Report for 2001CO1761B: Applicability of Trophic Status Indicators to Colorado Plains Reservoirs

- Conference Proceedings:
  - Hall, Emile; 2001, Nitrogen Phosphorus Ratios in South Platte Basin Reservoirs: A Recipe for Eutrophication and Blue-Green Algae?, in Wassup in the South Platte Basin, Proceedings of the 12th Annual South Platte Forum, October 24-25, 2001, Colorado Water Resources Research Institute, Colorado State University, Fort Collins, CO, p.73.
- Dissertations:
  - Hall, Emile, Nutrients in Off-Channel Storage Reservoirs of the South Platte River, Colorado, MS Dissertation, Department of Earth Resources, College of Natural Resources, Colorado State University, Fort Collins, CO, 119 pp.
- unclassified:
  - Hall, Emile; Nitrogen and Phosphorus in Reservoirs Along the South Platte River, in Proceedings of the Fifth Annual Colorado State University Student Water Symposium, p. 13, published on-line at the Student Water Symposium website http://watersym.colostate.edu/

Report Follows:

SYNOPSIS

Project Number: 2001CO1761B Start: 3/01
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Title: Applicability of Trophic Status Indicators to Colorado Plains Reservoirs

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Problem and research objectives

Anecdotal evidence indicates that off-channel storage reservoirs on the eastern Colorado plains downstream of Denver, Colorado are experiencing symptoms of eutrophication. Measures of eutrophication include nutrient concentrations, chlorophyll-a measurements and water transparency. Algal growth promoted by high nutrient inputs may create costly maintenance problems in reservoirs and water distribution systems, ecological changes, low dissolved oxygen and fish kills.

To mitigate the potential impacts of high nutrient inputs and resulting algae growth, Trophic Status Indices (TSI) and linear models are often used in classification and management. Although currently in use, the applicability of the models, and other efforts to determine a trophic status of reservoirs in Colorado, has not been examined. The recent proposed change in the Cherry Creek Reservoir TMDL brought to light several issues about using a trophic status index (TSI) for water quality in Colorado reservoirs. Concerns range from applicability to interpretation.

The overriding objective of this study is to evaluate the applicability of various trophic status indices and models to Colorado reservoirs using existing and collected water quality data from several South Platte River reservoirs. Specific objectives of this research are to:

1. Compile existing nutrient, chlorophyll-a and secchi disk data for eastern Colorado reservoirs in the South Platte Basin.
2. Collect additional nutrient, chlorophyll-a and secchi disk data, where necessary.
3. Determine the applicability of various TSI (EPA 1974, Vollenweider 1976, Carlson 1977, OECD 1982) and linear phosphorous~chlorophyll-a models.
4. Evaluate TSI in relation to reservoir hydrology and management.

This analysis will aid reservoir operators and water managers in Colorado, as well as explain the chemical and biological processes that control eutrophication in Colorado reservoirs.

Methodology

Data from seven reservoirs were compiled and considered for use in TSI and model evaluation. Three reservoirs were selected for further data collection. The compiled and collected data were used in two Microsoft Excel ® spreadsheets developed to evaluate the TSI and nutrient~chlorophyll-a models.

The first spreadsheet compared reservoir classification determined by different TSI to evaluate their applicability to Eastern Colorado reservoirs in the South Platte Basin. The worksheet allows the input of data and computes the resulting index and classification (oligotrophic, mesotrophic or eutrophic) based upon each parameter. The final results can then be compared.

In order to compare the effectiveness of common nutrient~chlorophyll-a models, the second spreadsheet was developed to compute five measures of precision between the computed and observed chlorophyll-a values (Canfield 1983, Brown 2000):

1. Pearson's correlation coefficients between measured and calculated chlorophyll -a
2. Pearson's correlation coefficients between the logarithm of the measured and calculated chlorophyll-a values
3. 95% confidence limits for calculated chlorophyll-a concentrations from the standard deviation of the mean difference of the logarithms of measured and calculated values. The user must input the appropriate z value based upon the number of samples. The confidence limits are computed as the standard deviation * z +/- the mean.
4. Average error is computed using untransformed values as the mean of the absolute value of the difference between measured and calculated values.
5. Percentage error is the mean of the same differences standardized by dividing by the measured value and multiplied by 100 to express the value as a percent.

Seasonal nutrient declines, ratios, and relationships determined from collected data were also utilized in determining TSI and model applicability to eastern off-channel storage reservoirs in the South Platte Basin.

Principal findings and significance

The first objective of this project, to compile existing reservoir nutrient, chlorophyll-a and secchi disk data was met with limited success as relatively little information capable of TSI evaluation exists. No alga studies on the reservoirs were found, and there is little information on algae in the plains region of the South Platte Basin (USGS 1995a). Two sources of water quality data for the reservoirs were found. The NAWQA Program of the USGS collected data on five off-channel reservoirs in 1995, however the study was limited to four sampling days, and only three days had chlorophyll-a information. In addition, secchi disk depth was not reported, but was assumed to be half of the sampling depth. Another source of nutrient data was added to the NAWQA data; water quality data collected on Milton and Barr Reservoirs by Dr. John Stednick. Again, little chlorophyll-a and secchi disk information was available making most TSI and models difficult to evaluate.

Given the lack of existing data the second objective, collection of additional data, became more important. Nutrient, chlorophyll-a and secchi disk depth data were collected at North Sterling, Prewitt and Jackson Reservoirs on ten days between March and October 2001. Colorado State Parks provided boats for sample collection.

The third objective of determining the applicability of TSI and linear models is described below.

TROPHIC STATUS INDICES

A spreadsheet was developed to determine the trophic state of a reservoir or lake using three of the common computational methods, Carlson's TSI (1977), OECD fixed boundary system

(OECD 1982) and EPA NES guidelines (USEPA 1974) . Vollenweider's plots (based upon phosphorous loading) and OECD Probability Plots were also included to assess the trophic state of the reservoirs (Vollenweider 1976, OECD 1982).

On two days, Jackson Reservoir was classified as mesotrophic based upon chlorophyll-a using the EPA method. On all other days, the reservoirs were classified in the highest category available in the EPA method, eutrophic. Based upon the OECD fixed boundary system all of the reservoirs were hypereutrophic for each parameter. The Carlson TSI reports the trophic state as a number from 0 to approximately 100 in an attempt to quantify trophic status and offer more than three descriptive categories for trophic state. Secchi disk depth was the least reliable with respect to the other measures, especially at Prewitt Reservoir, leading to the highest mean TSI . TP concentrations generally gave higher TSI than chlorophyll-a or Secchi disk depth in Jackson and Sterling Reservoirs. Chlorophyll-a gives the lowest TSI at all three reservoirs. Even though the TP concentrations were high, the primary production did not reach the same trophic classification levels. Most eutrophic lakes have TSI greater than 45 (Novotny and Olem 1994). The lowest value for any parameter and date was 50 indicating that by all measures the reservoirs are eutrophic based upon Carlson's TSI. Based upon an average of all the values, Prewitt showed the highest degree of eutrophication, followed by Jackson and Sterling Reservoirs, respectively.

Vollenweider plots use the total input of phosphorous per year per surface area. Based upon the calculated incoming load estimated from mean South Platte River TP concentrations at Weldona in 2001, annual inflow, hydraulic residence time and maximum reservoir depth, all three reservoirs would be classified as eutrophic. The mean TP concentration (374 μg/L) was calculated using 3 samples collected in 2001 at Weldona, which is located between the Jackson and North Sterling Reservoir inlet canals (Sprague 2002). Residence time, defined as initial reservoir volume/total yearly outflow, was 0.84 years for Sterling, 2.4 years for Prewitt and 1.2 years for Jackson. The yearly area loading of TP was determined by multiplying the total inflow by the concentration and dividing this number by the initial reservoir surface area giving Sterling (4.34 g TP/m^2/yr), Prewitt (2.78 g TP/m^2/yr) and Jackson (1.01 g TP/ m^2/ yr). The calculated values are used along with mean depth to determine the trophic state using the plot (Figure 3). Since the mean depth was not available, the maximum depth was used as a conservative measure. Using the maximum depth on the x-axis (depth / residence time) will produce a higher value for the horizontal axis, making the potential classification more likely lower on the trophic scale. Estimation based upon Vollenweider plots is approximate because the incoming TP was estimated from South Platte River mean concentrations, the surface area and depth are approximate and they fluctuate seasonally. The incoming phosphorous loads indicate that regardless of the depth or residence time, the reservoirs are classified as eutrophic.

Using the OECD probability plot, North Sterling, Prewitt and Jackson Reservoir concentrations were beyond the greatest value and are therefore considered hypereutrophic based upon TP concentrations. North Sterling had a 10% probability of being eutrophic and 90% probability of being hypereutrophic based upon mean chlorophyll-a. Jackson had a 5% probability of being eutrophic with a 95% probability of being hypereutrophic based upon chlorophyll-a concentrations. Prewitt reservoir chlorophyll-a concentrations were greater than the largest value on the graph leading to a 100% probability of hypereutrophic conditions based upon chlorophyll-a.

MODELS

A spreadsheet with common nutrient~chlorophyll-a models was developed which allows input of observed values and reports five measures of precision for the input data. This spreadsheet was used to evaluate the models given the data from 8 sampling days at the reservoirs.

In evaluating the measures of precision at North Sterling Reservoir, an equation using both TN and total phosphorus had the best correlation coefficient between measured and predicted log chlorophyll-a values (0.82) and the lowest percent error (38.2%); (Smith 1982); (Table 13). A different equation, developed for nutrient balanced lakes, had the lowest average error (59.8) (Brezonik 1984). The correlation coefficient using untransformed values was also best for a TP and TN mixed model (Canfield Jr. 1983). The smallest 95% confidence interval was 28-120% based upon a TP model developed for Florida lakes (Baker et al. 1981).

In contrast with North Sterling Reservoir, the best models for Prewitt Reservoir, based upon correlation coefficients between measured and predicted chlorophyll, were models based upon TP alone (r=0.52). The smallest confidence interval was 33 - 71 % for the calculated chlorophyll. The smallest average error and percentage error was found using an equation developed by Brown (2000).

At Jackson Reservoir the highest correlation coefficient between predicted and measured log chlorophyll-a values was based upon TP (r=0.77). The untransformed values yielded the best correlation of r = 0.92 using TP models. The lowest average error was 35.30 based upon an equation for nitrogen limited lakes using TN (Brezonik 1984). The smallest percent (70.5%) error was found for Carlson's total phosphorus equation (Carlson, 1977), however it produced a large average error and 95% confidence interval. Similar to North Sterling Reservoir, the smallest 95% confidence interval was between 27-231 % using the model developed by Baker (Baker et al. 1981).

Several factors limit the use of TSI: nitrogen limitation, mean concentration utilization and limited classification categories. Nitrogen limitation hinders the utility of models based solely on TP. Although a nitrate decline was previously described, the EPA model does not account for that because it relies on mean nutrient concentrations. The use of the OECD fixed boundary system or the EPA fixed boundary system provided terminology to describe the trophic state of the reservoirs, but only offered between 3 and 5 options (ultraoligotrophic, oligotrophic, mesotrophic, eutrophic and hypereutrophic) for describing the reservoirs. In 2001, the reservoirs (excluding Jackson Reservoir chlorophyll-a for the first two sampling days) were generally in the highest classification based upon each parameter. The chlorophyll-a concentrations did not lead to a trophic classification as high as the other parameters. It is clear from the indices that the reservoirs are eutrophic or hypereutrophic, but little other information is provided from the indices. For example, the mean TP concentration at North Sterling Reservoir was 161 μg/L and the mean concentration at Prewitt Reservoir was 100 μg/L greater. Although this is a large difference in concentrations, both are classified as eutrophic, not reflecting the higher phosphorous concentration at Prewitt Reservoir. The indices are useful only for minimal description of the reservoirs.

Similar to the EPA method at Jackson Reservoir, TP concentrations result in higher trophic classification by the Carlson method than does chlorophyll-a. One strength of the Carlson method is that it allows a gradient of numerical classifications so that information is retained, unlike the fixed boundary systems. The reservoirs are classified between approximately 0 and 100, with occasional classification greater than 100. Using this system it is possible to decide which parameter, chlorophyll-a, TP or Secchi disk depth, would be most appropriate for the system. For example, in the South Platte off channel storage reservoirs with high TP concentrations and high turbidity, primary production may be a better metric upon which to base trophic status indices.

Although the Carlson TSI offers the advantage of retaining information about the system, there are several reasons why it may not be appropriate for the reservoirs. First, this study has shown the importance of total and inorganic-N in contributing to primary production in South Platte Basin Reservoirs. Based upon linear regression with log TP alone, only 50 percent of the chlorophyll-a was described, but this value increased to between 60 and 80 percent by including nitrogen. The abilities of the Carlson TSI to describe the system are limited since it does not include nitrogen. The TP and chlorophyll-a equation was evaluated along with 23 other equations utilized in the model worksheet; it gave the smallest percentage error at Jackson Reservoir, but other equations provided a better determination of chlorophyll-a based upon phosphorous concentrations. Also, the use of Secchi depth in the reservoirs may not yield accurate values, depending upon the non-chlorophyll light attenuating substance in the water. Carlson advised that chlorophyll-a be used instead of Secchi depth whenever possible (Carlson, 1980).

The high nutrient concentrations and loads coming into the reservoirs result in a eutrophic classification using the Vollenweider plot. This plot is useful in that the proximity of the trophic state of the lake or reservoir can be seen in relation to the others plotted on the graph. In addition, Vollenweider developed a plot based upon incoming TP concentration rather than loads (Vollenweider 1976), which may be useful where annual loading information is not available.

The OECD probability plots, also developed by Vollenweider and others, are useful in that they recognize the uncertainty of the trophic designations and report the trophic state as a probability. However, these plots rely upon the average chlorophyll-a and TP concentrations. These measurements are not normally distributed and it may improve the plots to use the median value. In addition, these measures say nothing about the phosphorous, chlorophyll-a or transparency relationships within the reservoir.

Analysis of the TP models that predict chlorophyll-a was completed using several metrics (r^2 of log and untransformed values, 95% confidence interval for the calculated chlorophyll, percentage error and actual error). Different equations were best depending upon which metric was evaluated, but for Sterling and Prewitt Reservoirs, one model had the best fit with several different measurements. The North Sterling Reservoir correlation coefficient, percent error and average error were all best using the multivariate relationship. As a result, an equation using nitrogen and phosphorous is recommended for North Sterling Reservoir predictions (Smith 1982). The lowest average error at Jackson Reservoir was derived from a nitrogen based equation (Brezonik 1984), but the correlation coefficient, confidence interval and percent error are best using TP alone. The equation with the highest log and untransformed correlation coefficients and the smallest confidence interval was developed for Florida Lakes (Baker et al. 1981). At Prewitt Reservoir, the equation with the lowest average and percentage error and the typical correlation coefficient (r=.52) was developed in 2000 using annual mean phosphorous and chlorophyll data for 274 lakes (Brown et al. 2000). Equations were also developed for nitrogen alone and nitrogen and phosphorous, but the TP equation gave the lowest values. Thus, different equations were determined at each reservoir to best represent the nutrient~chlorophyll-a relationship.

The final objective was to evaluate the TSI in relation to reservoir hydrology and management. As the reservoirs are primarily designated for agricultural storage, they are filled in the spring and decrease to between 10-30% of their initial volume by October. Since the TSI rely upon nutrient, chlorophyll-a and secchi depth information, their utility will relate to changes caused in those parameters by the decrease in reservoir volume. This must be evaluated on a case by case basis, since each reservoir has varying nutrient and chlorophyll-a concentrations, management and hydrology. In 2001, over the sampling period as reservoir volume decreased, the Carlson TSI based upon chlorophyll-a increased over the season. In general, the TSI based upon TP and Secchi disk depth also increased over the season. This increase is expected which indicates that any study should consider the time of year samples are collected and avoid using yearly or seasonal mean values in decision making as they will not represent the highest trophic state of the reservoir.

Principal findings and significance

This project relies upon nutrient, chlorophyll-a and secchi disk depth data. Little data containing all three elements is available. Thus, samples were collected to evaluate TSI and nutrient-chlorophyll-a models. The off-channel storage reservoirs in 1995 (five reservoirs) and 2001 (three reservoirs) exhibit a seasonal nitrate decline to below detection limits indicating potential nitrogen limitation. This nitrogen limitation, along with mean concentration utilization and limited classification categories, hinders TSI usage for off-channel storage reservoir evaluation. Typically total phosphorous gave a higher trophic status than chlorophyll-a indicating that another factor may be controlling primary production in the reservoirs. Different linear equations were determined to best represent each reservoir and equations using both nitrogen and phosphorous best characterized the system on several occasions. Thus, nitrogen may be a controlling factor at times in off-channel storage reservoirs and the lack of nitrogen use in TSI may hinder their applicability. Reservoir volume changes dramatically over the season and the month of sample collection with regard to trophic status determination should be considered.

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