GRAND RIVER BASIN WATER MANAGEMENT STUDY

TECHNICAL REPORT SERIES

REPORT #15

PLANT COMMUNITY ASSESSMENT TECHNIQUES DATA COLLECTION AND FIELD PROCEDURES

Prepared for
the Grand River Implementation Committee

by
R. Walker
K. Willson
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Water Modelling Section
Water Resources Branch
Ontario Ministry of the Environment
Toronto, Ontario, Canada

FOREWORD

The report "Plant Community Assessment Techniques" is one of a series of technical documents prepared for the Grand River Basin Water Management Study. The project described herein was undertaken through the Grand River Study Team at the request of the Grand River Implementation Committee.

The material contained in these reports is primarily technical support information and, in itself, does not necessarily constitute policy or management priorities. Interpretation and evaluation of the data and findings, in most cases, cannot be based solely on this one report but should be analyzed in light of other reports produced within the comprehensive framework of the overall study. Questions with respect to the contents of this report should be directed to the Co-ordinator of the Grand River Study, Water Resources Branch, Ministry of the Environment, 135 St. Clair Avenue West, Toronto.

Credits and Acknowledgements

The writers wish to acknowledge the efforts of L. Wong and staff of the Limnology and Toxicity Section of MOE's Water Resources Branch who initiated many of the data collection and analysis programs documented in this report.

Field data collection and subsequent analysis were carried out over several years by staff of the Limnology Unit and River Systems Unit of the Ministry of the Environment Water Resources Branch. The writers wish to express their appreciation to staff of the West-Central Region of the Ministry of the Environment and the Grand River Conservation Authority for the technical advice and assistance provided during the field surveys.

Thanks are also due to Ms. L. E. Oakley and Dr. I. W. Heathcote for their constructive criticism in the preparation of this report.

This project was conducted initially under the direction of Dr. P. Dillon of the Limnology Unit, and subsequently D. G. Weatherbe of the River Systems Unit, both within the MOE Water Resources Branch.

DISCLAIMER

Reference to equipment, brand names or suppliers in this publication is not to be interpreted as an endorsement of that product or supplier by the authors or the Ministry of the Environment.

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SUMMARY

The objectives of this report were to summarize the various techniques utilized in the Grand River Basin Water Management Study to assess both the extent of the aquatic plant growth in the river and the impact of the plant growth upon the instream water quality. The report also discusses the field procedure and data collection schedules required for such an assessment.

Techniques discussed in this report include the estimation of: solar radiation at both the water surface and at the plant depth, biomass density, biomass nutrient chemistry, and productivity and respiration of the plant community.

Also included is a discussion on the data interpretation and a recommended field survey required to provide the necessary input for the ecological model, ECOL1, which is described fully in the companion report, Report #14, "Aquatic Plant Model Derivation and Application".

Examples of data collected for both the plant community assessment and for the ecological modelling are provided in the appendices.

1. INTRODUCTION

Several shallow streams in Ontario have been identified as providing ideal habitats for attached aquatic plants (macrophytes). When these streams become enriched with nitrogen and phosphorus, plant communities can become prolific, resulting in a serious imbalance in the stream ecosystem. Extreme diurnal fluctuations of dissolved oxygen concentrations and obnoxious weed mats are symptomatic of this imbalance. The Speed River, downstream of Guelph, and the Avon River, near Stratford, are examples of streams suffering from this condition.

The control of nuisance aquatic plants requires detailed knowledge of the plant community, the conditions in the stream which cause the problem, and the effects of potential stream management policies on the stream's ecosystem. As well, it is often the case that a stream water quality problem has been identified in terms of violations of dissolved oxygen minima and an assessment must be made to evaluate the relative contribution of the aquatic plant community to the problem. This assessment is often complicated by other instream Processes such as sediment oxygen demand (SOD), carbonaceous biochemical oxygen demand (BOD), and nitrogenous oxygen demand (NOD).

It is the purpose of this document to outline the techniques used to assess the effects of an attached plant community on a stream and to assist in the interpretation of the data. Two suggested field study programs are presented at the end of this report. The first is for a descriptive survey aimed at evaluating the extent of an existing plant problem and its potential to grow. The second is an intensive quantitative assessment of a plant problem aimed at satisfying the calibration data requirements of the aquatic plant community dynamics model ECM. The second program would allow for assessment through simulation. Simulation might then be used to determine the extent of the problem under various conditions of flow or temperature, for example, or to estimate the impact of various proposed stream management policies on the stream.

Technical Report #15 is complemented by Grand River Technical Report #14: Aquatic Plant Model - Derivation and Application. This report discusses the development of the aquatic plant model ECOL1 and includes the rationale involved in interpreting pertinent data. Documentation of this model is available upon request from the Water Resources Branch, Water Modelling Section.

2. RADIATION

2.1 Solar Radiation

Solar radiation data can be acquired from the Atmospheric Environment Services (AES) Branch of Environment Canada. These data are collected at a series of meteorological stations across the country (there were 4 stations in Ontario in 1977) and is compiled in Monthly Radiation Summaries for all stations. Total hourly radiation and total daily radiation are reported in units of langleys/hr, which is also gm. calories/cm^2-hr.

If the stream in question is located a considerable distance from the nearest AES station or if local conditions tend to alter radiation values from those collected at the nearest station, it may be necessary to monitor solar radiation directly. A pyranometer, which is a simple electromechanical device whose operation is based on the difference in radiation absorption rates between different coloured metal strips, is used for this purpose. This type of instrument is fragile but reliable and provides measurements of received energy, broken down by wavelength. One must ensure that the instrument is located in a clear area away from shading and excessive dust or soot.

2.2 Photosynthetically Available Radiation (PAR)

Plants are able to utilize only a portion of total solar radiation as energy. Plant pigments are energy receptors which select from the broad band of wavelengths available. Various authors have measured the available portion of the total incident radiation and their estimates range from 38 to 54% (Won, 1978). It is generally accepted that the higher percentage is realized on overcast days and that this percentage decreases on sunny days. In the Grand River Basin Water Management Study (GRBWMS), the PAR (photosynthetically available radiation intensity taken here as wavelengths from 400 to 700 nm) was found to constitute from 46 to 62% of the total radiation with the higher percentage occurring on cloudy days*.

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* Clouds tend to filter out the shorter wavelengths of radiation. Therefore the PAR, which is mostly longer wave radiation, becomes a higher percentage of the residual radiation on passing through clouds.

This was determined from the long-term continuous solar radiation monitoring data collected during the study. For simplicity, a typical value of 54% can be used. More research is needed in this area to better quantify this estimation of PAR.

2.3 Underwater Light

The PAR at the depth in the water at which the majority of plants are located, is dependent on PAR at the water surface, the percentage of back reflection from the water surface, the transmission properties of the water and the depth of water. The pertinent algorithms describing these processes are discussed in detail in Technical Report #14. The transmission properties of water can be described by a parameter Ke known as the extinction coefficient. The method of estimating Ke involves measuring light intensity underwater with an underwater quantum sensor. The light sensor measures photo-synthetically available radiation in the 400-700 nm range. Triplicate readings are taken at ten centimetre depths below the surface. The values derived in this way will yield a straight line semi-logarithmic relationship with depth.

The extinction coefficient Ke can be calculated from the Beer-Lambert equation where,

$$Ke = \frac{\ln I_1 - \ln I_2}{Z_2 - Z_1} \qquad (1)$$

I_1 is the light intensity at depth Z_1.

Ke is a function of the optical properties of water and is strongly influenced by water colour, particulate content and nature, and dissolved material concentration. It has been shown to relate particularly to the water quality parameters of turbidity and suspended solids. This relationship would, however, be site and season dependent.

Relationships developed for the GRBWMS are as follows:

$Ke = 0.20 \bullet T + 0.35$ Upper Middle Grand (2)

$Ke = 0.23 \bullet T + 0.33$ Lower Speed River (3)

where T is turbidity (JTU). Relationships of this sort should be developed at each study site. They can be developed with the data collected in an intensive survey and will simplify data collection requirements in the long term.

If the PAR, % back reflection, Ke and depth are known, the photosynthetically available radiation at plant depth (PAR) can be calculated by the following equation:

$$PARz = PARo \bullet \frac{e^{(4.6 - Ke \,.\, z)}}{100} \qquad (4)$$

where z is the mean depth of the reach in question in metres and PARo is the PAR below the surface of the water. Ke is estimated from a relationship with turbidity or suspended solids, as shown above in equations (2) and (3).

Empirical relationships have been incorporated into ECOL1 to account for back reflection of radiation at the water surface and are discussed in the GRBWMS Technical Report #14. Under moderately overcast skies, back reflection as a percent is taken as

$$BACKREF = 17.45\, e^{(-0.86 \,\bullet\, ANGLE)} \qquad (5)$$

where ANGLE is the angle of incidence of the sun (radians) and can be calculated from empirical relationships also discussed in Technical Report #14.

3. NUTRIENTS

Aquatic plants require a large variety of nutrients to grow and synthesize new plant material. All of these nutrients are generally present in sufficient quantities in natural streams with the exception of phosphorus and sometimes nitrogen. *Cladophora* and *Potamogeton pectinatus* are able to utilize nitrogen in any of the common inorganic forms, nitrate (NO_3^-), nitrite (NO_2^-) and ammonia (NH_3), although NH_3 is preferentially utilized when available (Walker *et al*, 1979). Assimilation ratios of nitrogen are variable in the range of 0.01 to 0.03 gm N/gm dry biomass.

Plants require about one-tenth as much phosphorus as nitrogen with minimum assimilation ratios of about 0.0015 gm P/gm dry biomass. However, since these plants can stockpile excess phosphorus, the actual assimilation ratio could be considerably higher in eutrophic conditions.

The supply rate of available phosphorus is also of importance. Plants are unable to assimilate particulate phosphorus, so only dissolved forms of phosphorous are bioavailable. The filterable fraction of phosphorus (FP), defined as that portion which passes a 0.45 µ filter, has been found to be available to plants in streams (Walker *et al* 1979). The so-called reactive fraction (FRP) of the filterable fraction is preferentially utilized but no limitation to growth is evident in plant communities existing in streams with very low FRP concentrations when FP is available in sufficient quantities.

In lakes, the particulate material containing phosphorus often remains in suspension in the water column for long periods of time (several months) where it is subjected to bacterial decomposition and solubilization. In those systems, particulate phosphorus can be an important contributor to the supply of FP. However, in streams the residence time is short (a few days) and decomposition and solubilization does not take place to a significant degree. Therefore, particulate phosphorous is not a major source of FP in streams.

The phosphorus and nitrogen requirements of plants are related to ambient conditions. For instance, when conditions of temperature and sunlight are ideal, plants will exert a higher demand for nutrients than when conditions are less ideal. It is therefore common for a plant community to be nutrient-limited only during the peak production hours. Plants may draw upon phosphorus stored in tissue to satisfy demand at these times and store excess nutrient during less optimum periods when there is an adequate nutrient flux. Demand will therefore be a function of plant density, bed size and potential growth rate. Supply should be measured in mass flow units, i.e. kg/hr. Phosphorus flux in the order of 0.5 kg FP/hr. has always been observed to meet the demand of a 175,000 m^2 weed bed when densities are below 200 gm/m^2 in the Grand River.

In order to estimate the nutrient balance of the weed bed, that is, the mass flux of nutrient into the biomass, nutrients (NH_3, NO_3^-, NO_2^-, FP) should be sampled at each end of a weed bed within the same "plug" of water during the peak hours of productivity (12:00 to 16:00 hr). As well, when weed beds exist upstream of the reach in question, short term (72 hr) intensive nutrient sampling should be conducted at each end of the reach at frequent time intervals (3 hr) in order to determine whether a significant diurnal fluctuation of incoming nutrients occurs. Upstream plants can significantly reduce incoming nutrient loads during the latter portion of the photoperiod. This could also be the case downstream of sewage treatment plants which display fluctuating effluent load characteristics.

4. BIOMASS DENSITY AND CHEMISTRY

4.1 Cropping

Biomass densities in a reach can be estimated within acceptable limits of confidence if access to the reach is not a problem. This information can be extrapolated to the stream area of interest provided that substrate mapping has *been* done (see Section 6.2).

Cropping techniques are simple. A Surber sampler, usually 1 foot square, is placed over a representative section of substrate and the attached plants are removed. Samplers usually have an attached net on the downstream side to catch the harvested plant fragments. When the sample area is cleared of visible macrophytes the sample can be quantified as either the density per square foot fresh weight or dried in an oven. Drying of samples takes about 2 hours at 100°C in a ventilated oven. Densities are measured in areal units of attached macrophytes and are more consistent in dry units. Of course, the periphyton community will not be included in this estimate.

Periphyton can be estimated by scraping several rocks taken from a known area and drying the collected material. The sample should be volatilized in order to determine the organic weight in a known area*. This step is necessary since non-organic material will be collected along with the periphyton and would otherwise lead to an overestimate of the density. Plant material is usually about 50 to 80% volatile by weight. Several rocks should be sampled within a known area and scraped completely clean to estimate the areal density. A large sample area will reduce the error resulting from spaces between rocks and different rock slopes.

The number of samples required to estimate the average density in a large area is a function of total area of weed bed, homogeneity of the bed density and accuracy required.

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* The volatile fraction is determined by heating the sample at 400°C for about 2 hours.

Non-homogeneity can be overcome by taking three or four samples, evenly spaced at evenly distributed transects along the stream. Transects should be evenly spaced at intervals of 100 to 500 metres depending on the total length of the reach. This distribution of transects will provide an essential element of randomness in the sampling.

The variability associated with a particular sample or group of samples (as representative of the entire reach) can be estimated using the sample variance. The variance S^2 and standard deviation S of a randomly-collected set of samples are calculated as follows:

$$S^2 = \frac{n\,(\Sigma\, x^2) - (\Sigma\, x)^2}{n\,(n - 1)} \qquad (6)$$

and $S = \sqrt{S^2}$

where x is an individual sample density and n is the number of samples. In a normally-distributed set of samples, 68% of sample observations will lie within ±1 standard deviation of the mean, and 95% and 99% will lie within 2 and 3 standard deviations, respectively. The standard deviation is therefore a useful measure of variation in a data set: if it is a small number, the implication is that most observations are close to the mean value.

Sometimes it may be useful to calculate the sample size required to estimate reach biomass well (say ± 10%) and consistently (say 95% of the time). To do this, the allowable error margin (here 10%) must first be selected and applied to the mean biomass density.

Calculate the quantity as

$$L = \bar{x} \bullet E \qquad (7)$$

where E is the allowable error and $\bar{x}$ is the mean. Then select the level of consistency desired in sampling. Some error due to random or chance effects will always be present, but by making the test criteria very stringent, one can be 95%, or 98% or 99% certain that the observed effects are real, not fortuitous.

The sample size required to achieve a given error, 95% of the time, is therefore calculated as

$$n = \frac{t^2_{.95} \bullet S^2}{L^2} \qquad (8)$$

where n = the number of samples required, t = Student's t statistic (for 95% significance, obtained from tabulated values), and S^2 = variance of the sample.

As an example, if 21 samples are cropped, yielding

$$\Sigma x = 58.7$$

and $$\Sigma x^2 = 203.2$$

$$\overline{x} = 2.80$$

$$\text{then} \quad S^2 = \frac{21\,(203.2) - (58.7)^2}{21 \times 20} = 1.96 \qquad (9)$$

The sample size, n, for a ± 20% error with 95% confidence is then

$$n = \frac{1.96^2 \times 1.96}{(0.2 \times 2.8)^2} = t_{\infty\ 0.95} = 1.96 \qquad (10)$$

$$= 25$$

If only 10% error is desired, the number of the quadrat samples, n, required to attain an error of less than ± 10%, 95% of the time, is

$$n = \frac{1.96^2 \times 1.96}{(0.1 \times 2.8)^2} = 96 \qquad (11)$$

These sample sizes are meant as a guide to field data collection. When a data set has been collected and analysed, this method can be used to calculate the error involved at some desired level of confidence and as a guide to further biomass estimation.

If sampling is based on sound statistical principles, then interpolation of resultant densities within the sampled area will yield a good estimate of plant densities.

4.2 Aerial Photography

Aerial photography aimed at estimating the relative extent and distribution of plants in a river is a reasonable approach when very large areas are involved or access is particularly difficult. However, aerial photography is much more meaningful when followed by ground surveys and should not be considered as an alternate independent method. Several errors can result in interpreting aerial photographs largely due to changes in stream depth and shading. The process is also considerably more expensive than cropping as a method of estimating instream biomass.

4.3 Phosphorus in Plants

A great deal of information can be gained by subjecting plant samples to an analysis of phosphorus in tissue. Wong *et al* (1976) found that phosphorus in plants showed a positive relationship to stream phosphorus concentrations; this relationship would be site specific. Based on results from the Grand River Study, when phosphorus in plants decreases below 0.0015 gm P/gm biomass, the plant community is likely to be growth limited to some extent by the availability of phosphorus. Very high tissue phosphorus indicates a luxurious supply of phosphorus since plants can store excess phosphorus in tissue. Stored phosphorus will tend to decrease as density and total demand increases through a weed bed and plant communities will often continue to grow until a phosphorus limitation is realized. The plant nutrient analysis data are included in Appendix 1.

4.4 Nuisance Biomass Densities

The density at which a plant community can cause violations of DO criteria in a stream, in the absence of other respiratory processes (SOD, BOD, NBOD), is a function of the stream's reaeration potential, the flow rate, the time-of-travel and the length and density of the plant bed.

The species of nuisance plants commonly found to infest Ontario streams (*Cladophora*, *P. pectinatus*) prefer to inhabit relatively shallow, fast flowing stream sections in which velocity exceeds 0.3 m/sec and reaeration is high, (K_2 >3 day^{-1}). Under these conditions,

a 2 km stream reach would have a time of travel of about 2 hours. Typical nuisance attached plant densities are greater than 100 gm (dry)/m^2 under these conditions. Densities of 200 gm/m^2 will, in most cases cause severe diurnal fluctuations with night-time values falling below the DO objective of 4 mg/L (25°C).

A biomass density of 200 gm (dry)/m^2 would result in an areal respiration rate of about 0.9 gm O_2/m^2 hr at 20°C - a significant uptake rate (assuming 2 gm dry of biomass respires at a rate of 0.0045 gm O_2/gm hr at 20°C).

5. PRODUCTIVITY AND RESPIRATION

5.1 Oxygen and Temperature Monitoring

In order to measure productivity and respiration in a river reach, oxygen and temperature monitors must be installed. The resultant data serves three purposes.

(1) it is used as a primary measure of stream water quality,
(2) it allows for the use of Odum's productivity analysis, to be discussed in the next section,
(3) it provides calibration data for use in the aquatic plant model ECOL1.

If a detailed Odum's analysis is to be carried out (dual curve analysis, see Section 5.2 and Chapter 7) two such monitoring units will be required and their location is critical. The monitoring stations should be located on a river section where there is good lateral and vertical mixing. This reduces the risk of stratification in one or two dimensions which is common in slow and wide or deep sections. As well, the two stations should be located at either end of a reach fairly homogeneous in terms of morphometry and plant densities if possible. Stations should be no more than 3 hours and no less than 1 hour time-of-travel apart. The location of significant point sources of flow and/or effluent within the study reach will also result in errors and analytical difficulties.

The single curve method also requires careful placement of monitoring equipment. The single curve method is based on short-term changes in oxygen concentration occurring in the reach upstream of the monitoring station. The station should be at the downstream end of a homogeneous section supporting plants. Time of travel within the weed bed should be at least one hour. No point sources of flow should be located within the upstream reach in question.

Oxygen probes should be suspended as close to the centre of the flow as possible and protected from drifting material (see Figure 1) by a net or screen. This screen will require frequent cleaning at times. EIL oxygen meters (Electronics Instruments Ltd.) coupled

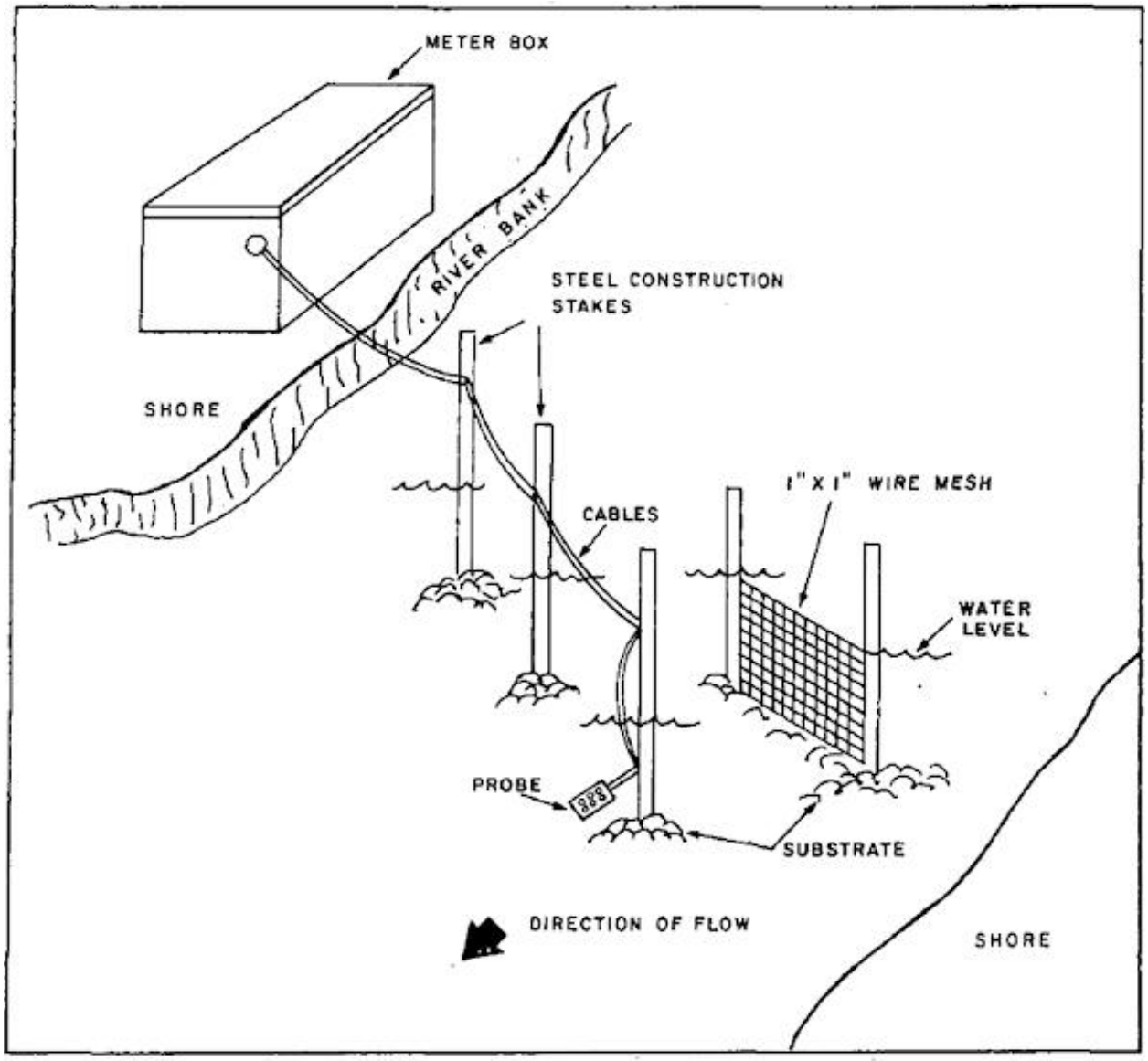

FIGURE 1: Diagram Illustrating the Installation of Dissolved Oxygen and Temperature Monitoring Equipment in Shallow Streams**.**

with Rustrak recorders (Gulton Instruments) have been found to work well in rigorous field circumstances. These instruments are accurate to about ± 3% of oxygen saturation.

Before installation of meters and probes, the monitoring equipment should be checked and calibrated, and at the end of the monitoring period a re-calibration should be done; corrections can also be applied between calibrations. Calibration can be done using the Azide Modification of the Winkler technique (WPCF, 1975).

Diurnal oxygen fluctuations should be monitored for at least 72 hours to ensure the reliability of measured productivity parameters. As well, rainfall, cloud cover or fluctuating flows may invalidate data for any single day for specific purposes. The meters should be checked at least once a day and recalibrated if necessary. At this time the screen should be cleaned and pertinent data recorded on the recorder tape such as the date and time of day, the corrected oxygen saturation and temperature and the station number. Continuous and reliable data will be collected if the equipment is maintained in an orderly fashion.

5.2 Productivity Analysis

The method of productivity analysis discussed in this section was first proposed by Odum (1956) and is a measure of total community productivity of submerged plants and the total of all respiration processes in the reach in terms of oxygen transfer. In this analysis technique, hourly changes of dissolved oxygen at each station are calculated. In the two station method, the two resultant curves are compared with the downstream curve shifted one time-of-travel ahead. The net changes between these curves at each hour then constitute the total net hourly change of oxygen in volumetric units in the reach. The contribution from respiration, productivity and reaeration can then be partitioned systematically in order to assess the relative impact of the plant community. In the single curve method, the stream for several hours time-of-travel upstream of the station, should be in steady state conditions (simultaneous and equal change). This condition is seldom met and therefore this method is less accurate and the results must be viewed in relative

terms only. The following is a description of the graphical dual curve method used in the Grand River study; other refinements of the method exist.

Dual Curve Analysis

The dual curve analysis involves several steps and is therefore time consuming. It can be performed on a desk top calculator but if large amounts of data are involved, as would be collected over a period of 10 days, it is recommended that an appropriate computer program be used. This program is available from the MOE Water Resources Branch, Water Modelling Section.

The procedure is as follows:

1. Set up the raw data in a tabular form for each monitor, as shown in Table 1. This table should start at sunset. This will allow for the analysis of one complete night-time period, essential in this technique. Note that the saturation deficit is positive when the dissolved oxygen concentration is less than saturation.

2. Construct dissolved oxygen concentration versus time-of-day curves. The downstream curve must be shifted to the left a time period equal to the time-of-travel. This allows for a direct comparison of hourly 'plugs' of stream water in terms of dissolved oxygen (see Figure 2).

3. Construct a curve of saturation deficit for both stations. No shift is required here (see Figure 3). This curve allows for an estimation of the average saturation deficit within the reach at any time. Note that at 1600 hrs in Figure 3 the average saturation deficit ($\overline{SD}$) is 8.3 mg/L.

TABLE 1: Dual-Curve Productivity Analysis Data.

TIME	% Saturation	Temperature °C	DO sat [1] mg/L	DO sat [2] mg/L	Saturation Deficit (1-2) mg/L
2000	152	21.0	8.82	13.40	- 4.58
2100	134	21.0	8.82	11.81	- 2.99
2200	108	20.5	8.91	9.62	- 0.71
2300	92	20.1	8.98	8.26	+0.72
2400	78	19.9	9.01	7.03	+1.98
100	68	19.5	9.09	6.18	+2.91
200	62	19.1	9.18	5.69	+ 3.49
300	54	18.8	9.24	4.99	+ 4.25
400	50	18.0	9.40	4.70	+ 4.70
500	47	18.0	9.40	4.41	+ 4.99
600	45	17.2	9.56	4.30	+ 5.26
700	46	17.0	9.61	4.42	+ 5.19
800	51	16.8	9.65	4.92	+ 4.73
900	74	17.4	9.51	7.04	+ 2.47
1000	100	17.8	9.43	9.43	-
1100	128	19.0	9.20	11.77	- 2.57
1200	156	19.7	9.06	14.13	- 5.07
1300	180	20.0	9.00	16.20	- 7.20
1400	204	20.5	8.91	18.17	- 9.26
1500	212	20.9	8.84	18.73	- 9.89
1600	218	21.3	8.76	19.10	-10.34
1700	216	22.0	8.64	18.66	-10.02
1800	209	22.0	8.64	18.06	- 9.42
1900	188	22.0	8.64	16.25	-7.51
2000	173	22.0	8.64	14.95	- 6.31
2100	150	21.6	8.71	13.07	- 4.36
2200	124	21.3	8.77	10.87	- 2.10
2300	104	21.2	8.78	9.13	- 0.35
2400	88	21.0	8.82	7.76	+ 1.06
100	74	20.8	8.85	6.55	+ 2.30
200	68	20.2	8.96	6.09	+ 2.87
300	57	20.0	9.00	5.13	+ 3.87
400	54	19.5	9.09	4.91	+ 4.18
500	50	19.0	9.20	4.60	+ 4.60

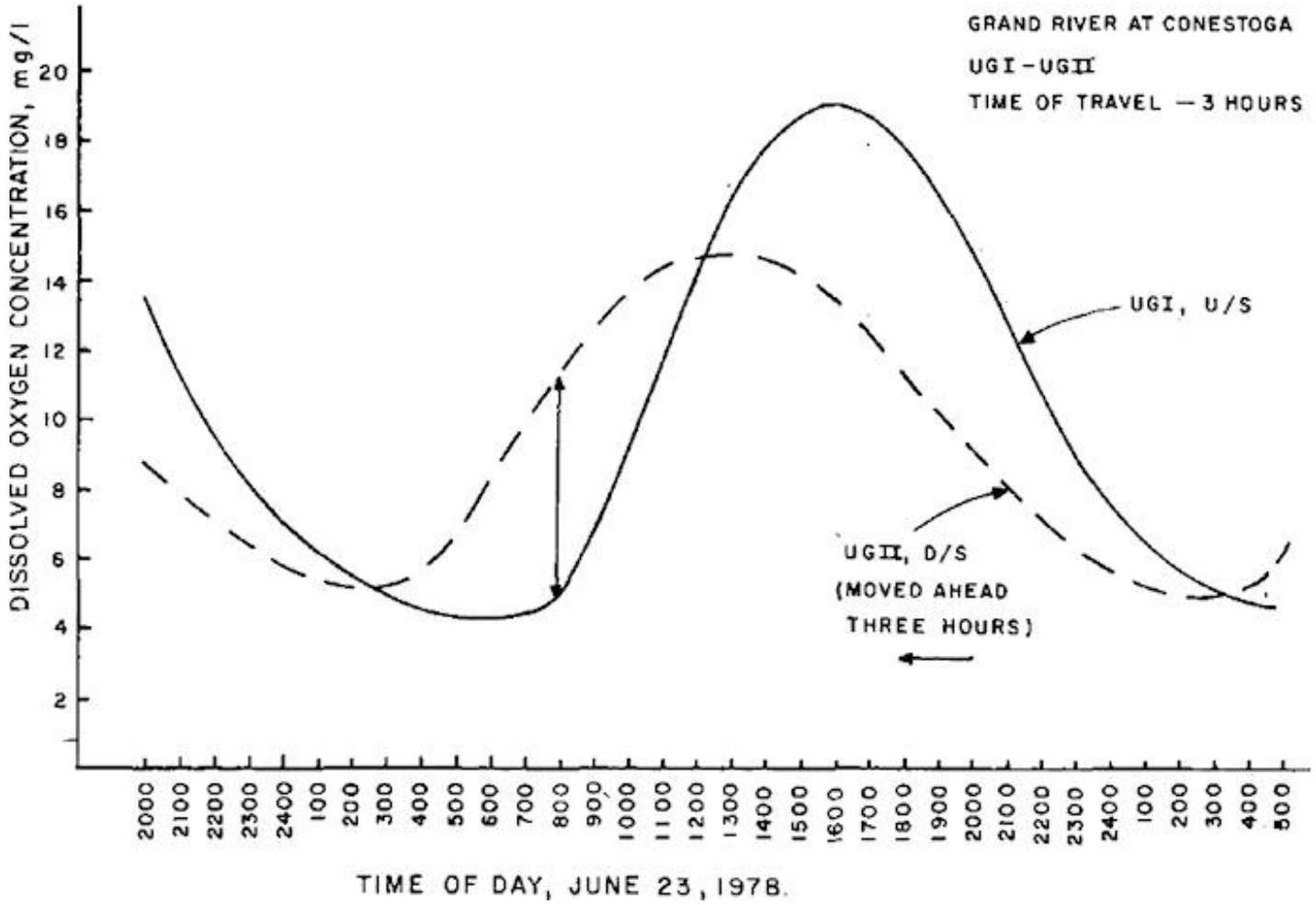

FIGURE 2: Diurnal Oxygen Curves For Two Stations On The Grand River.

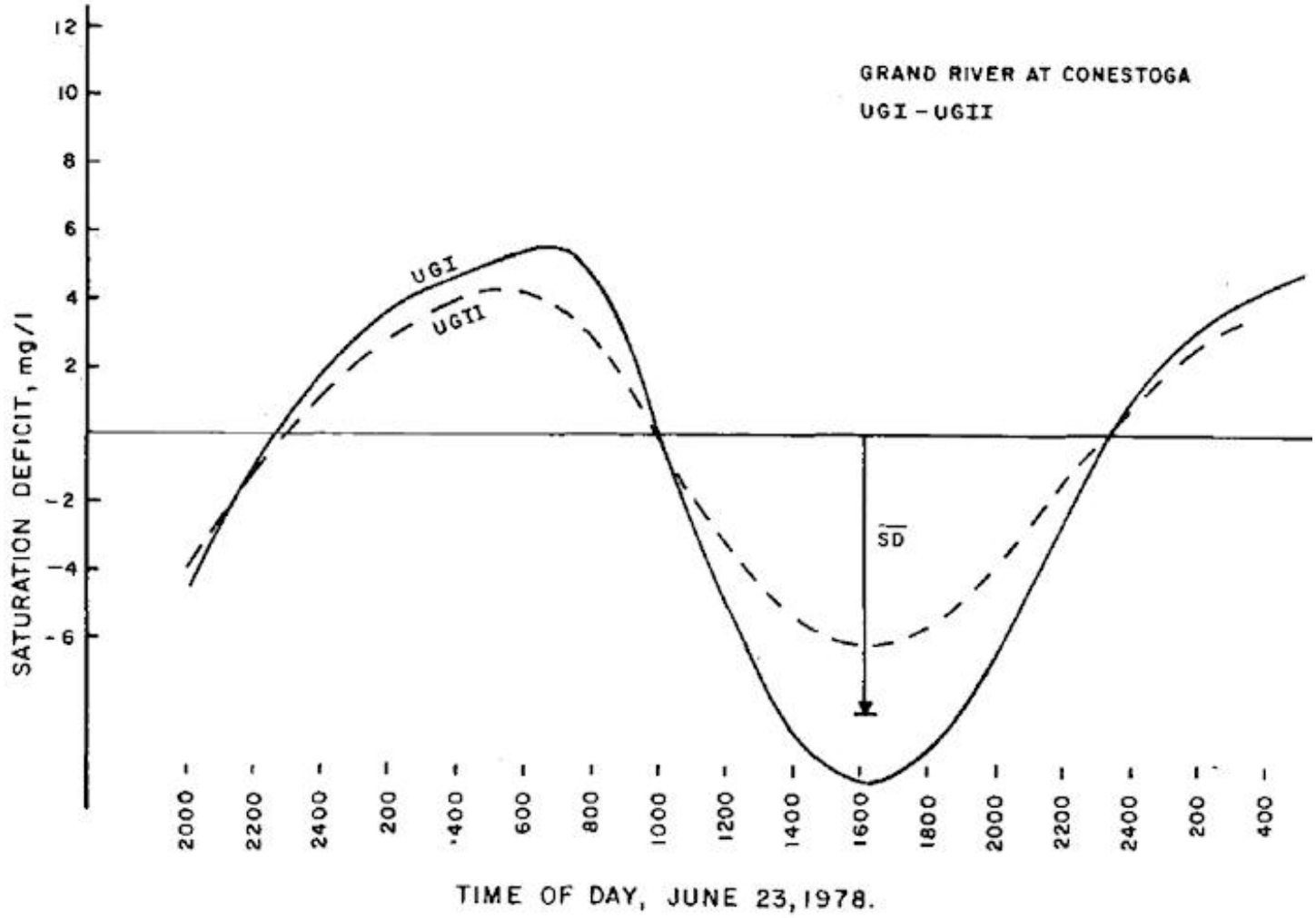

FIGURE 3: Saturation Deficit Curves.

4. At hourly intervals determine the net change of oxygen concentration, ΔO_2, between the two stations. These values can be taken directly from Figure 2. Note that at 0800 hr on June 23rd, the two curves differed by 6.3 mg/L. This change actually occurred between 0800 at station UGI, the upstream station and 1100 at UGII, the downstream station. Therefore the net change is recorded as having occurred at 0930, one half the travel time of the plug in question.

5. Net oxygen changes from Figure 2 are in units of mg O_2/L per time-of-travel and must be converted to areal units of gm/m^2 per hr. This is done by multiplying the ΔO_2 values by depth (m)/Time-of-travel. In the example shown this is 0.33 m/3.0 hr = 0.11.

6. Construct a curve of net oxygen exchange in areal units such as that shown in Figure 4. Note that the values in this figure are advanced half of the time-of-travel from those shown in Figure 2; that is, the 0.3 mg/L difference at 0800 in Figure 2 is converted to areal units and becomes 0.70 gm/m^2hr and is plotted at 0930 in Figure 4. This value is then the hourly areal oxygen exchange rate which was, in effect, in a plug of water which entered the reach at 0800 and exited at 1100 on June 23.

7. Plot night-time values of ΔO_2, taken from Figure *2,* versus the SD values taken from Figure 3 and converted to areal units. SD is converted to areal units by multiplying by mean depth. These values should form a straight line (see Figure 5). The slope of this line equals the K_2 or reaeration coefficient value and the intercept in the ΔO_2 axis is equal to hourly respiration since

$$\frac{\Delta O_2}{\Delta t} = K_2 SD - R;$$

at night the equation is a straight line with slope K_2 and intercept R.

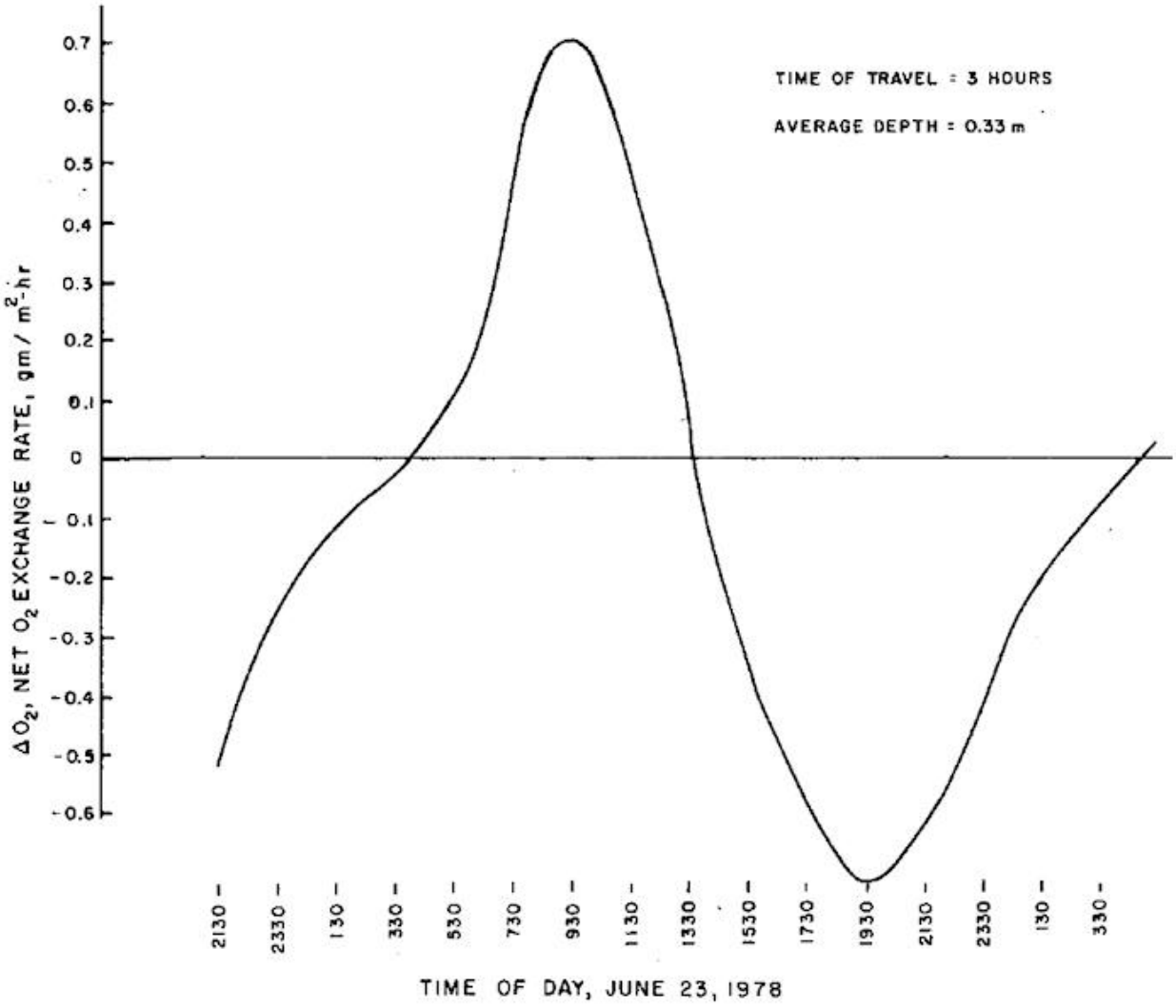

FIGURE 4: Net Oxygen Exchange Curve.

8. Construct a table like Table 2. Hourly reaeration rates are calculated as $\overline{SD} \times K_2$. Net productivity (P-R) is equal to $\Delta O_2 / \Delta t$ - Reaeration. At night this is equal to R.

9. Construct a curve of net productivity versus time as in Figure 6. The values during night-time can be averaged to estimate R by another method. In the example a value of 0.37 is estimated for R and compares favourably with the value of 0.34 taken from Figure 2.

10. Using an R value of 0.37 gm/m^2hr the gross productivity GP column in Table 2 is constructed. GP is simply NP + the absolute value of R.

11. Daily P_{max} can be taken from Figure 6 and total daily Gross P is the sum of hourly values from Table 2. Total daily respiration TR is simply 24 x R. Net daily productivity is GP-TR. In this example the plant community had a net gain of 1.06 gm O_2/m^2day meaning that there was a net increase in biomass over the day.

TABLE 2: Hourly Productivity Analysis.

Time	Avg. Saturation Deficit gm/m^2	Reaeration gm/m^2-hr.	$\Delta O_2/\Delta t$ gm/m^2 -hr.	Net Prod. gm/m^2-hr.	Gross Prod. gm/m^2 -hr.
2200	-0.30	-.07	-.42	-.35	-
2300	+0.13	+.03	-.30	-.33	-
2400	+0.50	+.12	-.21	-.33	-
100	+0.83	+.20	-.14	-.34	-
200	+1.1	+.26	-.08	-.34	-
300	+1.3	+.31	-.05	-.36	-
400	+1.47	+.35	0	-.35	-
500	+1.53	+.37	+.07	-.30	.05
600	+1.60	+.38	+.16	-.22	.14
700	+1.53	+.37	+.32	-.05	.31
800	+1.23	+.30	+.58	+.28	.64
900	+0.67	+.16	+.69	+.53	.89
1000	- 0.07	-.02	+.70	+.72	1.08
1100	- 0.76	-.18	+.58	+.74	1.10
1200	- 1.33	-.32	+.40	+.72	1.08
1300	- 1.93	-.46	+.20	+.66	1.03
1400	- 2.73	-.66	-.07	+.59	.96
1500	- 2.67	-.64	-.27	+.47	.84
1600	- 2.73	-.66	-.42	+.24	.62
1700	- 2.70	-.65	-.53	+.12	.51
1800	- 2.50	-.60	-.58	+.02	.40
1900	- 2.17	-.52	-.70	-.18	.20
2000	-1.70	-.41	-.71	-.30	.08
2100	- 1.20	-.29	-.66	-.37	.01
2200	- 0.70	-.17	-.57	-.40	-
2300	- 0.16	-.04	-.47	-.43	-
2400	+0.31	+.07	-.35	-.42	-
100	+0.68	+.16	-.24	-.40	-
200	+0.93	+.22	-.17	-.39	-
300	+1.13	+.27	-.11	-.38	-
400	+1.30	+.31	-.05	-.36	-
TOTAL				9.94 gm O_2/m^2	

Total Respiration = 24 x 0.37 = 8.88 gm O_2/m^2

Net Productivity = 9.94 - 8.88 = 1.06 gm O_2/m^2

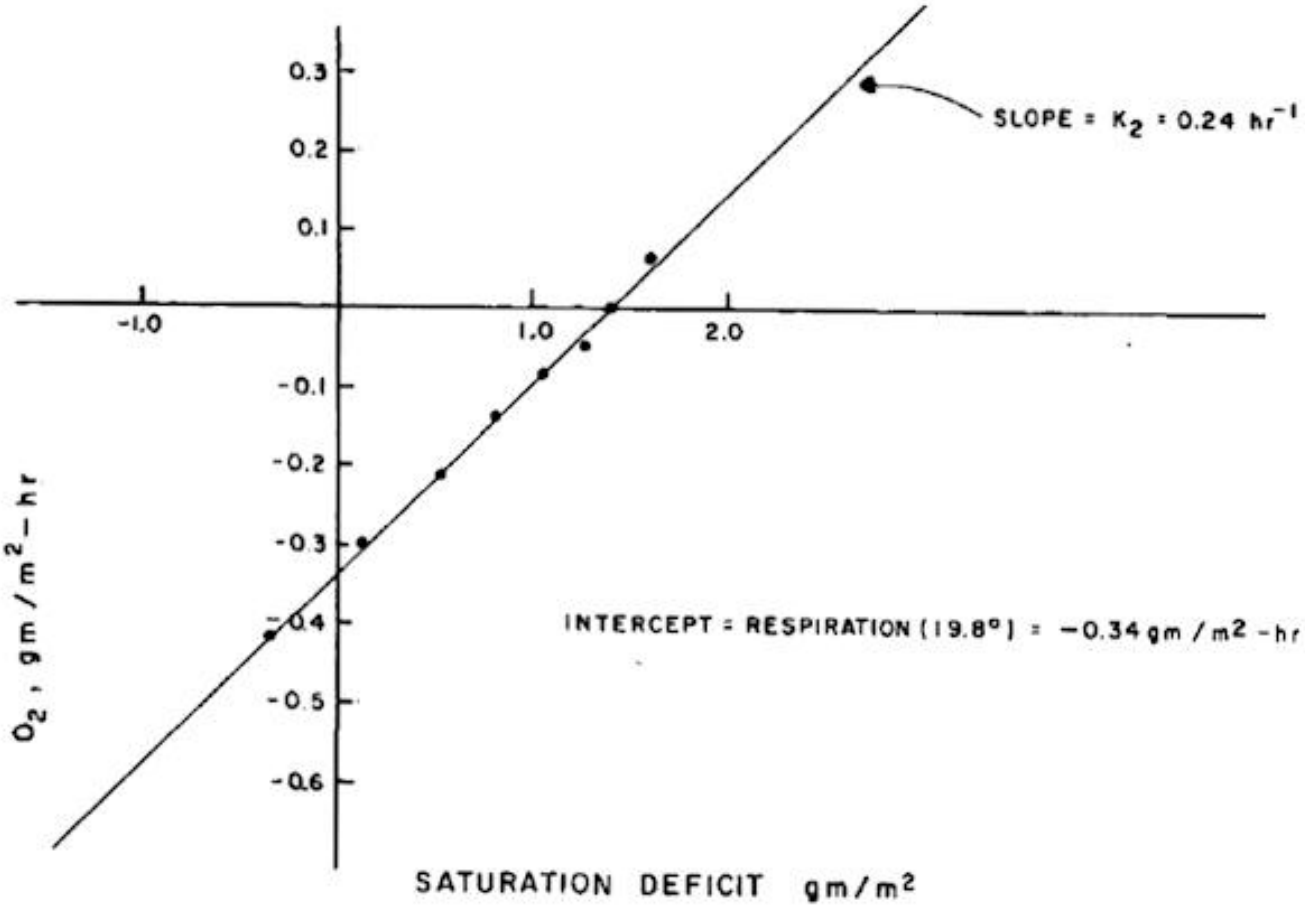

FIGURE 5: Regression Of Nighttime DO Against Saturation Deficit.

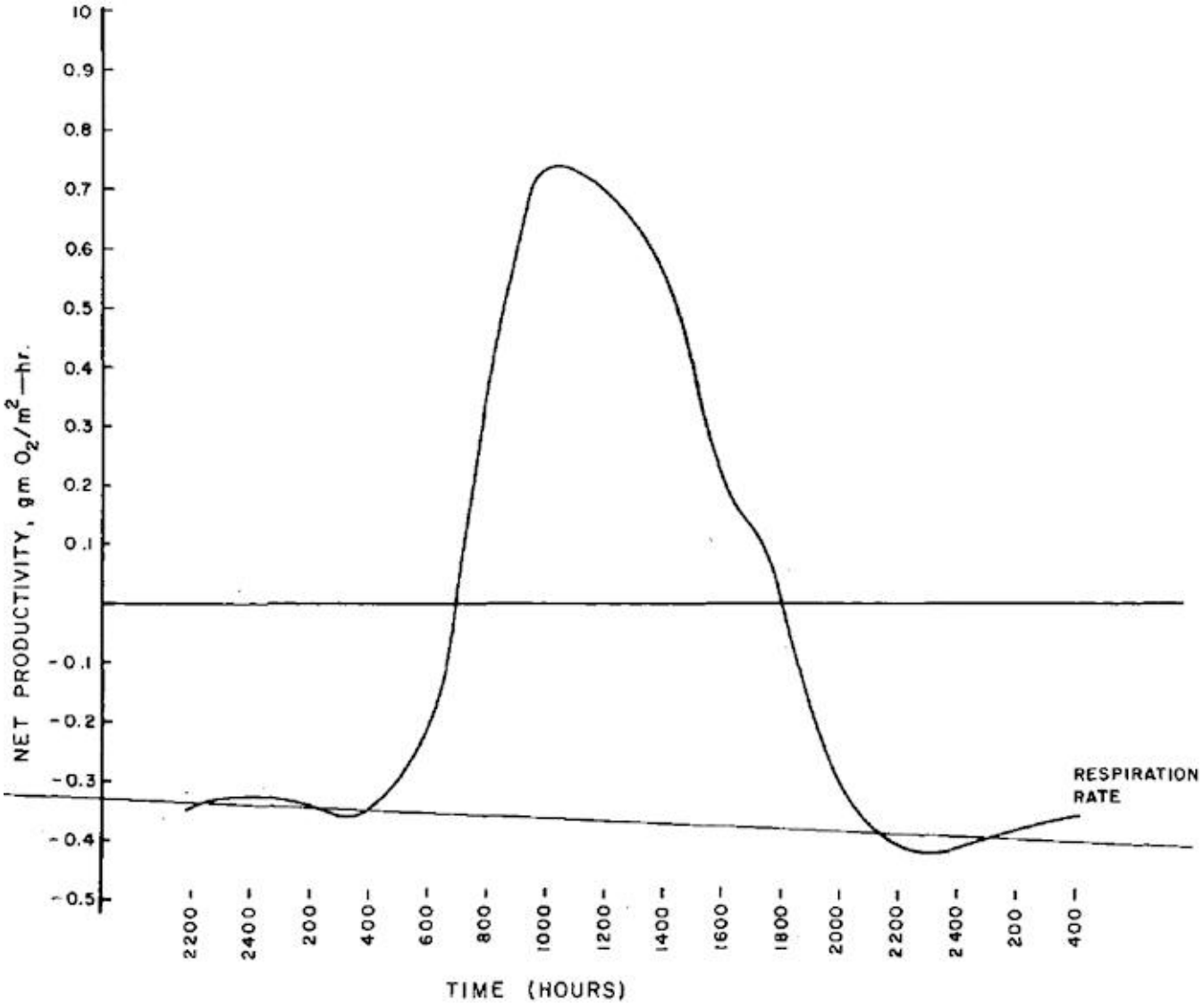

FIGURE 6. Net Productivity Curve.

6. HYDRAULICS AND SUBSTRATE

6.1 Hydraulic Parameters

Mean depth in a river reach which supports attached aquatic plants is of prime concern. Depth is used to calculate the volumetric effects of surface active processes such as SOD and plant respiration. Depth also affects the quantity of light available to plants. Direct measurement is labour intensive and often inaccurate. As well, direct measurement does not supply the information necessary to relate mean depth to flow. Mean depth can be calculated from time-of-travel (TOFT) and flow measurements (Q) and reach area as

$$\text{MEAN DEPTH} = \frac{Q \times TOFT}{AREA}$$

Area can be estimated by measuring stream width at each biomass cropping transect and estimating reach length from small scale topographical maps or aerial photographs.

Flow can often be acquired from existing gauging stations or by direct measurement. Various methods are available and will not be discussed here. Accurate flow measurement is essential in these assessments.

It is also essential to know the time required for the water to travel from one station to the next. A water mass travelling downstream will not remain in a "plug" but will gradually disperse longitudinally. For this reason the retention time is best measured by noting the progress of a fluorescent dye (eg: Rhodamine WT) from one station to the next. The time-of-travel of the dye cloud will be comparable to the time-of-travel of the water body. The amount of dye used depends on the volume of water in which it will be diluted. Two or three liters of 20% Rhodamine WT dye diluted with water into two one gallon aliquots for injection will allow visual detection of the cloud in small rivers (approx. 5 to 7 cm). Care should be taken when using dye tracers in streams. The situation should be assessed to check the impact on downstream water uses, particularly water supplies and livestock watering. The amount of dye used in a particular study should be guided

by both the stream flow and the length of the stream being investigated. Visual detection of the approaching dye cloud at the downstream station is important for proper sampling. The time-of-travel is determined as follows:

1. Position one person on either side of the river 100 meters upstream of the first station. They begin injecting the dye, while walking towards each other in the stream, in a slight downstream direction. The dye is poured such that the total amount is used upon reaching midstream. By walking in a "V" the final dye cloud will be in a reasonably straight band across the river.

2. The amount of time that the leading edge of the dye cloud takes to arrive at the station is called dead time. Two samples should be taken at each station before the dye arrives and a third should be taken in the leading edge. Take approximately fifteen samples after the arrival of the dye cloud over a length of time equivalent to the dead time. The sampling interval can be shortened as the centroid (visible maximum concentration) passes to ensure accurate plotting of the curve of concentration vs time. Longitudinal dispersion of the dye cloud becomes greater with progression downstream but the samples should still be collected for a length of time equivalent to the dead time. For this reason a dye run past several stations could take considerable time and often an entire day should be set aside for the study. In addition, the dye cloud may arrive at the second station before the sampling has been completed at the first, necessitating two crews.

3. The dye concentration of each sample is determined by measuring the absorbance at 560 nm (for Rhodamine WT) using a spectrophotometer or fluorometer.

4. The individual concentrations are plotted against time and the time-of-travel between stations is represented by the time interval between the centroids of the individual station curves. Pronounced centroids can usually be observed directly off the graphs, but some downstream concentration curve centroids may have to be calculated mathematically (the differential determination of area under the curve

to establish the mid point representing half of the area).

5. Individual time-of-travel determinations are then compared to a staff gauge height or flow rate under three or more different flow rates. The retention time can then be determined on occasions when a dye run was not conducted by measuring the flow rate or staff height and then referring to its relationship with the retention time.

Time-of-travel and flow measurements should be made under a variety of flows in order that appropriate empirical relationships can be established. Useful site-specific relationships are:

Staff Height: Flow
Flow: Time-of-Travel
Flow: Mean Depth
Flow: K_2 (Reaeration Coefficient)

Additional details of these procedures are contained in the Stream Water Quality Assessment Procedures Manual (MOE, March 1980).

6.2 Substrate Mapping

In any shallow stream reach the benthic surface will be composed of a variety of substrate types. *Cladophora* and *P. pectinatus* require a stony substrate typical of shallow, fast flowing stream sections. Even in a reach which is predominantly of this sort, small areas will exist in which flow is subcritical and sedimentation processes will dominate. If these areas are in isolated pools, away from the main flow, then their contribution to stream processes is unimportant. However, if these silty bottom areas are in the mainflow, they may be sites of significant oxygen utilization by sediment chemical and biological processes (SOD). This component of the total respiration should be subtracted from the total in order to estimate the plant portion. Good estimates of the SOD

(sediment oxygen demand) can be achieved through the use of the dome respirometer designed by the River Systems Unit. A description of the construction and use of the respirometer is included in Appendix 8.

If silty bottom areas are judged to constitute a significant portion of the total area (>10%) then the reach substrate should be mapped. A simple division between silty and rocky substrates is sufficient. These estimates can be made visually from a canoe or estimated from aerial photographs. If a small but significant biomass exists the mapping procedure will be easier.

7. FIELD STUDY OUTLINES

7.1 Descriptive

'This section is intended as a guide to the design of field programs aimed at identifying an aquatic plant community and estimating its present and future nuisance potential, for instance when a plant community has been observed on a stream and the stream's water quality is questionable. The study program outlined (Table 3) would provide the data needed to determine whether a plant-induced problem exists and whether the full potential of the problem has been reached under the existing condition. Obviously this exercise will be most meaningful if it is conducted during a time when plant biomass is near its seasonal peak and stream flow and temperature are critical from a dissolved oxygen point of view.

7.2 Intensive

The intensive measurement program (summarized in Table 4) is a more comprehensive one which will result in the assembly of a calibration data set which satisfies the requirements of the aquatic plant model ECOL1. After ECOL1 has been 'tuned' at a stream site it can be used to simulate various possible future conditions and assess the impact

TABLE 3: Descriptive Study Plan for Assessment of the Magnitude of an Aquatic Macrophyte Community.

TASK	FREQUENCY OR DISTRIBUTION	USE OR INTERPRETATION
DO-Temp monitoring	Continuously for 72 hours at a single downstream station.	▸ Total community productivity and respiration from Odum's analysis. ▸ Reaeration coefficient ▸ Dissolved oxygen ▸ Biomass estimate.
Biomass survey	3 quadrats at each transect. Transects should be about 100-200 metres apart, evenly spaced. Major species should be identified along with the % of the total biomass.	▸ Biomass density ▸ Species distribution
Biomass Chemistry (Phosphorus in plants)	5 samples from along the weed bed.	▸ Phosphorus in plants indicates the degree of nutrient limitation.
Water Quality ($FP, NO_3, NO_2, NH_3, BOD_5$)	3/day at each end of weed bed	▸ Loss of BOD_5 and N in reach indicates respiration processes other than plants. ▸ FP loss confirms plant productivity and FP flux indicates level of potential growth.
Mean depth and flow rate.	At each change in flow	▸ Necessary in Odum's analysis and estimation of mass flow of nutrients.

and net gain of various remedial measures. This analysis is most suited to a time period when the biomass is healthy and has reached a significant density. As well, the survey will be more meaningful if it takes place during low flow conditions. Data collected from one of the descriptive surveys are included in Appendices 2 and 3 while data collected during the intensive study are shown in Appendices 4 and 5. Appendices 6 and 7 illustrate data obtained from the dome respirometers during the intensive study.

TABLE 4: Intensive Study Plan to Provide the Input Data Required by the ECOL1 Model.

TASK	FREQUENCY OR DISTRIBUTION	USE OR INTERPRETATION
DO-Temp monitoring	Continuously for 1 full week at each end of the study reach but not more than 3 hrs time-of-travel apart.	▸ Total community productivity and respiration from Odum's analysis. ▸ Reaeration coefficients. ▸ Dissolved Oxygen ▸ Total biomass estimate.
Biomass survey	3 quadrats cropped at each transect. Transects should be located at 100-200 metre intervals. Major species should be identified along with % of the total. Cropping should be repeated if survey lasts longer than 1 week.	▸ Biomass density. ▸ Species distribution.
Biomass Chemistry (Phosphorus in plants)	5 samples/week at each end of reach.	▸ Degree of nutrient (P) limitation
Solar Radiation	Continuous monitoring if stream is not near an AES station.	▸ Solar radiation on site.
Underwater Light	Daily at each end of reach	▸ Extinction coefficient
Water quality (FP, NO_3, NO_2, NH_3, BOD_5, SS or Turb)	Mid-daily at each end of reach and on 4 hr intervals for 48 hrs.	▸ Nutrient supply ▸ BOD and BNOD respiration ▸ SS or Turb. used to relate to Ke and establish relationship. ▸ Variability characteristics.
Flow, Time-of-travel Depth, Staff Height	At each major flow change.	▸ Odum's analysis ▸ Used in ECOL1
Sediment Mapping	Once	▸ Establishing area subject to plant growth or SOD.
SOD	3 to 4 locations if significant area is suitable. Frequency should be based on variability of SOD found.	▸ Partition total reach respiration into SOD, BOD and plant resp.

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APPENDIX I
PLANT NUTRIENT ANALYSIS

DATE		LOCATION	DOMINANT PLANT TYPE	TP mg/g	TN mg/g	TKN mg/g	LOI %
May	23	UGI	Cladophora	1.9	14	-	-
	23	UGII	Cladophora	2.8	27	-	-
	26	UGI	Cladophora (T)	1.8	-	13	-
	26	UGII	Cladophora (T)	0.84	-	8.4	-
June	5	UGI	Cladophora (S)	3.8	-	33	-
	8	UGII	Cladophora (S)	1.1	-	23	-
	15	UGI	Cladophora	1.3	25	-	--
	15	UGII	Cladophora	0.9	14	-	-
	19	UGI	Cladophora	2.1	13	-	-
	20	UGII	Cladophora	1.6	29	-	-
	23	S7.5	Cladophora	5.3	53	-	-
	26	S7	Sagittarius	3.4	27	-	-
	26	S7.5	Cladophora	3.0	25	-	-
	26	UGI	Cladophora	3.0	30	-	-
	26	UGII	Cladophora	2.7	29	-	-
	27	Plate from S7	Periphyton	1.7	16	-	-
July	4	UGI	Cladophora	1.9	29	-	-
	4	UGHII	Cladophora	1.8	28	-	-
	12	S7	Cladophora (S)	4.3	30	-	-
	12	S7.5	Cladophora (S)	3.7	38	-	-
	19	S7	Cladophora (T25)	3.2	14	-	-
	19	S7.5	Cladophora(T33)	3.3	15	-	-

APPENDIX 1 (CON'T)

DATE	LOCATION	DOMINANT PLANT TYPE	TP mg/g	TN mg/g	TKN mg/g	LOI %
Aug. 1	UGI	Pot. Pec. (T)	1.1	21	-	-
1	UGII	Pot. Pec. (T)	1.7	24	-	-
3	UGII (T24)	Pot. Pec. (T)	2.4	24	-	-
11	UGI	Pot. Pec. (S)	3.4	27	-	-
11	UGII	Pot. Pec. (S)	2.6	27	-	-
11	S7	Pot. Pec. (T)	2.6	22	-	-
11	S7.5	Pat. Pec. (T)	3.4	28	-	-
16	UGI	Pot. Pec. (T)	4.2	25	-	-
24	S7	Pot. Pec. (S)	4.8	35	-	-
24	S7.5	Pot. Pec. (S)	4.0	31	-	-
29	Speed (T25)	Pot. Pec. (T)	3.3	18	-	-
29	(T33)	Pot. Pec. (T)	4.8	25	-	-
31	UGI	Pot. Pec. (T)	3.5	25	-	-
31	UGII	Pot. Pec. (T)	2.1	24	-	-
Sept. 8	UGI	Pot. Pec. (T)	3.8	29	-	61
8	UGII	Pot. Pec. (T)	2.0	23	-	64
8	S7	Pot. Pec. (T)	3.7	29	-	78
8	S7.5	Cladophora (T)	5.0	45	-	65
11	S7	Periphyton (P)	1.2	9.4	-	17
12	UGI	Pot. Pec. (T)	4.0	28	-	61
12	UGII	Pot. Pec. (T)	2.2	25	-	64
12	S7	Pot. Pec. (T)	3.8	23	-	75
12	S7.5	Pot. Pec. (T)	2.8	30	-	86
12	UGI	Periphyton (P)	1.5	8.2	-	12
12	S7	Periphyton (P)	1.4	16	-	27
13	UGI	Periphyton (P)	1.4	8.1	-	13
15	UGI	Pot. Pec. (T)	3.3,	21	-	51
15	UGII	Pot. Pec. (T)	2.5	27	-	63
15	S7	Pot. Pec. (T)	3.5	30	-	72
15	S7.5	Pot. Pec. (T)	3.4	31	-	80

T - Transect S - Screen P - Plate

APPENDIX 2: Descriptive Survey Data
Station UGI Grand River.

Date	Temp. (°C)	Biomass (gm/m^2 dry)	Flow (cm)	Turbidity (JTU)	Filtered T.P. (mg/L)	FRP (mg/L)	NO_3 (mg/L)	NH_3 (mg/L)
June								
1	20	175	7.3	3.35	-	.013	2.14	.016
2	20	185	4.5	3.35	-	.012	2.29	.020
5	17	390	4.3	3.15	.019	.001	3.36	.036
6	18	390	4.3	2.90	.022	.001	2.85	.040
12	21	220	4.4	2.35	.027	-	-	-
14	15	210	7.0	2.60	.036	-	-	-
15	15	205	6.8	3.00	.033	-	-	-
20	21	185	7.0	3.00	.044	.005	1.92	.046
22	19	165	6.0	3.45	.040	.027	1.95	.030
23	20	160	5.4	1.75	.046	.009	1.97	.040
26	22	145	5.3	5.20	.025	.003	1.17	.044
27	24	140	5.2	4.05	.035	.004	1.21	.044
28	24	125	5.1	4.30	-	.003	1.13	.030
29	24	125	5.0	4.70	.037	.020	1.05	.030
30	24	125	9.6	8.30	.029	-	-	-
July								
4	19	115	4.8	5.55	.060	.007	1.62	.038
5	21	110	4.8	3.40	.041	.011	1.75	.052
6	23	105	4.7	5.00	.025	.017	1.21	.052
20	25	90	5.1	5.20	.034	.005	0.90	.048
25	23	80	5.2	5.35	.068	.008	1.12	.036
28	22.5	70	5.2	7.10	.039	.005	0.917	.038
31	20	65	5.2	5.10	.025	.005	0.784	.034
Aug.								
1	20	60	5.1	5.40	.028	.004	0.968	.038
10	22	60	5.2	1.20	.030	.008	0.860	.046
21	22	60	7.2	5.4	.023	.007	0.620	.042
23	22	60	7.4	6.4	.031	.001	0.665	.058
29	22	65	4.7	5.6	.065	.013	1.46	.044
30	21	65	4.3	4.5	.047	.010	1.14	.036
31	21	65	4.2	-	.055	.019	1.02	.024
Sept.								
1	20	65	4.2	3.3	.034	.007	0.92	.034
5	21	70	4.0	5.0	.011	.002	0.545	.034
7	21	70	3.9	5.4	.053	.026	0.990	.046
8	19.5	75	3.9	1.34	.020	.011	0.655	.040

APPENDIX 3: Descriptive Survey Data
Station S7 Speed River.

Date	Temp. (°C)	Biomass (gm/m^2 dry)	Flow (cm)	Turbidity (JTU)	Filtered T.P. (mg/L)	FRP (mg/L)	NO_3 (mg/L)	NH_3 (mg/L)
June								
1	20	92	3.7	3.4	.052	.028	8.31	0.830
2	21	97	3.6	4.6	.038	.019	1.95	0.610
5	17	128	3.4	5.1	.029	.003	5.42	1.20
6	17	144	3.7	5.0	.029	.005'	4.42	1.25
12	20	208	3.8	4.3	.093	-	-	-
14	15	230	3.3	4.5	.044	-	-	-
15	15	240	3.4	3.6	-	-	-	-
20	21	335	3.3	3.8	.081	.040	1.47	0.810
22	19	400	3.0	3.8	.049	.036	1.51	0.980
23	20	455	2.8	3.8	.072	.049	1.49	0.900
26	22	536	2.9	3.4	.063	.006	2.00	1.42
27	24	499	3.0	3.4	.075	.010	1.19	1.77
28	23	505	2.9	3.9	.102	.073	1.21	1.27
29	24	478	2.9	3.5	.055	.036	1.18	.870
30	23	494	3.0	2.5	.050	.008	1.09	1.71
July								
4	18	572	2.7	4.3	.013	.010	1.58	1.09
5	20	604	2.6	3.2	.049	.030	1.32	1.41
6	23	588	2.5	3.2	.099(?)	.037	1.19	1.59
20	25	348	3.0	1.55	.025	.003	1.30	1.40
25	23	305	2.3	3.2	.035	.007	1.78	0.65
28	22	319	2.4	3.0	.038	.004	1.91	0.386
31	20	340	2.5	2.4	.035	.004	2.84	0.362
Aug.								
1	20	349	2.5	2.7	.028	.009	2.23	0.47
10	21	384	2.8	2.5	.027	.017	1.79	0.40
21	22	371	2.3	2.8	.036	.010	1.61	1.12
23	22	372	1.8	3.2	.038	.005	2.10	0.27
29	21	327	1.8	4.4	.043	.008	0.83	0.53
30	20	318	1.7	3.1	.046	.016	1.27	0.86
31	20	318	1.7	3.3	.060	.045	1.17	0.95
Sept.								
1	20	327	2.1	2.7	.119	.026	1.89	1.70
5	21	332	2.2	2.8	.071	.021	1.91	1.66
7	21	-	2.2	2.5	.885	.071	1.09	1.62
8	19	-	2.3	2.2	.056	.040	1.17	1.71

APPENDIX 4. Intensive Survey Data
GRAND RIVER

DATE		NITROGEN DATA				PHOSPHORUS DATA					
		STATION UGI		STATION UGII		STATION UGI			STATION UGII		
		NH_3 mg/L	NO_3 mg/L	NH_3 mg/L	NO_3 mg/L	TP mg/L	FP mg/L	FRP mg/L	TP mg/L	FP mg/L	FRP mg/L
Apr.	7	.376	7.72	.336	5.73	.340	.141	.042	.202	.109	.009
	14	.188	2.26	.176	3.68	.124	.072	.017	.118	.081	.021
	19	.220	18.7	.186	2.88	.137	.088	.023	.139	.086	.016
	20	.154	3.46	.130	2.28	.127	.090	.028	.115	.082	.023
	27	.072	3.80	.048	2.53	.091	.023	.003	.129	.023	.002
	28	.068	4.15	.040	2.83	.048	.032	.003	.064	.020	.002
May	1	.052	3.68	.098	2.54	.029	.012	.002	.047	.010	.042
	2	.090	4.47	.038	2.53	.028	.015	.002	.020	.009	.001
	3	.060	4.69	.030	2.93	.030	.012	.002	.023	.009	.001
	4	.082	4.36	.038	2.83	.029	.014	.005	.018	.006	.004
	5	.152	4.11	.034	2.81	.038	.029	.005	.023	.010	.002
	8	.092	3.92	.030	3.13	.037	.010	.001	.027	.007	.001
	9	1.08	4.09	.226	2.92	-	-	.100	.178	.084	.004
	10	.120	4.18	.030	2.77	.152	.072	.007	.113	.078	.003
	11	.236	3.55	.098	2.46	.093	.046	.001	.119	.116	.001
	12	.222	3.43	.030	2.32	.103	.081	.001	.119	.091	-
	15	.042	3.01	.010	2.24	.060	.103	-	.062	.013	.001
	17	.024	3.36	.006	2.05	.046	.014	.001	.040	.015	-
	18	.010	2.67	.012	2.17	.054	.016	.001	.039	.017	-
	19	.010	2.86	.016	4.09	.053	.022	.003	.034	.013	-
	23	.070	-	.012	1.62	.048	.024	.001	.029	.015	.001
	24	.002	2.13	.012	1.55	.044	.023	.005	.028	.011	.001
	25	.048	2.98	.022	1.68	.050	.026	.007	.026	.010	.001
	26	.102	2.03	.014	1.50	.061	.031	.011	.027	.011	.001
	29	.056	2.92	.016	1.64	.051	.031	:001	.028	.013	.001
	30	.098	4.87	.030	1.26	.072	.044	.002	.028	.014	.001
	31	.062	1.94	.036	1.41	-	.047	.004	.029	.012	.001

APPENDIX 4 (CON'T)

DATE		NITROGEN DATA				PHOSPHORUS DATA					
		STATION UGI		STATION UGII		STATION UGI			STATION UGII		
		NH_3 mg/L	NO_3 mg/L	NH_3 mg/L	NO_3 mg/L	TP mg/L	FP mg/L	FRP mg/L	TP mg/L	FP mg/L	FRP mg/L
June	1	.016	2.14	.030	1.12	.051	.038	.013	.030	.012	.001
	2	.020	2.29	.018	1.18	.062	.037	.012	.025	.023	.001
	5	.036	3.36	.038	1.59	.031	.019	.001	.020	.006	.001
	6	.040	2.85	.024	1.89	.034	.022	.001	.015	.009	.001
	7	.036	2.59	.036	1.71	.031	.018	.003	.015	.008	.001
	8	.076	3.06	.038	2.21	.033	.020	.002	.017	.007	.001
	9	.126	3.92	.036	2.06	.071	.062	.023	.013	.007	.001
	12				-	.040	.027	-	.020	.009	-
	13	-	-			-	-	-	.026	.014	-
	14	-	-	-	-	.056	.036	-	.024	.011	-
	15	-	-	-	-	.053	.033	-	.017	.010	-
	16			-	-	.047	.033	-	.019	.008	-
	19	.042	3.09	.034	1.58	.092	.065	.010	.025	.011	.001
	20	.046	1.92	.032	1.21	.074	.044	.005	-	.009	.002
	21	.056	1.90	.044	1.16	.099	.055	.006	.049	.011	.003
	22	.030	1.95	.030	1.12	.077	.040	.027	.062	.010	.001
	23	.040	1.97	.030	1.07	.090	.046	.009	-	.009	.001
	26	.040	1.17	.044	.895	.071	.025	.003	.031	.010	.001
	27	.044	1.21	.050	.900	.076	.035	.004	.039	.010	.001
	28	.030	1.13	.034	.870	.083	-	.003	2.00	.014	.001
	29	.030	1.05	.044	.770	.082	.037	.020	.047	.011	.002
	30	-	-	.034	.755	.089	.029	-	.053	.034	.001

APPENDIX 4 (CON'T)

DATE		NITROGEN DATA				PHOSPHORUS DATA					
		STATION UGI		STATION UGII		STATION UGI			STATION UGII		
		NH_3 mg/L	NO_3 mg/L	NH_3 mg/L	NO_3 mg/L	TP mg/L	FP mg/L	FRP mg/L	TP mg/L	FP mg/L	FRP mg/L
July	4	.038	1.62	.042	1.08	.072	.060	.007	.035	.006	.001
	5	.052	1.75	.050	1.01	.061	.041	.011	.028	.008	.002
	6	.052	1.21	.056	.855	.062	.025	.017	.037	.009	.002
	7	.056	1.13	.052	.779	.072	.029	.003	.054	.015	.001
	10	.048	1.09	.052	.750	.074	.034	.003	.047	.200	.002
	11	.036	1.39	.046	.851	.073	.039	.005	.036	.013	.002
	12	.038	1.29	.046	.822	.063	.041	.002	.038	.012	.003
	13	.032	1.12	.036	.727	.076	.030	.019	.037	.009	.001
	14	.040	1.42	.042	.930	.066	.036	.003	.040	.011	.001
	17	.040	1.00	.042	.577	.057	.026	.011	.040	.008	.001
	18	.038	1.09	.040	.730	-	.025	.003	.043	-	.002
	19	.042	.093	.042	.631	.076	.026	.003	.037	.012	.002
	20	.048	0.90	.052	.618	.075	.034	.005	.043	.017	.002
	21	.056	1.08	.052	.723	.099	.048	.007	.051	.014	.002
	24	.034	0.911	.040	.515	.104	.057	.040	.047	.020	.005
	25	.036	1.12	.034	.584	.098	.068	.008	.044	.016	.002
	26	.040	1.02	.040	.528	.104	.060	.007	.041	.010	.001
	27	.042	1.09	.046	.697	.113	.060	.007	.041	.017	.001
	28	.038	0.917	.042	.528	.091	.039	.005	.045	.013	.002
	31	.034	0.784	-	-	.061	.025	.005	.034	.011	-

APPENDIX 4 (CON'T)

DATE		NITROGEN DATA				PHOSPHORUS DATA					
		STATION UGI		STATION UGII		STATION UGI			STATION UGII		
		NH_3 mg/L	NO_3 mg/L	NH_3 mg/L	NO_3 mg/L	TP mg/L	FP mg/L	FRP mg/L	TP mg/L	FP mg/L	FRP mg/L
Aug.	1	.038	0.968	.032	.535	.059	.028	.004	.037	.010	.001
	2	.040	0.872	.042	.514	.068	.028	.016	.035	.011	.001
	3	.044	0.879	.044	.527	.102	.040	.023	.048	.010	.001
	4	.036	0.801	.034	.493	.072	.033	.021	.066	-	.005
	8	.044	0.825	.046	.465	.070	.026	.009	.038	.011	.002
	9	.044	0.975	.050	.580	.079	.033	.003	.040	.009	.002
	10	.046	0.860	.032	.560	.069	.030	.008	.040	.014	.001
	14	.050	0.575	.048	.317	.068	.032	.006	.041	.015	.001
	15	.042	0.816	.046	.441	.106	.037	.003	.039	.016	.001
	16	.056	0.659	-	-	.115	.030	.019	.062	.011	-
	17	.084	0.850	.030	.639	.086	.027	.008	.048	.013	.001
	18	-	-	.026	.473	.072	.017	-	.046	.146	.001
	21	.042	0.620	.046	.685	.067	.023	.007	.038	.014	.004
	22	.068	0.800	.042	.620	.055	.021	.018	.038	.010	.014
	23	.058	0.665	.044	.375	.070	.031	.001	.045	.011	.002
	24	.048	0.355	.048	.415	.058	.024	.001	.043	.009	.004
	25	.288	1.30	.070	.795	.128	.085	.069	.048	.019	.009
	28	.032	1.68	.032	1.14	.050	.043	.003	.090	.020	.007
	29	.044	1.46	.040	.82	.054	.065	.013	.096	.018	.002
	30	.036	1.14	.028	.605	.046	.047	.010	.084	.016	.001
	31	.024	1.02	.022	.510	.049	.055	.019	.088	.017	.002
Sept.	1	.034	0.920	.034	.39	.069	.034	.007	.027	.012	.002
	5	.034	0.545	.022	.415	.031	.011	.002	.034	.011	.001
	6	.022	0.595	.020	.495	.041	.018	.006	.030	.016	.001
	7	.046	0.990	.036	.380	.09]	.053	.026	.037	.011	.002
	8	.040	0.655	.026	.510	.052	.020	.011	.036	.015	.008
	11	.024	1.04	.024	.460	.093	.064	.011	.058	.014	.003
	12	.54	1.60	.040	.87	.360	.285	.100	.065	.027	.005
	13	.024	1.14	.020	.65	.098	.076	.018	.042	.026	.004
	14	.028	1.14	.024	.52	.096	.057	.010	.034	.013	.003
	15	.18	1.32	.076	.82	.205	.129	.100	.087	.037	.021

APPENDIX 5: INTENSIVE SURVEY DATA
SPEED RIVER

DATE		NITROGEN DATA				PHOSPHORUS DATA					
		STATION S7		STATION S7.5		STATION S7			STATION S7.5		
		NH_3 mg/L	NO_3 mg/L	NH_3 mg/L	NO_3 mg/L	TP mg/L	FP mg/L	FRP mg/L	TP mg/L	FP mg/L	FRP mg/L
Apr.	18	.440	2.54	.470	2.38	.080	.055	.001	.067	.079	.003
	19	.356	1.87	.346	1.95	.080	.053	.002	.082	.064	.003
	20	.356	2.01	.330	1.89	.105	.073	.006	.091	.065	.006
	27	.450	1.81	.440	1.86	.067	-	.003	.053	.014	.002
	28	.454	1.90	.384	1.76	.098	.026	.003	.063	.026	.003
May	1	.680	1.94	.600	1.94	.047	.019	.003	.042	.019	.003
	2	.720	2.21	.600	1.96	.039	.017	.003	.037	.015	.002
	3	.750	1.95	.590	2.17	.049	.013	.003	.039	.020	.004
	4	.730	2.49	.620	2.03	.054	.018	.010	.113	.019	.011
	5	.790	2.48	.640	2.08	.057	.022	.012	.051	.018	.011
	8	.890	1.77	.730	1.87	.062	.020	.004	-	-	.003
	9	.640	2.02	.550	1.88	.146	.119	.009	.071	.026	.016
	10	.520	2.89	.420	1.82	.164	-	.009	.145	-	.009
	11	.880	3.42	.480	1.49	.094	.011	-	.133	.120	.001
	12	.590	1.55	.610	1.97	.158	.132	-	.146	.137	-
	15	.366	1.42	.410	1.58	.087	.017	-	.058	.085	-
	16	.316	1.49	.312	1.30	.065	.018	.002	.070	.015	.001
	17	.290	1.45	.260	1.29	.074	.018	-	.055	.014	-
	18	.330	2.16	.298	1.74	.062	.015	-	.054	.017	.003
	19	.440	1.62	.368	1.48	.076	.021	.001	.057	.019	.003
	23	.510	1.70	.540	1.38	.063	.018	.001	.060	.016	.001
	24	.440	1.81	.058	.335	.058	.020	.001	.051	.022	.001
	25	-	-	.126	1.98	.059	.028	-	.044	.021	.003
	26	.370	2.99	-	-	.073	.040	.017	.054	.032	-
	29	.770	1.50	.450	4.00	.060	.023	.001	.052	.021	.001
	30	.470	1.38	.160	1.82	.086	.050	.003	.064	.034	.013
	31	.560	1.90	.114	1.87	.079	.048	.025	.062	.031	.010

APPENDIX 5 (CON'T)

DATE	NITROGEN DATA				PHOSPHORUS DATA					
	STATION S7		STATION S7.5		STATION S7			STATION S7.5		
	NH_3 mg/L	NO_3 mg/L	NH_3 mg/L	NO_3 mg/L	TP mg/L	FP mg/L	FRP mg/L	TP mg/L	FP mg/L	FRP mg/L
June 1	.830	8.31	.290	3.20	.088	.052	.028	.058	.032	.013
2	.610	1.95	.162	2.02	.097	.038	.019	.075	.043	.013
5	1.20	5.42	-	2.50	.073	.029	.003	.047	.022	.011
6	1.25	4.42	-	2.80	.074	.029	.005	.052	.028	.003
7	-	1.75	.380	2.60	.084	.041	.010	.056	.031	.005
8	1.05	5.57	.368	2.50	.082	.044	.017	.061	.036	.010
9	-	1.95	-	1.77	.121	.073	.025	.093	.066	.018
12	-	-	-	-	.074	.093	-	-	.051	-
13	-	-	-	-	.098	.060	-	.078	.040	-
14		-	-	-	.083	.044	-	.050	.035	-
15	-	-	-	-	.067	-	-	.053	.029	-
16			-	-	.095	.061	-	.060	-	-
19	.850	1.75	.100	2.44	.089	.056	.003	.071	.043	.004
20	.810	1.47	.140	2.06	-	.081	.040	.093	.057	.006
21	.750	1.42	.184	1.94	.098	.049	.009	.074	.041	.022
22	.980	1.51	.150	2.21	.091	.049	.036	.074	.036	.020
23	.900	1.49	.104	1.91	.123	.072	.049	.084	.039	.022
26	1.42	2.00	.362	2.57	.106	.063	.006	.067	.019	.001
27	1.77	1.19	.382	2.14	.139	.075	.010	.104	.030	.003
28	1.27	1.21	.068	2.10	.145	.102	.073	.097	.025	.003
29	.870	1.18	.054	1.79	.099	.055	.036	.104	.034	.003
30	1.71	1.09	.206	2.08	.086	.050	.008	.085	.025	.003

APPENDIX 5 (CON'T)

DATE	NITROGEN DATA				PHOSPHORUS DATA					
	STATION S7		STATION S7.5		STATION S7			STATION S7.5		
	NH_3 mg/L	NO_3 mg/L	NH_3 mg/L	NO_3 mg/L	TP mg/L	FP mg/L	FRP mg/L	TP mg/L	FP mg/L	FRP mg/L
July 4	1.09	1.58	.160	2.52	.076	.013	.010	.072	.007	.001
5	1.41	1.32	.190	2.65	.114	.049	.030	.056	.008	.007
6	1.59	1.19	.220	2.35	.137	.074	.037	.068	.034	.001
7	1.15	1.13	.090	2.08	.070	.046	.027	.047	.009	.004
10	2.25	1.35	.340	2.65	.064	.036	.003	.056	.014	.001
11	1.74	1.24	.450	2.47	.090	.051	.017	.070	.025	.004
12	1.77	1.35	.296	2.72	.078	.037	.017	.064	.018	.004
13	1.27	1.46	.160	2.43	.087	.041	.021	.067	.018	.004
14	1.31	1.51	.330	2.24	.084	.035	.019	.078	.024	.011
17	1.35	1.82	.324	2.47	.063	.055	.020	.055	.024	.010
18	.910	1.28	.090	1.95	.075	.026	.004	.078	.021	.003
19	.670	1.45	.090	1.84	.066	.033	.003	.074	.020	.002
20	1.40	1.30	.146	1.92	.053	.025	.003	.066	.019	.002
21	.850	1.27	.278	1.56	.066	.029	.005	.180	.021	.005
24	.700	1.73	.058	2.17	.067	.039	.023	.086	.033	.018
25	.650	1.78	.056	2.30	.062	.035	.007	.050	.028	.003
26	.450	1.79	.052	2.17	.083	.050	.011	.076	.038	.004
27	.250	1.60	.044	1.82	.086	.039	.005	.095	.037	.004
28	.386	1.91	.038	1.99	.065	.038	.004	.064	.033	.005
31	.362	2.84	.032	3.10	.061	.035	.004	.060	.026	.003

APPENDIX 5 (CON'T)

DATE		NITROGEN DATA				PHOSPHORUS DATA					
		STATION S7		STATION S7.5		STATION S7			STATION S7.5		
		NH_3 mg/L	NO_3 mg/L	NH_3 mg/L	NO_3 mg/L	TP mg/L	FP mg/L	FRP mg/L	TP mg/L	FP mg/L	FRP mg/L
Aug.	1	.470	2.23	.060	2.61	.057	.028	.009	.056	.023	.004
	2	.262	2.02	.028	2.28	.048	.024	.006	.063	.022	.004
	3	.192	1.77	.026	1.83	.067	.025	.008	.101	.022	.012
	4	.600	2.22	.106	2.49	.062	.030	.018	.060	.021	.012
	8	.266	2.72	.068	2.36	.077	.031	.006	.071	.026	.008
	9	.930	1.85	.386	2.34	.065	.035	.007	.079	.026	.006
	10	.400	1.79	.060	2.03	.069	.027	.017	.057	.023	.007
	14	.670	2.11	.080	2.50	.050	.029	.004	.061	.029	.004
	15	1.48	1.25	.380	1.99	.067	.036	.004	.065	.024	.001
	16	1.28	1.20	.510	.916	.074	.039	.009	.078	.035	.007
	17	1.59	.87	.710	1.10	-	.051	.010	.080	.037	.010
	18	1.68	1.06	.870	1.73	.074	.041	.009	.061	.030	.024
	21	1.12	1.61	1.40	1.48	.066	.036	.010	.053	.028	.012
	22	1.23	1.18	1.26	1.18	.069	.036	.014	.057	.033	.014
	23	.270	2.10	.570	2.30	.067	.038	.005	.060	.028	.006
	24	.296	1.87	.600	1.68	.060	.025	.012	.078	.017	.009
	25	1.27	1.10	.470	1.68	.067	.036	.024	.060	.027	.018
	28	.800	1.45	.304	1.82	.200	.043	.007	.086	.048	.006
	29	.530	.830	.160	1.60	.080	.043	.008	.142	.040	.006
	30	.860	1.27	.276	1.76	.121	.046	.016	.078	.071	.012
	31	.950	1.17	.280	1.66	.117	.060	.045	.101	.075	.037
Sept.	1	1.70	1.89	.980	1.48	.158	.119	.026	.110	.086	.014
	5	1.66	1.91	.590	1.74	.117	.071	.021	.074	.050	.011
	6	1.58	1.90	.470	1.42	.157	.125	.105	.109	.070	.025
	7	1.62	1.09	.344	2.16	.101	.885	.071	.092	.060	.030
	8	1.71	1.17	.800	2.04	-	-	-	-	-	-
	11	1.37	2.41	.156	3.32	.122	.092	.017	.094	.056	.009
	12	.84	1.11	.550	1.47	.159	.109	.020	.205	.098	.015
	13	-	-	.248	1.73	.134	.103	-	.125	.090	.018
	14	.81	1.46	.358	1.87	.091	.060	.018	.106	.051	.007
	15	.374	1.31	.094	1.43	.086	.049	.025	.095	.046	.020

APPENDIX 6
RESPIROMETERS - GRAND

DATE		STATION	TEMPERATURE RANGE (°C)	RESPIRATION RATE ($g/m^2/hr$)
May	8	UGI	9.5 - 10.3	0.18
	9	UGII	11.0 -10.8	0.13
	9	UGII	11.2 - 10.7	0.21
	10	UGI	8.2 - 8.3	0.17
	29	UGI	19.0 - 21.0	0.59
June	1	UGI	19.6 - 21.4	0.44
	2	UGII	19.8 - 20.1	0.41
	5	UGI	15.2 - 17.0	0.42
	6	UGI	16.0 - 18.5	0.29
	12	UGI	20.5 -21.5	0.45
	14	UGI	13.5 - 15.8	0.22*
	20	UGI	20.0 - 23.0	0.36
	22	UGI	19.0 - 21.5	0.28*
	27	UGI	23.5 - 24.0	0.99*
	28	UGI	21.5 - 22.7	0.66*
July	5	UGI	20.2 - 21.8	0.42
	6	UGI	21.7 - 24.3	0.44
	10	UGI	19.4 - 22.3	0.34
	11	UGI	19.5 - 22.5	0.43
	11	UGII	19.0 - 20.0	0.47
	17	UGII	21.0 - 22.0	0.51
	18	UGI	22.5 - 24.2	0.48
	19	UGI	21.6 - 22.0	0.95
	20	UGI	25.0 - 25.5	2.20
	21	UGI	22.9 - 23.7	0.25
	24	UGI	19.8 - 21.5	0.66
	26	UGI	21.7 - 25.2	0.26
	27	UGI	19.8 - 20.4	0.26
	31	UGI	18.5 - 20.0	0.22

APPENDIX 6 (CON'T)

DATE		STATION	TEMPERATURE RANGE (°C)	RESPIRATION RATE ($g/m^2/hr$)
Aug.	1	UGI	18.2 - 19.0	0.28
	3	UGI	22.6 - 24.0	0.39
				0.15*
	8	UGI	20.2	0.34
	9	UGI	23.0 - 22.0	0.26
	10	UGI	19.6 - 21.6	0.34
	14	UGI	23.0 - 24.8	0.46
	16	UGI	21.7 - 22.5	0.22
	17	UGI	22.0	0.27
	21	UGI	20.3 - 21.4	0.29
	25	UGI	19.6 - 20.4	0.22
	29	UGI	21.3 - 22.0	0.30
	30	UGI	21.7 - 22.2	0.27
	31	UGI	20.3	0.34
Sept.	5	UGI	20.9 - 21.0	0.34
	7	UGII	20.1 - 22.0	0.30
	8	UGI	17.7 - 18.2	0.19
	11	UGI	22.5 - 22.5	0.33

* Inaccurate Line (Resp. Rate)

APPENDIX 7
RESPIROMETERS - SPEED

DATE		STATION	TEMP. °C	RESP. $g/m^2/hr$	NET PROD. $g\ O_2/m^2/hr$	GROSS PROD. $g\ O_2/m^2/hr$
May	11	S7	12.7	0.14	0.09	0.23
June	2	S7	21.0	0.24	-	-
	5	S7	17.0	-	0.13	-
	6	S7	15.5	0.22	0.15	0.37
	8	S7	17.5	0.24	-	-
	15	S7.5	14.6	0.38	-	-
	23	S7.5	19.0	0.58	1.9	-
	29	S7.5	23.5	-	-	-
July	4	S7.5	20.0	0.55	-	-
	10	S7.5	21.6	0.193	-	-
	11	S7	18.0	0.15	-	-
	12	S7.5	20.0	0.38	-	-
	13	S7.5	19.5	0.23	1.39	1.62
	17	S7	19.7	-	0.99	-
	18	S7	22.0	0.38	2.06	2.44
	19	S7.5	23.0	0.39	1.15	1.54
	20	S7	21.6	-	0.60	-
	21	S7.5	23.5	0.36	0.78	1.14
	21	S7.5	23.5	0.19	-	-
	24	S7.5	22.0	0.41	0.54	0.95
Aug.	2	S7	17.5	-	1.14	-
	3	S7.5	20.2	0.19	-	-
	4	S7	18.7	0.76	-	-
	9	S7	20.0	-	1.20	1.53
	9	S7	20.0	0.33	-	-
	10	-	-	-	0.64	-
	14	S7	21.2	0.27	-	0.98
	14	S7	21.6	-	0.71	-
	15	S7.5	24.0	0.89	-	-
	21	S7.5	22.0	0.25	-	-

APPENDIX 7 (CONT'D)

DATE		STATION	TEMP. °C	RESP. $g/m^2/hr$	NET PROD. $g\ O_2/m^2/hr$	GROSS PROD. $g\ O_2/m^2/hr$
Aug.	22	S7.5	20.5	-	1.09	1.39
	22	S7.5	20.5	0.30	-	-
	23	S7.5	23.0	0.22	-	-
	24	S7.5	22.5	0.25	-	-
	31	S7.5	19.0	0.23	-	-
	31	S7.5	19.0	-	1.06	1.29
Sept.	1	S7.5	18.5	0.24	-	-
	6	S7	22.5	0.41	-	-
	8	S7.5	20.0	0.21	-	-
	8	S7.5	21.0	0.45	-	-
	11	S7.5	20.5	0.43	-	-

APPENDIX 8: DOME RESPIROMETER

This appendix is a condensation from a technical report prepared by the River Systems Unit of the MOE. For additional information on the construction and use of the dome respirometer the reader is referred to the above-mentioned report.

In order to achieve accurate measurements of the stream sediment oxygen demand (SOD), it is necessary to isolate a small section of the stream substrate from the surrounding water column. The oxygen uptake rate of a particular sediment depends upon several factors, including physical conditions. Chemical and biological factors which influence the dissolved oxygen uptake include the indigenous bacterial algal and macrophyte communities, nutrient concentrations in the sediment and water, and the presence of chemical reducing agents. A dome respirometer, suitable for use in shallow rivers, was designed and built by the River Systems Unit, Water Modelling Section, MOE, for the purpose of measuring SOD. The unit is lightweight and easily handled by one person.

The dome respirometer was primarily designed for ease of use and is shown in Figure A1. The following five steps and figure outline the operational procedure:

1. A dissolved oxygen probe is calibrated and inserted into the aperture provided near the top of the dome.

2. The respirometer is lowered to the sediment with the air purge stopper removed and embedded into the sediment, to the level of the horizontal flange, making sure that a proper seal is obtained.

3. The battery leads are connected and the pump is turned on. After a minute or two the air purge stopper is put into place. This allows air bubbles trapped inside the respirometer to escape.

4. Initial DO readings in the dome and light (or dark) BOD bottle are taken.

5. After a period of time, usually 2-4 hours, the final DO readings are taken and the respirometer is removed.

The SOD is in $gmO_2/m^2/day$ is then calculated according to the following:

$$SOD = \frac{TOD - WCOD}{T} - 3.922$$

where SOD = sediment oxygen demand
TOD = total oxygen demand (sediment + water column)
WCOD = water column oxygen demand
T = duration of test

REFERENCE:

Ontario Ministry of the Environment. 1980. Dome Respirometer Construction and Use. River Systems Unit, Water Modelling Section, Water Resources Branch.

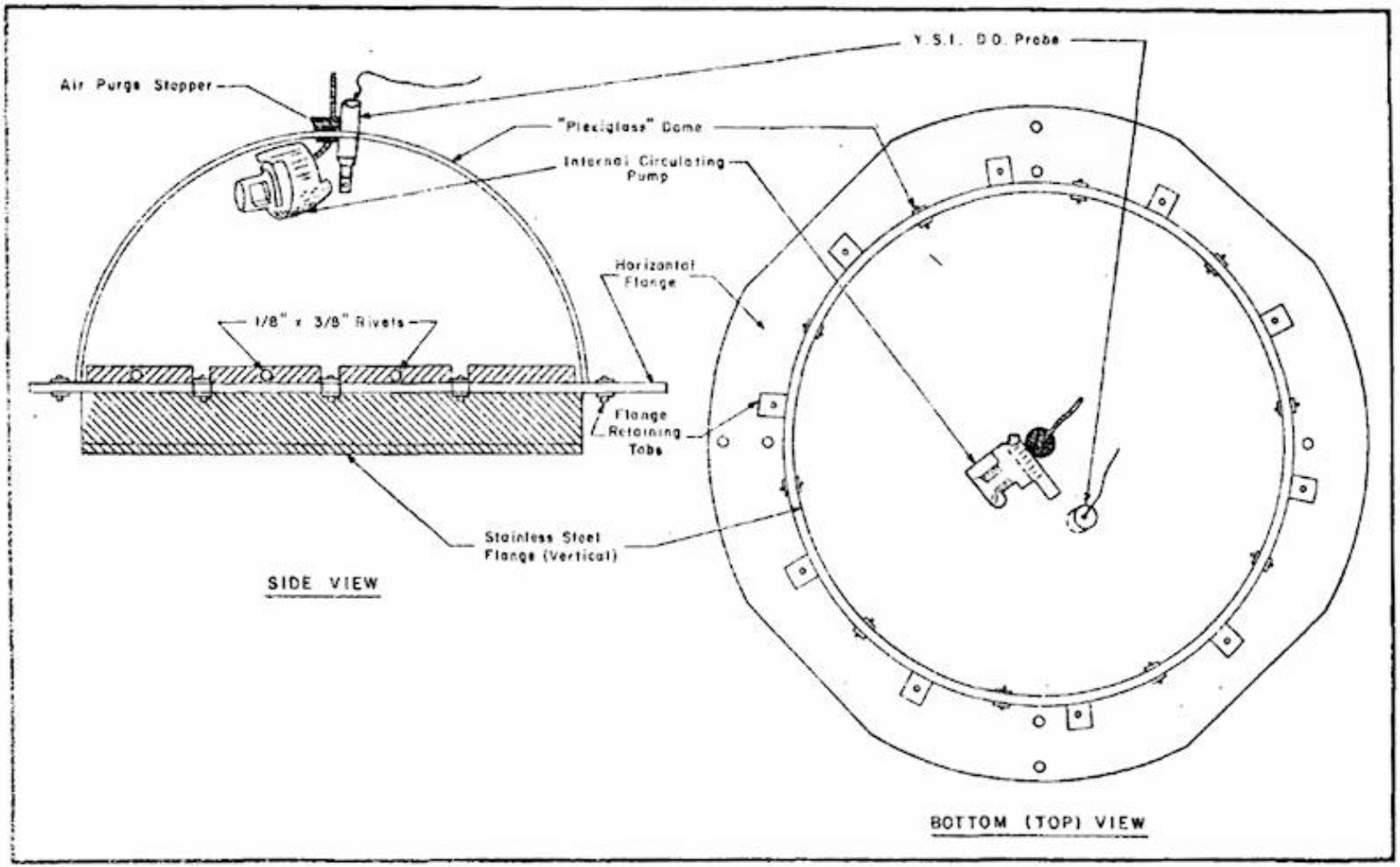

FIGURE A1: Dome Sediment Respirometer Detail.