secchi depth (or maximum light penetration depth) are shown in figures 18, 19, and 20. The MSS5/MSS4 ratio is able to predict secchi depth (or water clarity) to within + 20 cm. to at least a 1 meter depth, which is the limit of this Investigation. The ratios MSS6/MSS4 and MSS7/MSS4 yield reliable results for the more turbid water conditions corresponding to secchi depth in the range 0 to 40 cm and 0 to 20 cm respectively.

A study of ratio curves for MSS6/MSS5, MSS7/MSS5, and MSS7/MSS6 (not shown) indicates that these ratios are not very useful for correlation with suspended load or secchi depth.

It appears that gray levels obtained from electronic slicing of 9.5" black and white ERTS images will yield similar quantitative correlation with suspended load with nearly the same accuracy. This part of the investigation is still underway.

Also underway is an attempt to look for any slight correlations with other water quality parameters such as chlorophyll and the algal nutrients. So far MSS5/MSS4 ratios show no obvious correlation with chlorophyll concentrations up to 10 μ g/liter.

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5.0   Conclusions

and MSS7/MSS4

Inorganic suspended load is the dominant influence on reservoir reflection levels. MSS band ratios derived from CCT's can be used for reliable prediction of suspended load up to 900 ppm during at least the high sun angle warmer months and perhaps the entire year (see discussion on sun angle). The ratio MSS5/MSS4 is useful in the range 0 to 80 ppm with accuracy on the order of 10 ppm. The ratios MSS6/MSS4 are useful from 0 up to at least 900 ppm, which is the limit of this investigation, with accuracies of 30 ppm and 50 ppm respectively.

It is obvious that MSS band correlation with other water quality parameters such as chlorophyll and the algal nutrients will be slight if detectable at all. This part of the investigation is still underway.

References

1. Vincent, Robert K., "An ERTS Multispectral Scanner Experiment for Mapping Iron Compounds": Proceedings of the Eighth International Symposium on Remote Sensing of Environment, Ann Arbor, Michigan, Oct. 2-6, 1972, pp. 1239-1243.

2. Scherz, James P., "Monitoring Water Pollution by Remote Sensing": Journal of the Surveying and Mapping Division, ASCE, vol. 97, no. SU2, Proc. Paper 8550, Nov. 1971, pp. 307-320.

3. Yarger, H.L., et.al., "ERTS-1 Study of Reservoirs in Kansas": Proceedings of the Eighth International Symposium on Remote Sensing of Environment, Ann Arbor, Michigan, Oct. 2-6, 1972, pp. 1477-1490.

4. Yarger, Harold L. et., al., "Water Turbidity Detection Using ERTS-1 Imagery": Symposium on Significant Results Obtained from the Earth Resources Technology Satellite-1, Goddard Space Flight Center, March 5-9, 1973, pp. 651-658.

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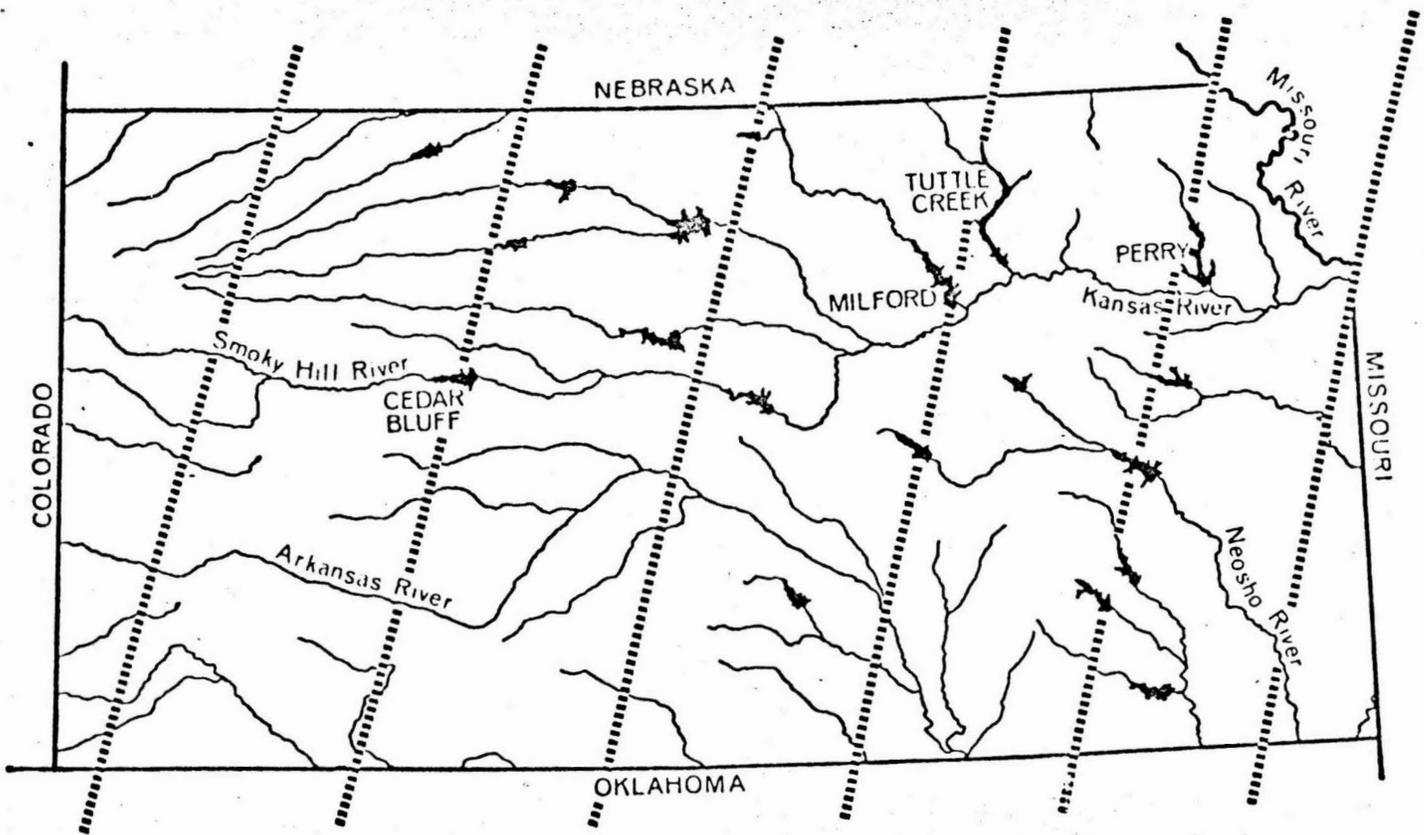
Figure 1. Reservoirs in Kansas

CATEGORY	PASSES	%
TOTAL RESERVOIR PASSES	50	100
CLOUD FREE PASSES	23	46
CLOUD FREE PASSES WITH GROUND TRUTH	16	32
CLOUD FREE PASSES WITH GROUND TRUTH AND IMAGERY	15	30
CLOUD FREE PASSES WITH GROUND TRUTH AND CCT'S	11	22

FIGURE 2. DATA ACQUISITION SUMMARY.
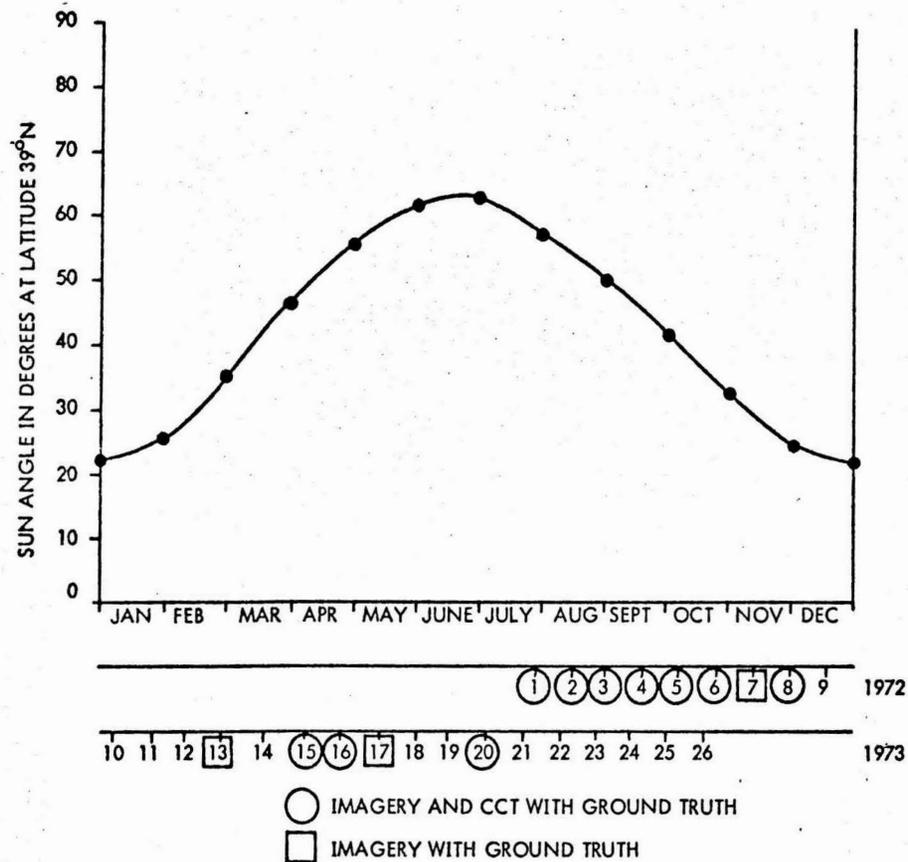
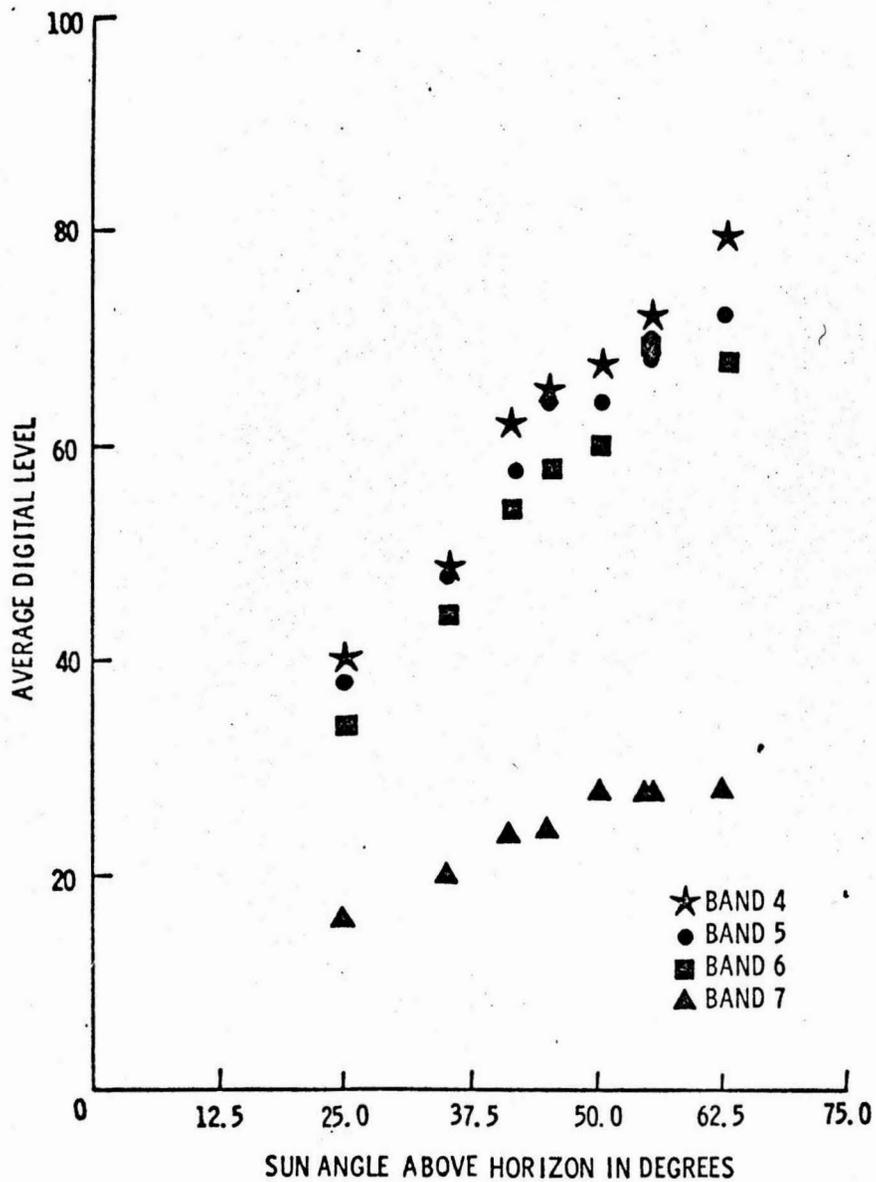FIGURE 3. DATA ACQUISITION vs SUN ANGLE.
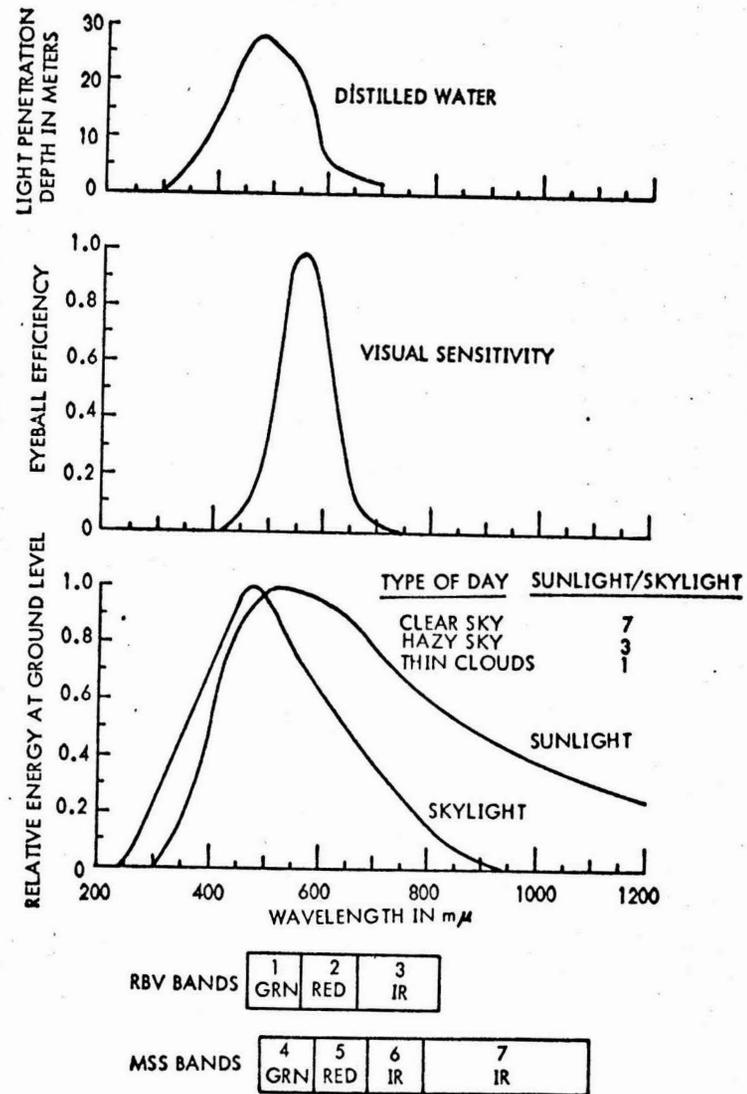
FIGURE 4. RADIANCE vs WAVELENGTH.

FIGURE 5. MSS DIGITAL LEVELS FROM CCT VS. SUN ANGLE
FOR TUTTLE CREEK CONCRETE DAM.
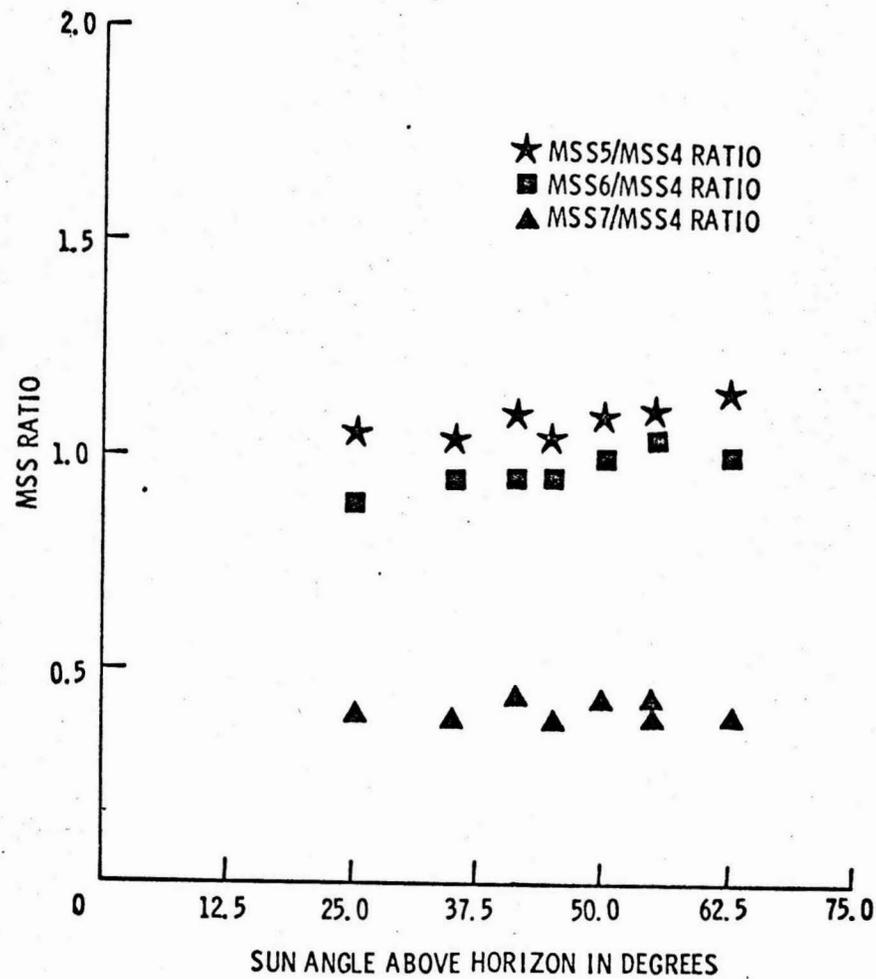
FIGURE 6. MSS BAND RATIOS FROM CCT VS. SUN ANGLE
FOR TUTTLE CREEK CONCRETE DAM.
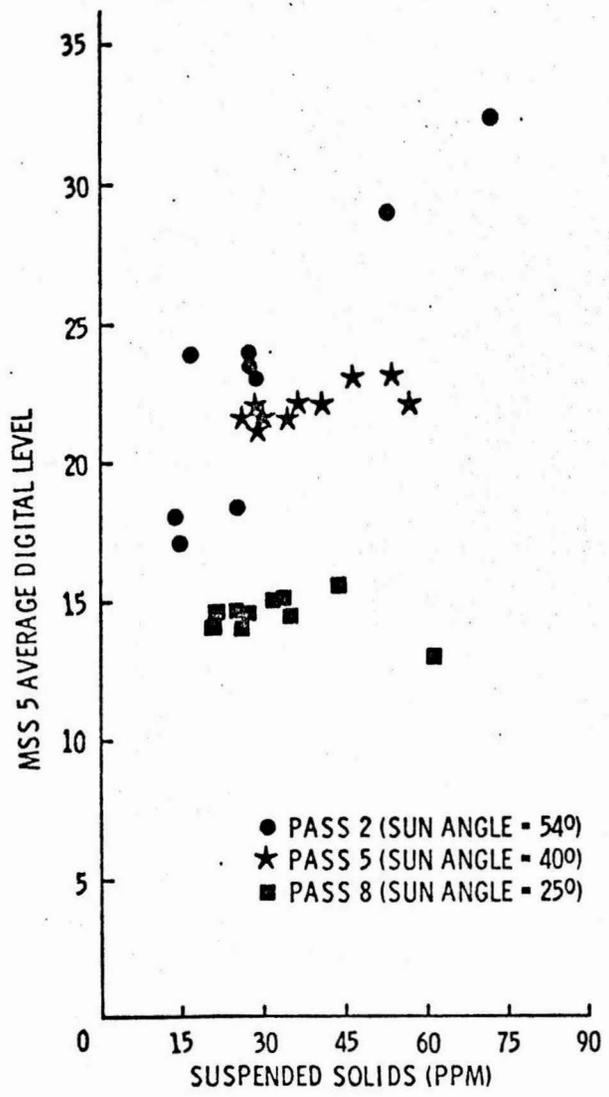
FIGURE 7. MSS5 DIGITAL LEVELS FROM CCT VS. SUSPENDED SOLIDS
FOR 28 WATER SAMPLES FROM 3 ERTS-1 PASSES.
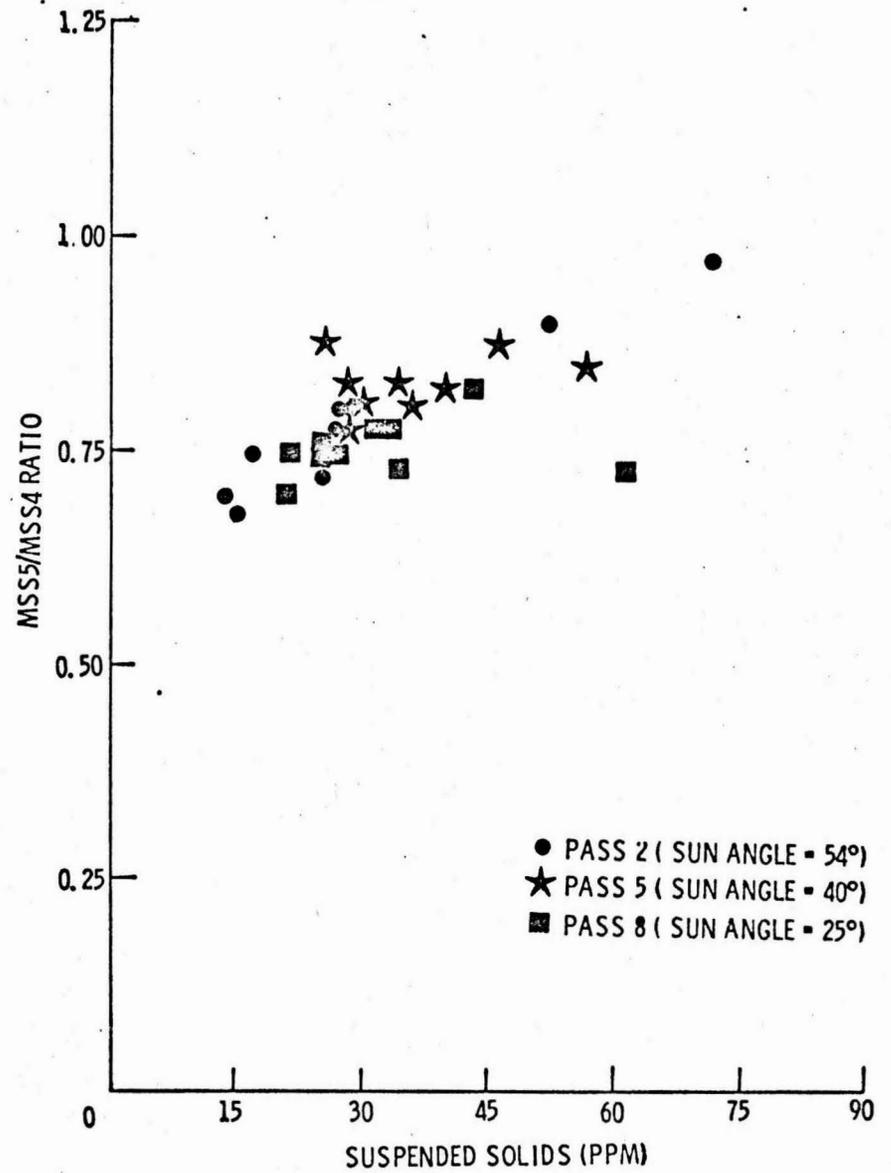
FIGURE 8. MSS5/MSS4 RATIO FROM CCT VS. SUSPENDED SOLIDS
FOR 28 WATER SAMPLES FROM 3 ERTS-1 PASSES.
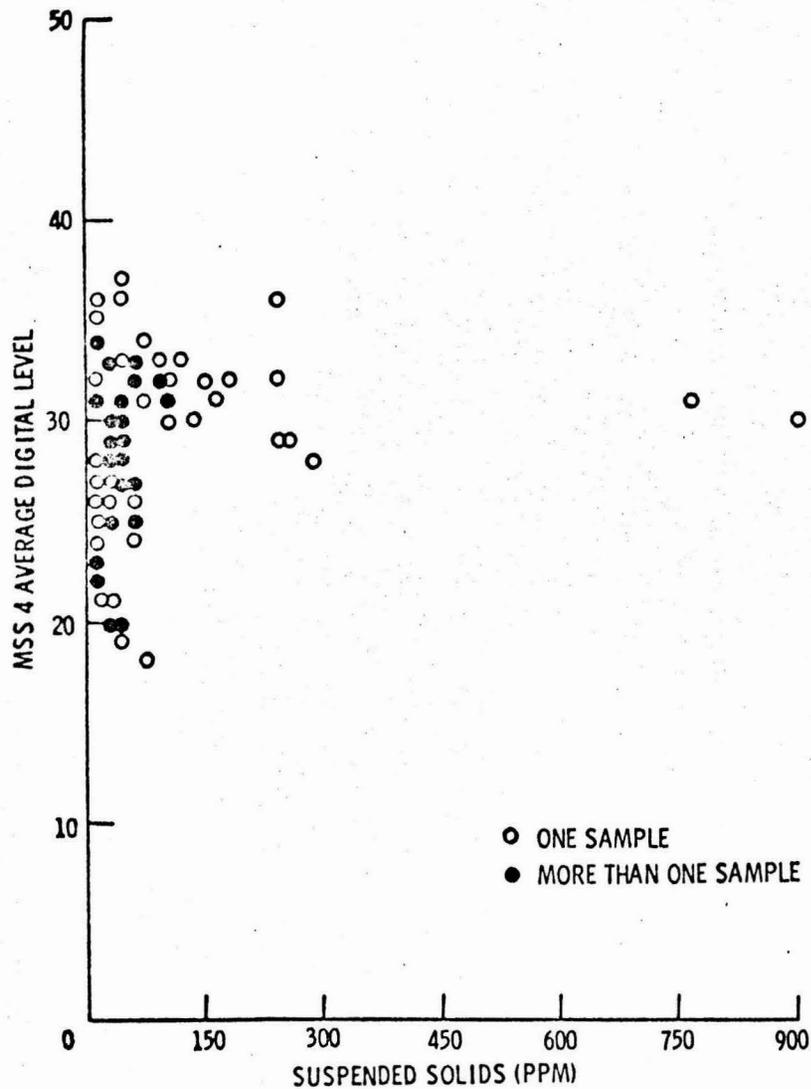
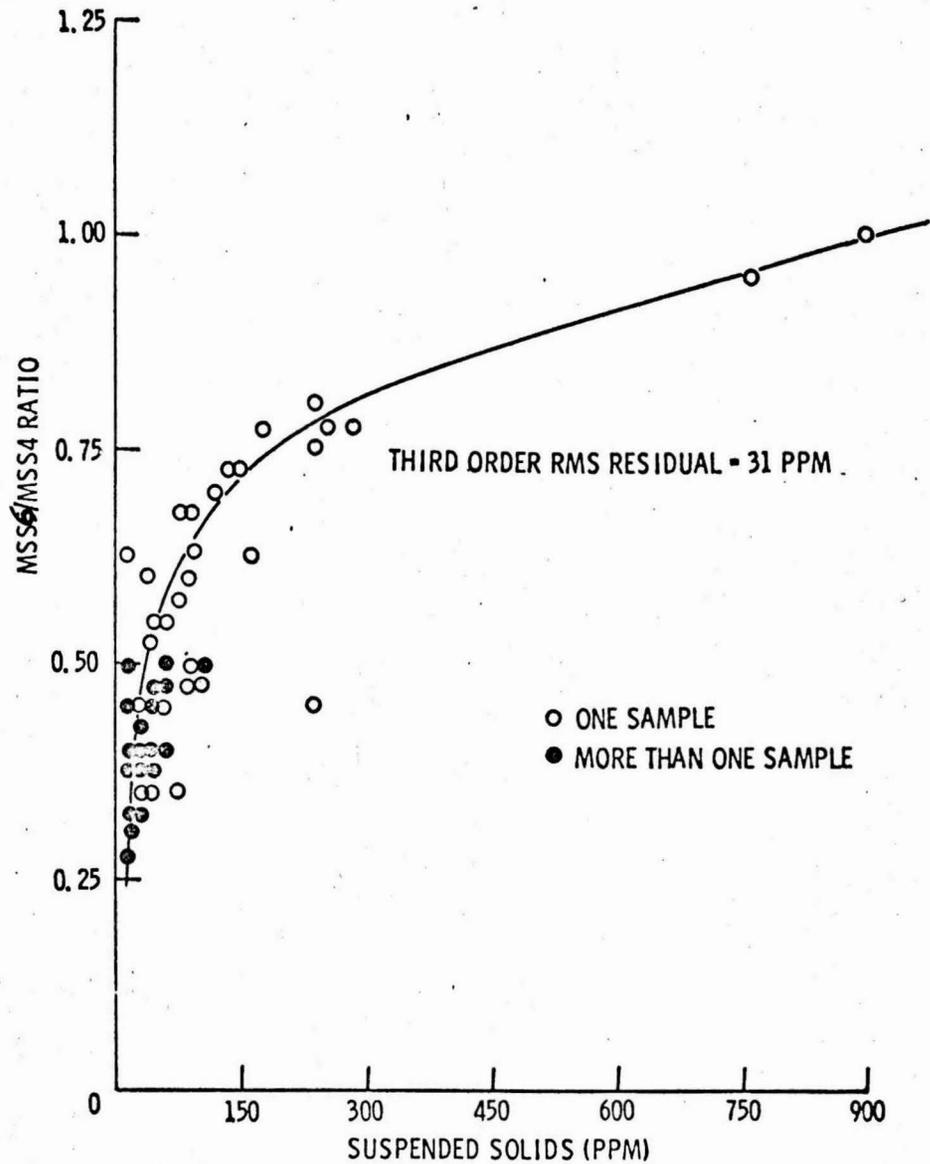FIGURE 9. MSS 4 DIGITAL LEVEL FROM CCT VS. SUSPENDED SOLIDS FOR 108 WATER SAMPLES FROM 11 ERTS-1 PASSES.
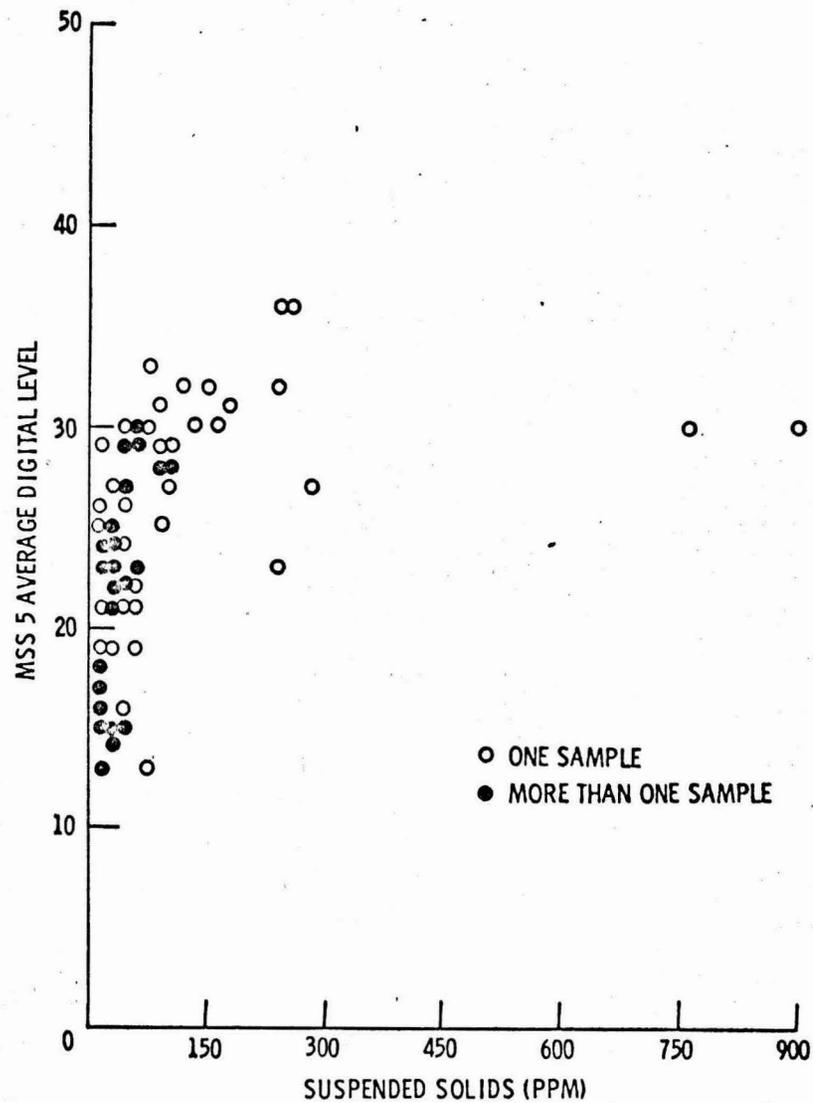
FIGURE 10. MSS 5 DIGITAL LEVEL FROM CCT VS. SUSPENDED SOLIDS FOR 108 WATER SAMPLES FROM 11 ERTS-1 PASSES.
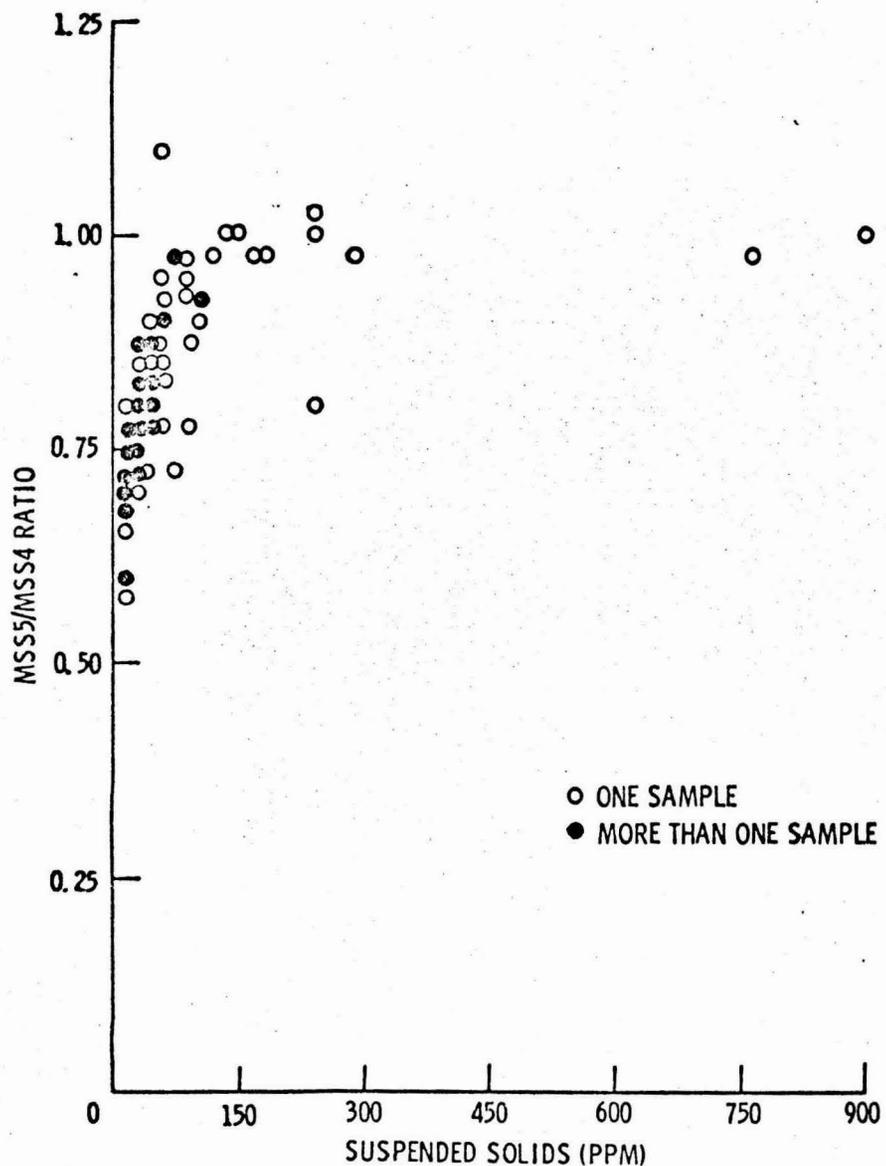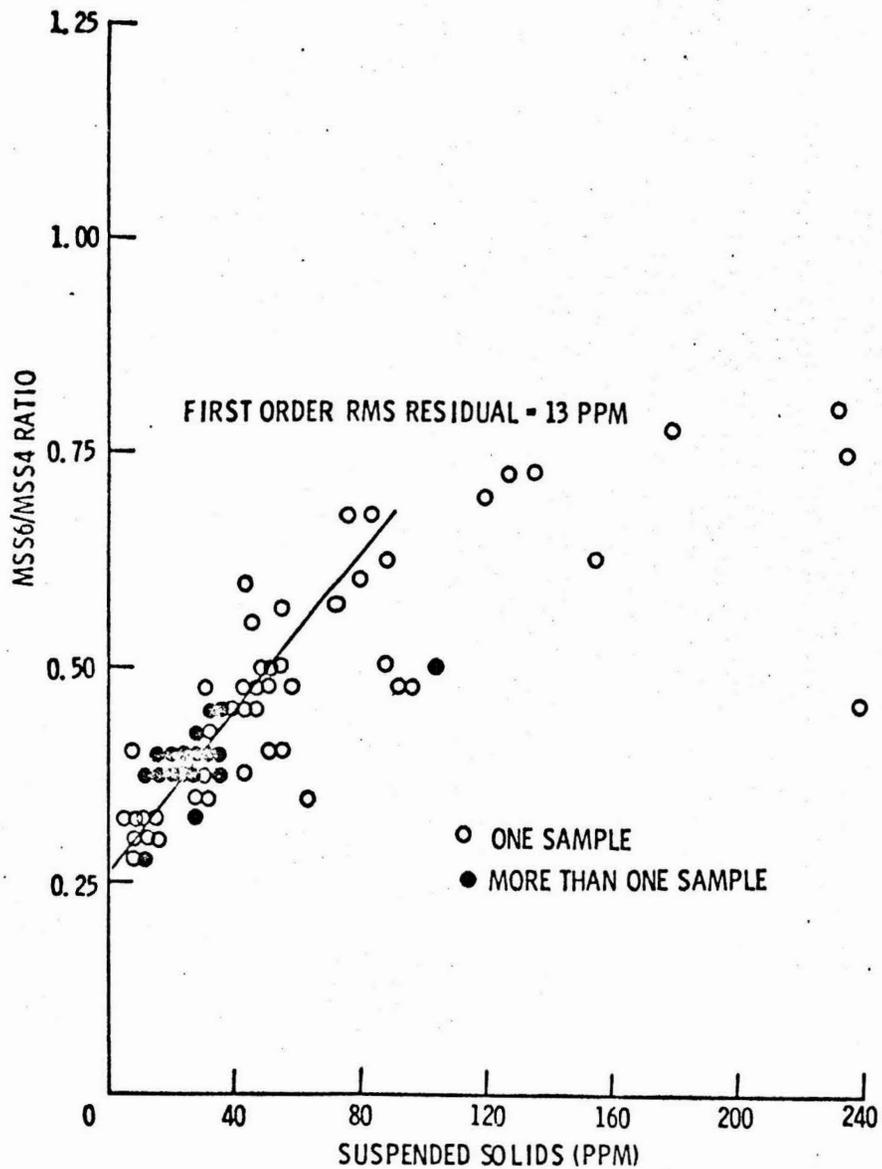
FIGURE 11. MSS5/MSS4 RATIO FROM CCT VS. SUSPENDED SOLIDS FOR 108 WATER SAMPLES FROM 11 ERTS-1 PASSES.
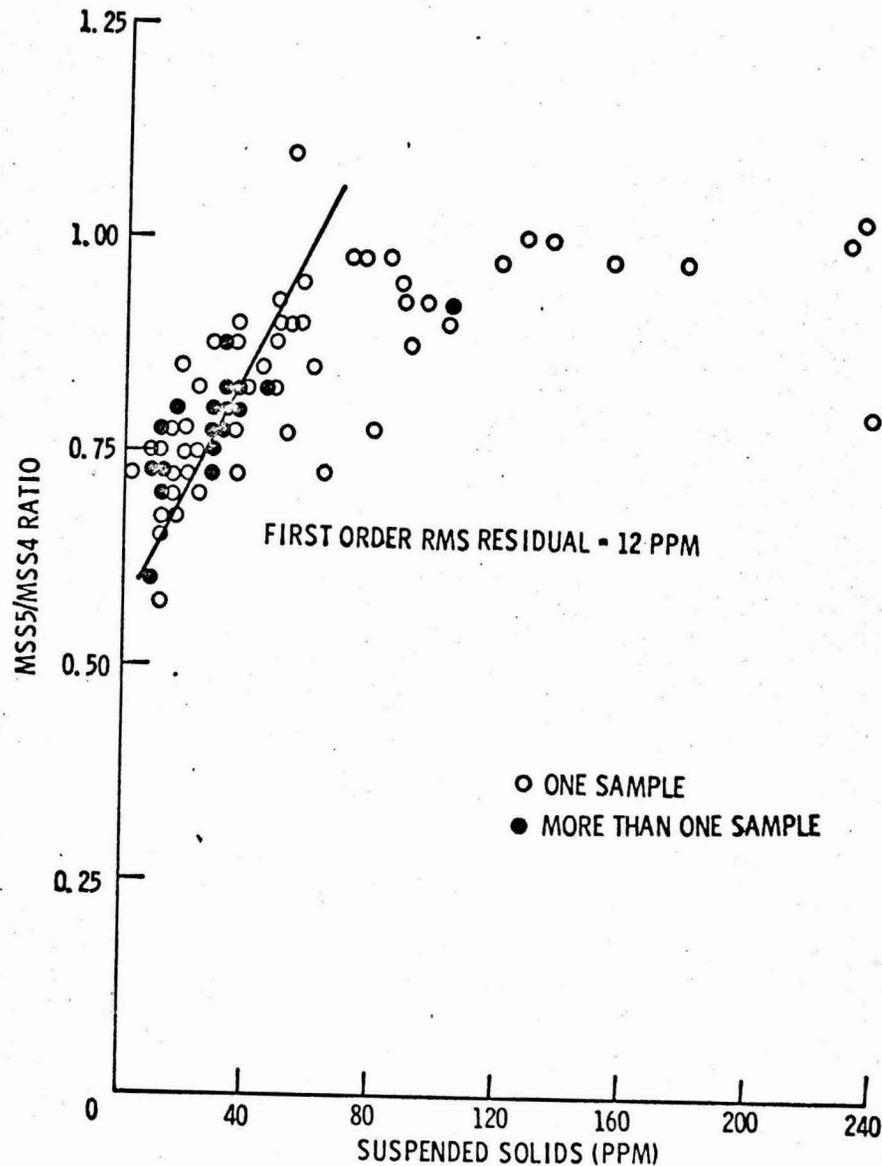
FIGURE 12. MSS5/MSS4 RATIO FROM CCT VS. SUSPENDED SOLIDS FOR 108 WATER SAMPLES FROM 11 ERTS-1 PASSES.
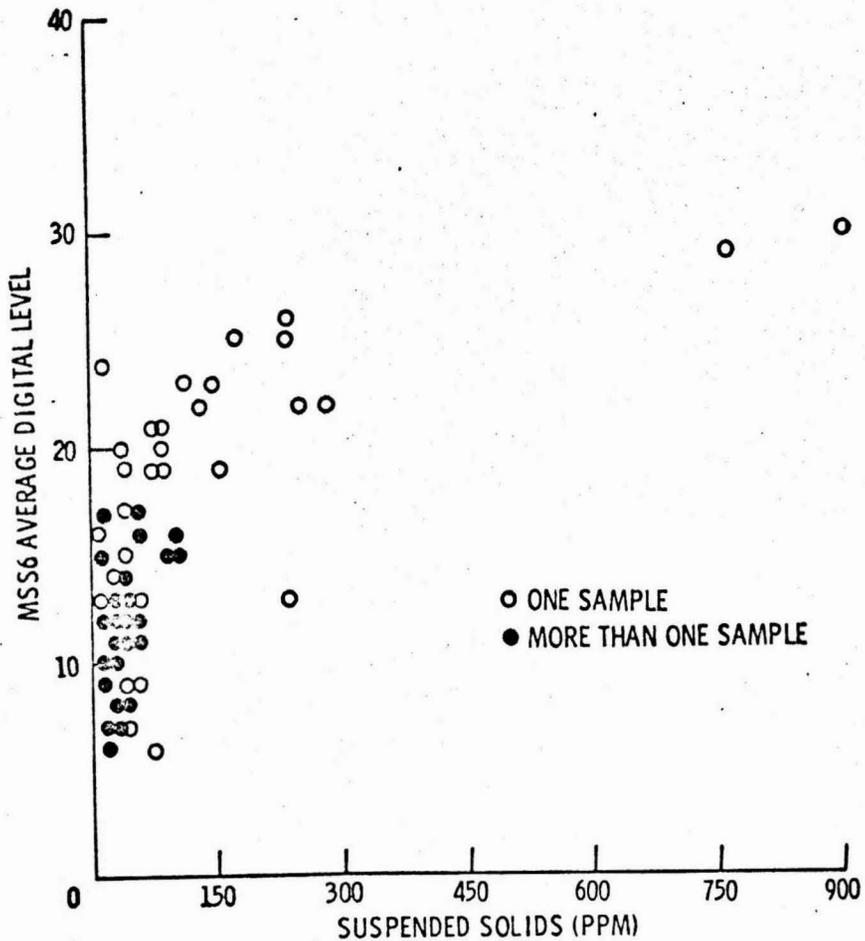
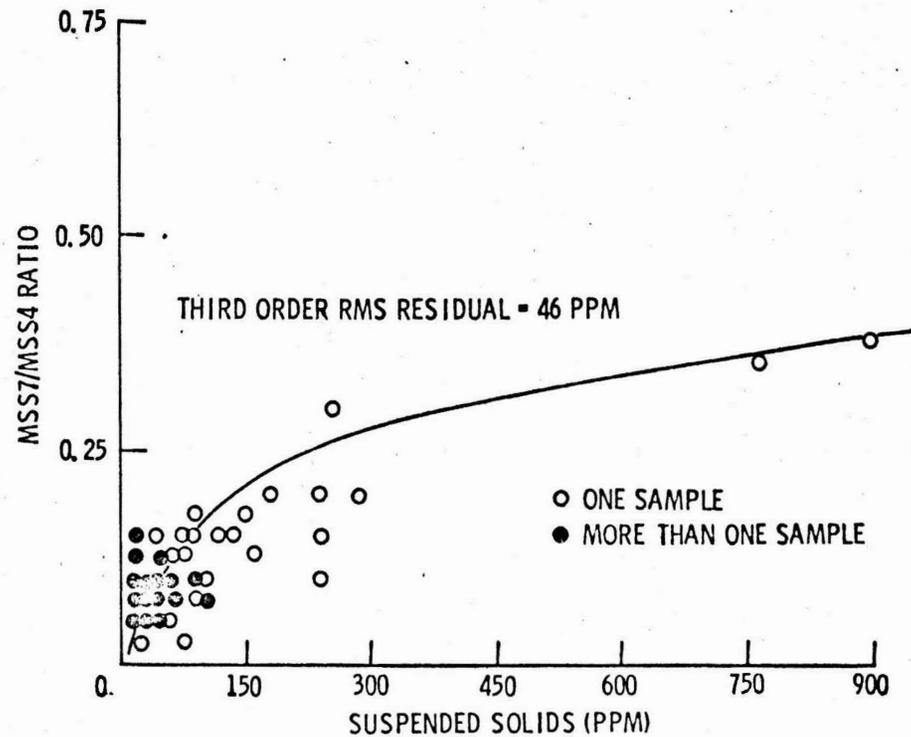FIGURE 13. MSS6 DIGITAL LEVEL FROM CCT VS. SUSPENDED SOLIDS FOR 108 WATER SAMPLES FROM 11 ERTS-1 PASSES.

THIRD ORDER RMS RESIDUAL = 31 PPM

○ ONE SAMPLE
● MORE THAN ONE SAMPLE

FIGURE 14. MSS6/MSS4 RATIO FROM CCT VS. SUSPENDED SOLIDS FOR 107 WATER SAMPLES FROM 11 ERTS-1 PASSES.

FIGURE 15. MSS6/MSS4 RATIO FROM CCT VS. SUSPENDED SOLIDS FOR 97 WATER SAMPLES FROM 10 ERTS-1 PASSES.

FIGURE 16. MSS7/MSS4 RATIO FROM CCT VS. SUSPENDED SOLIDS FOR 108 WATER SAMPLES FROM 11 ERTS-1 PASSES.
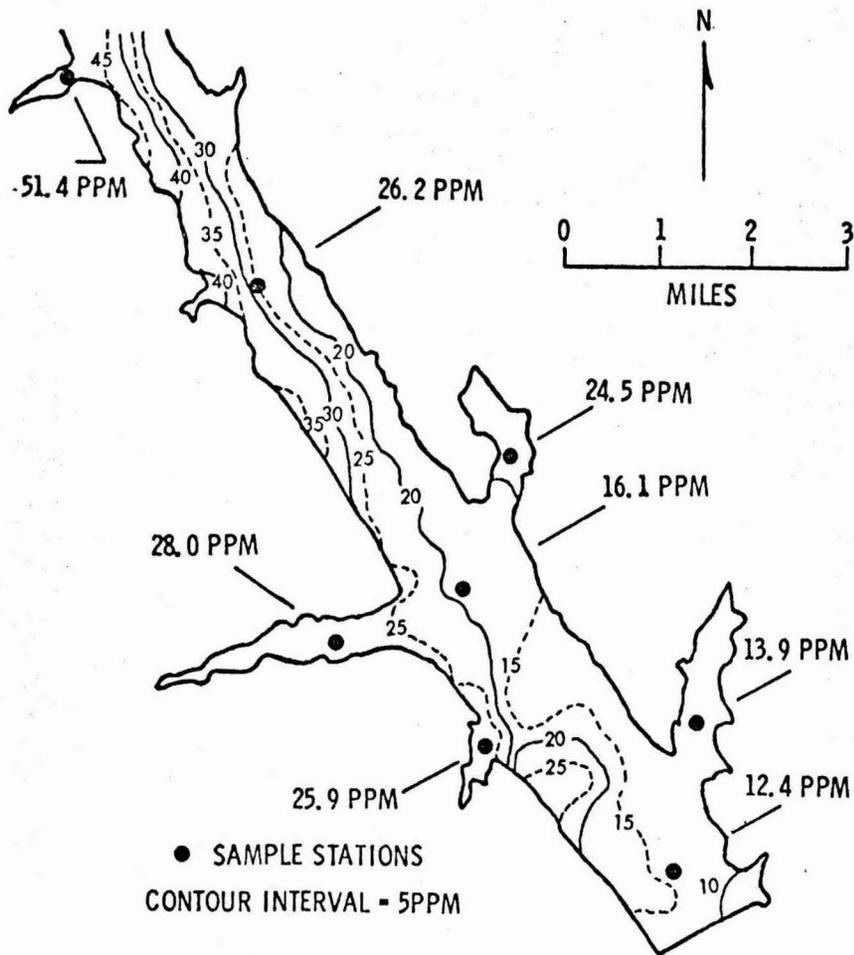
FIGURE 17. SUSPENDED SOLIDS CONTOUR MAP OF TUTTLE CREEK
RESERVOIR (AUGUST 14, 1972 ERTS-1 ID NO. 1022-16391-5)
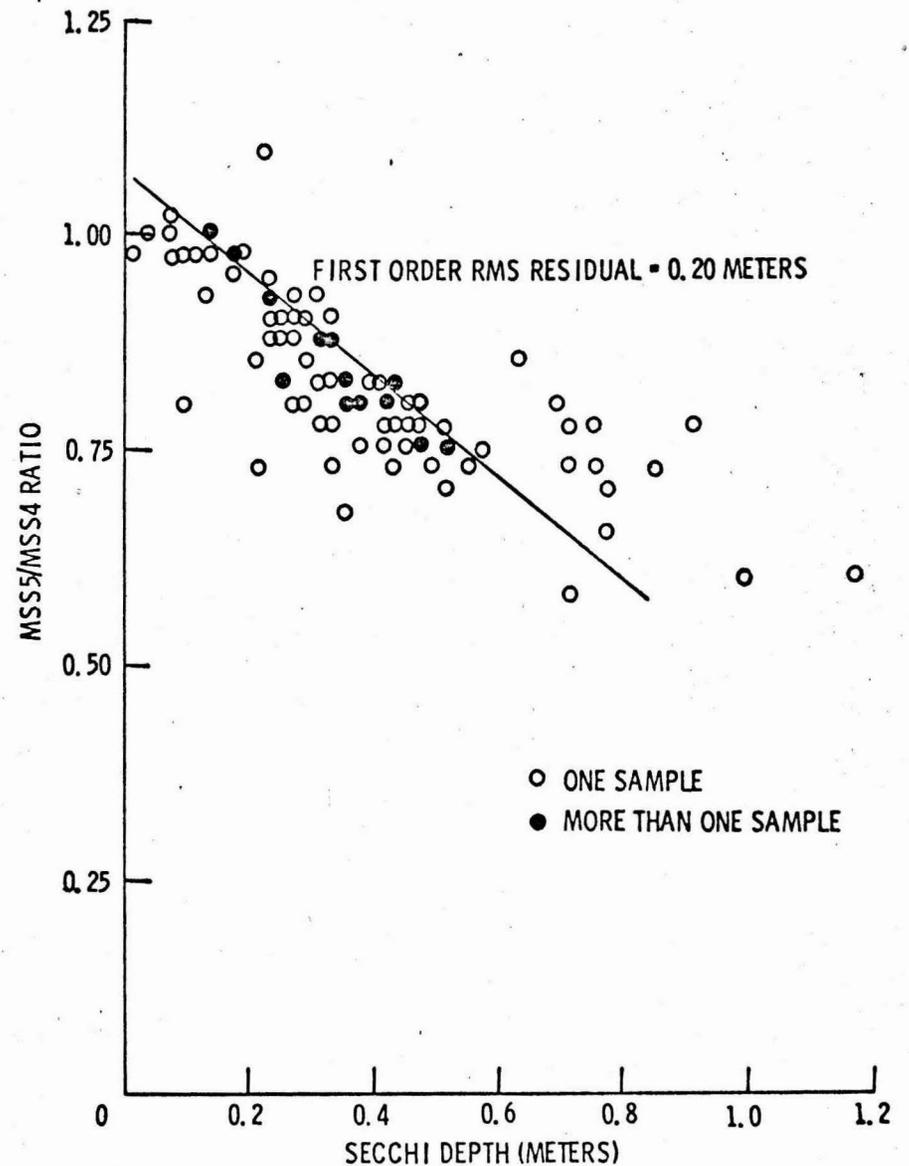DERIVED FROM CCTS (MSS 5) FOR 4 ERTS-1 PASSES.

FIGURE 18. MSS5/MSS4 RATIO FROM CCT VS. SECCHI DEPTH
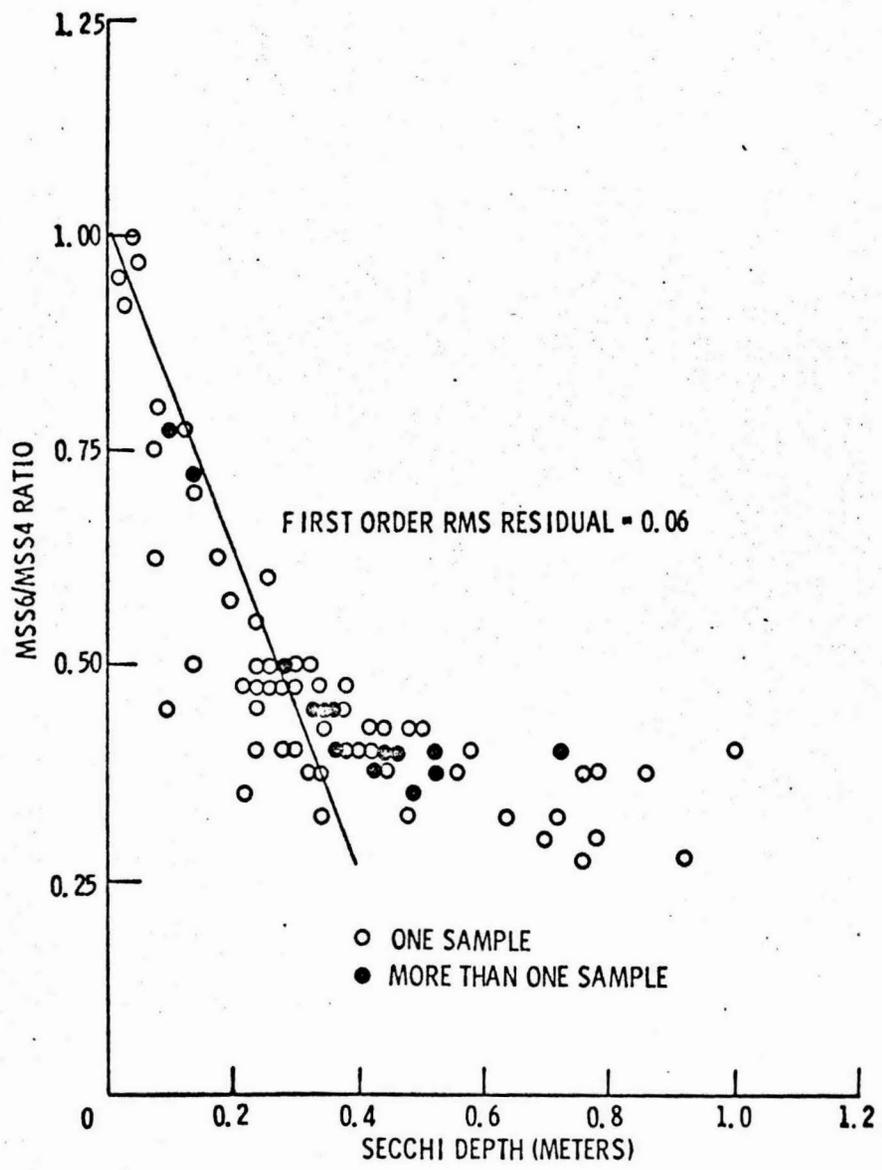FOR 97 SAMPLE STATIONS FROM 10 ERTS-1 PASSES.

FIGURE 19. MSS6/MSS4 RATIO FROM CCT VS. SECCHI DEPTH
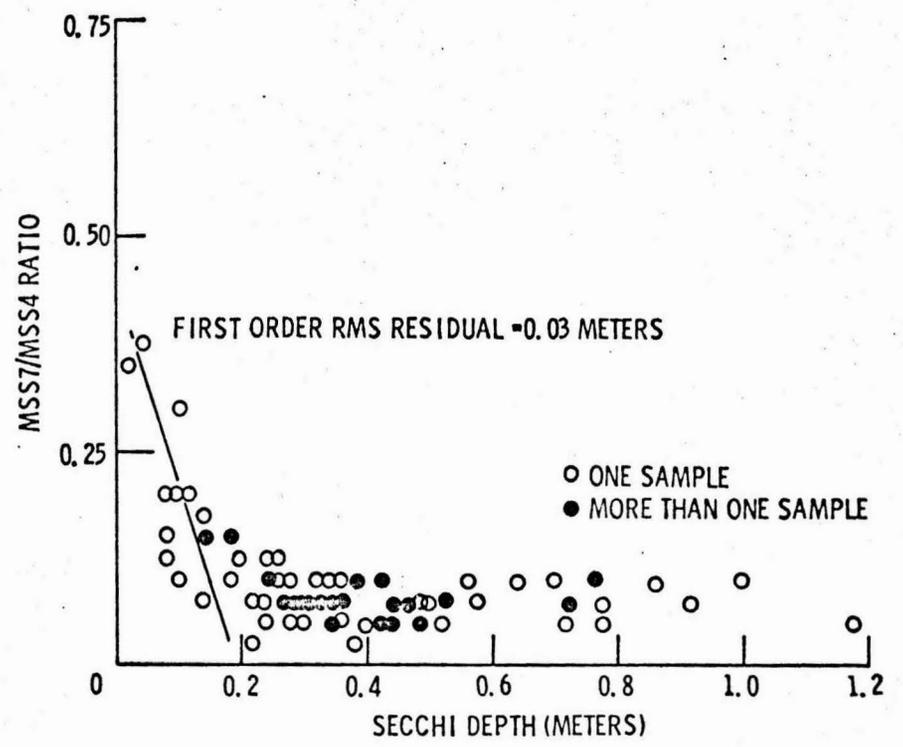FOR 96 SAMPLE STATIONS FROM 10 ERTS-1 PASSES.

FIGURE 20. MSS7/MSS4 RATIO FROM CCT VS. SECCHI DEPTH
FOR 97 SAMPLE STATIONS FROM 10 ERTS-1 PASSES.