

行政院國家科學委員會補助專題研究計畫成果報告

衛星遙測與空間統計應用於水庫優養評估之研究

**Application of Satellite Remote Sensing and Spatial Statistics to
Reservoir Trophic State Evaluation**

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計畫編號：NSC 89-2313-B-002-329

執行期間：90年8月1日至91年7月31日

計畫主持人：鄭克聲

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中文摘要

傳統上水庫或封閉水體之營養狀態(trophic states)是利用現地水質採樣之分析結果而判定。然而僅依靠有限之採樣點之分析結果未必能代表廣大水域水體之營養狀況。本研究利用衛星遙測之多光譜影像，評估水庫水體之整體與地區性營養狀況。研究結果顯示 Landsat 衛星之第二與第四波段光譜灰階與沙奇盤深度、總磷與葉綠素濃度等水質參數具有良好之關係。研究中提出一套修正型之營養狀況指標，以使該指標能正確反應地區性之水質參數特性，並建立適合德基水庫應用之營養狀況指標。最後本研究利用隨機變域繁衍技術以推估整體水域平均與各段面營養狀況指標之機率分布，此機率分布可作為水庫水體營養狀況機率評估之依據。

ABSTRACT

Reservoir water quality is traditionally monitored and evaluated based on field data collected at limited locations. Whether the limited field data represent the overall trophic state of a vast water body is often disputed. In this study we utilize Landsat TM data to evaluate the overall trophic state of Te-Chi Reservoir in Central Taiwan. Three

water quality parameters: concentrations of chlorophyll-a, total phosphorous measurement, and secchi disk depth, are found to have high correlations with transformed spectral features derived from bands 1, 2, 3 and 4 of TM data. Therefore, TM data are used to yield a trophic-state-index (TSI) map of the reservoir. We then apply the geostatistical simulation technique to generate a large number of TSI realizations. Using these realizations probability distribution of the overall reservoir trophic state can be estimated. TSI cutoff values of 60.6 and 73.5 are used to signify the reservoir trophic state of eutrophication and hypereutrophication. The reservoir trophic state is considered eutrophic or hypereutrophic if the probability that the overall TSI exceeds the cutoff value (60.6 or 73.5) is greater than 0.9. Based on this criterion, the trophic state of Te-Chi reservoir is found to be eutrophic, and occasionally hypereutrophic.

INTRODUCTION

Traditionally the quality and trophic state of water in impoundments has been assessed

using limnological methods and laboratory analyses of field-sampled data. This is time and cost consuming, and whether the limited field data represent the overall quality of a vast water body is often disputed. Using remote sensing data to assess the quality of water bodies has proven to be successful (Lillesand, et al., 1983, Ekstrand, 1992, Tassan, 1993, Lavery, et al., 1993, Avard, et al., 2000). The main objective of this study is to use TM data to map the water quality of a reservoir and give a probability-based decision on the overall trophic state of the reservoir.

RESERVOIR TROPHIC STATE INDEX

The Trophic State Index (TSI) (Carlson, 1977) was developed as a means to establish numerical relationships between three indicators—secchi disk depth (SDD), total phosphorus (TP), and chlorophyll-a (Chla). The TSI converts raw data from the three indicators to a standard numerical scale ranging from 0 to 100. An increase in TSI indicates an increase in overall productivity, and typically poorer water quality. The original Carlson TSI model is basically a logarithmic transformation of the three indicator parameters, and an increase of 10 TSI units relates to a halving of SDD. The statistical TSI models developed by Carlson have been modified for Te-Chi reservoir in Central Taiwan, based on historical water quality data. However, based on our field data we found that the 10-TSI per SDD halving rate is not adequate for Taiwan's environment and a modified model is developed for Te-Chi reservoir:

$$TSI(SDD) = 10 \left(8.605 - \frac{\ln(SDD)}{\ln(1.544)} \right) \quad (1)$$

$$TSI(Chla) = 10 \left(8.605 - \frac{1.8571 - 0.3264 \ln(Chla)}{\ln(1.544)} \right) \quad (2)$$

$$TSI(TP) = 10 \left(8.605 - \frac{2.1775 - 0.4230 \ln(TP)}{\ln(1.544)} \right) \quad (3)$$

$$\overline{TSI} = (TSI(SDD) + TSI(Chla) + TSI(TP)) / 3 \quad (4)$$

TSI cutoff values are 0–50 for oligotrophic, 50–60.6 for mesotrophic, 60.6–73.5 for eutrophic, and 73.5–100 for hypereutrophic. These categories reflect the reservoir's nutrient and clarity levels.

TSI Estimation Using Landsat TM Images

Landsat TM data from four dates (8/23/1993, 10/17/1994, 1/10/1995, and 7/22/1996) were analyzed. Corresponding to each TM image water quality samples were collected at five cross sections within the reservoir pool. Digital numbers of TM bands 1, 2, 3, and 4 are related to water quality parameters:

$$\ln SDD = 1.5680 - 0.1167 \left(\frac{TM3 + TM4}{\ln(TM1)} \right) \quad (5)$$

$$\ln Chla = 1.204 + 2.213 \ln(TM4) - 92.13 \left(\frac{TM3 + TM4}{TM1 \times TM2} \right) \quad (6)$$

$$\ln TP = 10.745 + 3.379 \ln(TM4) - 31.50 \left(\frac{\ln(TM3 + TM4)}{\ln(TM1 \times TM2)} \right) \quad (7)$$

Combining use of Eqs.(1)-(4) and Eqs.(5)-(7) yields \overline{TSI} images of the reservoir pool. The overall reservoir trophic state index is expressed as the areal average of \overline{TSI}

$$\overline{TSI}_\Omega = \frac{1}{\Omega} \int_\Omega \overline{TSI}(x) dx \quad (8)$$

where Ω represents the area extent of the reservoir pool.

Geostatistical Simulation Using HYDRO_GEN

The date-specific \overline{TSI} image derived from a set of Landsat TM data is considered one realization of the embedding random field that characterizes the spatial variation of \overline{TSI} . A geostatistical random field simulation model HYDRO_GEN (Bellin and Rubin, 1996) is utilized to generate two hundred realizations using parameters mean, variance, and variogram obtained from the TM-derived \overline{TSI} image. The probability distribution of \overline{TSI}_Ω is then estimated using these generated realizations. Table 1 demonstrates distribution parameters of \overline{TSI}_Ω for four Landsat images. Examples of \overline{TSI}_Ω histograms are shown in Figure 1.

Date	8/31/1993	10/05/1994	01/09/1995	07/22/1996
Mean	78.10	72.41	62.69	73.26
Std. Dev.	0.18	0.13	0.10	0.21

Table 1. Distribution parameters of \overline{TSI}_Ω

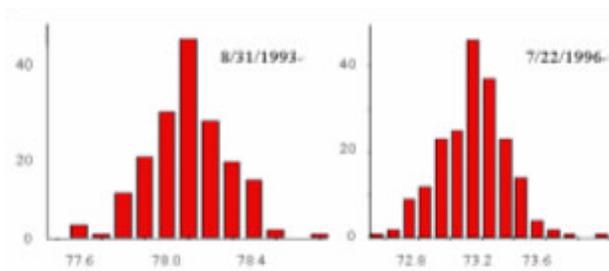


Figure 1. Examples of \overline{TSI}_Ω histograms.

Probabilistic Evaluation of Reservoir Trophic State

To circumvent the dispute about the overall trophic state of the reservoir we adopt a probabilistic approach for reservoir trophic state evaluation. A reservoir is considered eutrophic (or hypereutrophic) if the probability that \overline{TSI}_Ω exceeds the cutoff

value (ν_c) of 60.6 (or 73.5) is greater than 0.9, i.e.

$$P(\overline{TSI}_\Omega \geq \nu_c) \geq 0.9 \quad (9)$$

Figure 1 suggests that probability distribution of \overline{TSI}_Ω is normal and the exceedence probability $P(\overline{TSI}_\Omega \geq \nu_c)$ for various cutoff values is shown in Table 2.

Image Date	8/31/1993	10/05/1994	01/09/1995	07/22/1996
$\nu_c = 60.6$ Eutrophic	≈ 1.0	≈ 1.0	≈ 1.0	≈ 1.0
$\nu_c = 73.5$ Hypereutrophic	≈ 1.0	≈ 0	≈ 0	0.13

Table 2. \overline{TSI}_Ω exceedence probabilities of various cutoff values.

Conclusions

We demonstrate that reservoir water quality parameters are highly correlated with transformed spectral features of the TM data, and reservoir TSI map can be created using these relationships. By means of the geostatistical simulation the probability distribution of the overall trophic state index \overline{TSI}_Ω can be estimated. Based on the criterion of exceedence probability $P(\overline{TSI}_\Omega \geq \nu_c) \geq 0.9$ we conclude that the Te-Chi reservoir is eutrophic, and even hypereutrophic occasionally.

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