PLANT BIOMASS ASSESSMENT FOR RIVERS AND STREAMS

AN ASSESSMENT PROCEDURE
PREPARED FOR

WORKING GROUP II
OF THE WATER MANAGEMENT
STEERING COMMITTEE

Ontario

Ministry
of the
Environment

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Keith C. Norton. Q.C.
Minister

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Deputy Minister

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NOTE

The receiving water assessment techniques presented in this report describe the methods commonly in use within the Ministry. Alternative techniques exist and/or will eventually be developed. Consultation with Ministry of the Environment staff is advisable to determine the suitability of the alternative techniques.

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FOREWORD

This paper gives an overview of the problems associated with the nuisance level growth of aquatic plants in rivers and streams and suggests general procedures to be followed in assessing the problem in any stream. These procedures may be used in an assessment program which can be quite simple or complex, depending on the time and resources available. After an initial problem definition phase, a descriptive study phase may be entered which will provide an analysis of the problem suitable for a fairly well informed level of management.

The descriptive study phase is aimed at defining the level of the existing plant problem, and giving some indication as to differences expected as conditions change.

If a more detailed assessment is considered necessary in order that predictions may be made of the benefits deriveable from the implementation of remedial measures, simulation modelling provides a logical basis for decision making.

The modelling procedure described in this paper involves the use of the plant ecological model, ECOL1, developed by the River Systems Unit. The modelling phase itself can be undertaken at either of two levels of complexity; either a steady state, or a dynamic modelling approach. The ECOL1 model is common to both options. The dynamic modelling approach can answer more management questions about the behaviour of the modelled system, requires more data and considerably more data preparation and computer time.

It is not the intention of this paper to advocate sophisticated modelling techniques requiring extensive resources for data collection and analysis, to the extent that anyone is deterred from conducting needed assessments. The modelling approach provides a rationale for the conduct of a survey, and even if no actual simulation model is applied, the framework provided is of benefit in planning these studies in a comprehensive manner.

A detailed description of the methodology required for a comprehensive stream aquatic plant assessment is beyond the scope of this paper. This report presents an overview of the required procedures; it has been mainly derived from and should be used in conjunction with the following references:

(1) "Aquatic Plant Model-Derivation and Application" (Grand River Technical Report No. 14); and

(2) "Plant Community Assessment Techniques" (Grand River Technical Report No. 15).

Many procedures followed in field surveys required for stream biomass assessment are identical to those used in waste assimilation studies; therefore reference to Chapters 3 and 4 of the "Stream Water Quality Assessment Procedures Manual" should also be made.

ACKNOWLEDGEMENTS

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PLANT BIOMASS ASSESSMENT IN RIVERS AND STREAMS

by
D. Draper and R. Walker

INTRODUCTION

The analysis and handling of problem aquatic weed growth is difficult since it involves the impact of various land use activities on a complex ecological system. Differences in the ecological and physical character of a stream from place to place necessitate different study approaches. The approach developed by the River Systems Unit as it is described here may not be generally applicable, and in fact has not as yet been fully refined. However, some or all of the techniques outlined will be useful in defining and managing the principle factors contributing to the aquatic weed problems often found in the shallower rivers draining agricultural and settled areas of Ontario.

Nature of the Problem

The bio-energetic cycle of an unpolluted river is principally driven by primary production of a highly diverse plant community. Diversity involves both numbers of species and relative dominance by numbers of each species. In a polluted stream situation, diversity is drastically changed, with the plant community dominated by a large biomass of one or two species. As in many systems, where an overabundance of some species occurs, a situation of instability may result, in which large swings in populations, or physical and chemical conditions affected by the populations may occur.

When this happens the use potential of the stream is detrimentally affected in many ways. For example, the heterotrophic community (invertebrates, fish, etc.) are typically subjected to wide fluctuations in the ambient levels of dissolved oxygen resulting from the plant community's diurnal cycle of daytime oxygen production and nighttime respiration. The severe nighttime oxygen depletion often occurring in a polluted stream can result in the exclusion of fish species unable to survive by means of behavioural adaptation such as surface breathing or by virtue of physiological adaptation to lower oxygen availability. The reduced dissolved oxygen levels result in limitations in the stream's waste assimilative capacity for oxygen demanding substances in treated sewage effluents. This often results in requirements for high cost tertiary treatment in order to allow treatment plant expansion and maintenance of existing oxygen levels.

Large standing crops of algae or macrophytes can also act as a sediment "filter". The physical presence of aquatic weed growth can render spawning habitats useless to some desirable species and more favourable to some undesirable ones.

Aquatic plant infestation may be severe enough to impede the flow of water or the passage of small craft. Swimming may be curtailed by the rivers loss of aesthetic appeal or by the promotion of conditions which favour various undesirable insects and water-borne parasites.

Water for drinking may be impaired by changes in taste, or more rarely, by the production of toxins from blue-green algae blooms. The process of water pumping and purification itself may be hampered by clogging of equipment with plant biomass.

Although the above is only a brief mention of some aspects of the aquatic weed problem in rivers, it is evident that most major river water uses are affected to some degree when the normal level of plant growth is disrupted. In southern Ontario, plant infestation is often the single most significant factor limiting river water use, during at least part of the year, and at the same time may be among the more difficult environmental problems in terms of assessment and remedial action.

Causes

Aquatic plant biomass reaches problem proportions when activities in a watershed begin to significantly affect the chemical and physical nature of a stream. Erosion of nutrient-laden sediment or direct inputs of nutrients (mainly nitrogen and phosphorus) from municipal and industrial sewage treatment plants alter the trophic status of a stream. Agricultural activities, including manure spreading and the use of chemical fertilizers, contribute nutrients, a large proportion of which are in forms readily available to aquatic plants. Livestock manure enters streams in runoff from feedlots and barn lots close to streams and in summer is input more directly from cattle herds congregating in and near streams.

Water temperature and incident sunlight are also influenced by livestock activities. Pasturing of animals close to stream banks destroys tree cover through soil erosion and removes the natural shading. Other riparian activities including construction and row crop cultivation may have a similar affect. The bank erosion resulting from such practices leads to stream bank caving and slumping, and sediment laden runoff, all of which cause channel in-filling with sediment. Formerly deeper, rocky cold water channels can thus become fertile warm water shallows.

PROBLEM ASSESSMENT

There are two main reasons for undertaking an assessment of a stream's plant community: the concern may be that a problem exists presently, or it may be desired to assess the impact on the stream of some proposed future activity; e.g. expansion of a WPCP discharging to the stream. In the latter case (if the scale of proposed activities and the importance of the receiver warrants it) a fairly comprehensive course of action may be decided upon, involving field studies, computer simulation modelling and cost-benefit analysis of proposed remedial measures. The assessment procedures required for this level of assessment are discussed in a subsequent section and are based on experience of the River Systems Unit in the Grand River Basin Water Management Study.

For the purposes of this paper, plant community assessment is described on two main levels of complexity, a descriptive and a more intensive (simulation modelling) approach. The descriptive study is aimed at documenting a plant problem and estimating its present and future nuisance potential.

The intensive level of assessment is actually an extension of the descriptive type of study but involves further data collection in order that a simulation model of the system may be built. This model (ideally a calibrated and verified version) can be used to predict the responses of the plant community, and the resulting effects on water quality under various controls, changed environmental variables or pollutant source management.

Once formulated, the aquatic plant model described in this paper can be applied to determining cost-effective remedial measures required for the control of sources of nutrients and total BOD. Briefly, the procedure involves modelling various combinations of plant biomass and BOD loading under specified 'design' conditions and identifying those which are feasible and which produce the best dissolved oxygen conditions. The level of plant biomass density will be determined as output through a series of preliminary ECOL1 model runs using the various phosphorus loading levels of interest as input.

In some river situations, modelled plant biomass density within a specified reach will show little or no response to modelled reductions in the phosphorus loading from a point source. This would be the case if high levels of phosphorus already prevail upstream of the source under study and the plant community is therefore not 'limited' by phosphorus. If this situation obtains, resources would be needlessly expended on the modelling study. Therefore it is essential to ascertain in advance that definite indicators point to the need for this type of study. These are briefly described below.

A. Preliminary Studies

Before an assessment is actively undertaken there will usually be indications that the level of plant growth is approaching problem proportions:

(i) Growths dominated by one or two species of plant or algae are observed in large areas of the stream, or in very dense clumps where growth conditions are favourable. The two main problem species found in rivers in Southern Ontario are *Potamogeton* sp., a rooted aquatic macrophyte, and *Cladophora* sp., a filamentous green algae.

(ii) A fish kill is reported or fish population surveys may indicate low populations or stressed populations.

(iii) Continuous dissolved oxygen monitoring shows a diurnal range of 10 ppm or more. A maximum DO of over 150%, or a very low night-time DO may both be indicative of a plant problem; however, low DO's may result from processes other than plant respiration. Therefore, as a generally applicable indicator of plant problems the supersaturation figure is preferable.

Actual interpretation of stream DO monitoring data requires some judgement. The location of a DO monitor relative to the main area of weed growth is important. The presence of dams or rapids upstream of a DO monitor can greatly attenuate a DO cycle caused by weed beds upstream.

Before an assessment involving the plant model is undertaken, it must be demonstrated that changes in plant dynamics result from changes in nutrient loadings from the source under study and that dissolved oxygen conditions in the stream can be improved by managing that source. This will be indicated by applying one or both of the following criteria: (a) a previous waste assimilation steady state DO-BOD model has shown that DO violations cannot be mitigated by BOD control alone; (b) phosphorus concentration in plant samples indicates some degree of limitation by the nutrient. (See: "Biomass Chemistry".) If this is the case, the inference that a beneficial effect will be obtained by phosphorus control will be confirmed by the observation that plant growth is more luxuriant below the point source of interest than upstream of it. (When collecting plant samples or cropping to calculate plant densities below an STP, ensure that sampling is carried out far enough downstream that the effect of toxic substances such as residual chlorine and un-ionized ammonia is minimal.)

B. Nuisance Growth Levels

The level of plant growth which a stream can tolerate without causing DO problems is dependent upon a large number of factors influencing both plant processes and other DO sources and sinks. As a rough guideline, based on studies of *Cladophora* sp. and *Potamageton* sp. in southern Ontario streams, a density of greater than 100 g/m^2 (DW) (dry weight) indicates a problem level of growth and when density exceeds 200 g/m^2 (DW) DO violations are likely to occur. These figures are average densities over a river reach.

More accurate figures on sustainable plant biomass (i.e. which will not produce DO violations) for a particular reach could be determined using computer modelling procedures. This question is less likely to be raised than, for example questions as to the response of the existing plant community to changed nutrient loading levels; however it is mentioned here merely to point out that the means exist to derive an estimate of maximum acceptable level of biomass on a case-by-case basis.

C. Special Techniques

Many of the techniques required for a detailed assessment of the stream plant community and its processes are specialized for this type of study. Stream physical and chemical surveys may be required and the procedures are basically the same as those used in waste assimilation surveys. The additional requirements for this type of study are as follows:

Type of Survey	Procedure
Intensive	Substrate and weed bed mapping
Intensive	Solar radiation
Intensive	Underwater light
Intensive & descriptive	Biomass chemistry
Intensive & descriptive	Biomass survey

A very brief description of the above procedures is given here in order that the requirements of the suggested study plans subsequently described can be better appreciated.

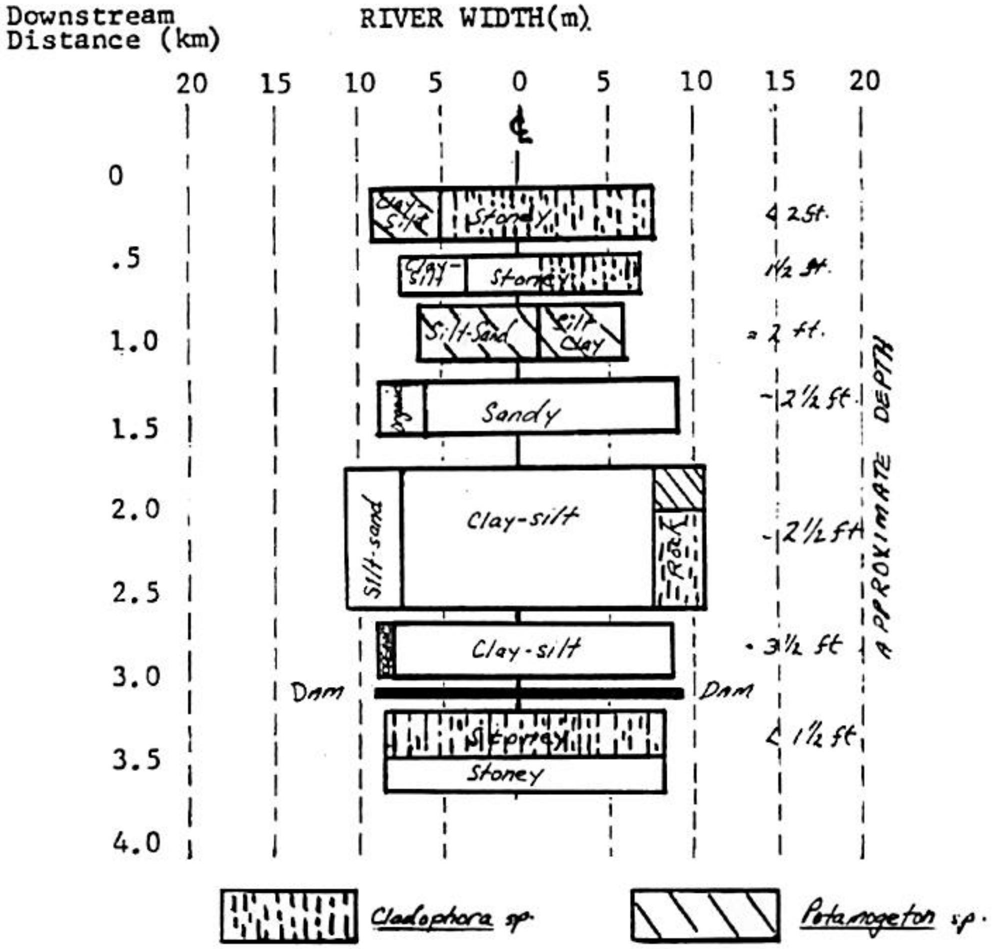

Figure 1: Schematic of River Reach Showing Section-by-Section Substrate, Plant Cover and Depth.

1. Substrate and Weed Bed Mapping

The study reach is visually surveyed to determine existing and potential zones of plant growth and sediment accumulation. Plants are identified and substrate is described as being stoney, rock ledge, silty, sandy, organic, etc. Since these observations will eventually have to be worked up into areal units, a schematic similar to that shown above might be used.

2. Biomass Chemistry

The only requirement as to plant chemistry is for total phosphorus in the plant tissue. The usefulness of this data hinges on the observation that phosphorus in plants relates positively to ambient stream phosphorus concentrations (3). Very high phosphorus in plants indicates a luxurious (over and above plant needs) supply of phosphorus as plants can store excess phosphorus. Conversely, low phosphorus in plants, less than 0.0015 gm P/gm biomass (DW) indicates that growth of the plant community may be limited to some extent by the availability of phosphorus.

3. Solar Radiation

Incident solar radiation data can be obtained from the nearest station. A pyranometer or similar instrument may also be obtained and located at the study site for better data.

4. Underwater Light

The light transmission characteristics of water vary from site to site and with flow-stage, season, etc. and must be carefully measured at the study site. The parameter of measurement is K_e, known as the light extinction coefficient (2). The method of estimating K_e requires that light intensity be measured at depth intervals using a quantum light sensor.

5. Biomass Survey

To avoid confusion, plant mass should always be reported in terms of dry weight per reach areal unit. If a plant density within a particular weed bed is reported this should be specifically stated. There are several ways of quantifying plant biomass in the reach.

1) Aerial photography with concurrent ground survey.

2) River survey - cropping is usually done using 1 ft^2 Surber samplers on quadrats selected using appropriate sampling strategy (See (2): Section 4.1).

3) If a continuous record of DO and temperature is available at the downstream end or at both ends of the study reach, the approximate biomass mean density can be estimated. Methods developed by H. T. Odum (4) are applied to an analysis of the DO data to achieve this. The procedure is based on knowledge of the biochemistry of plant photosynthesis and respiration, and requires data on other sources and sinks of dissolved oxygen in the study reach. The procedure is fully described in (2).

   If a continuous record of DO and temperature is available through the growing season, the Odum procedure may he used to calculate standing crop from day to day. This analysis can be facilitated by means of a computer program to process the large amount of data involved. A program suitable for productivity calculation from a single station data record is available from the River Systems Unit.

   This approach was applied with good results in the Grand River Basin Water Management Study (5) and an example of the results obtained for a three-year period of record is shown below in Figure 2.

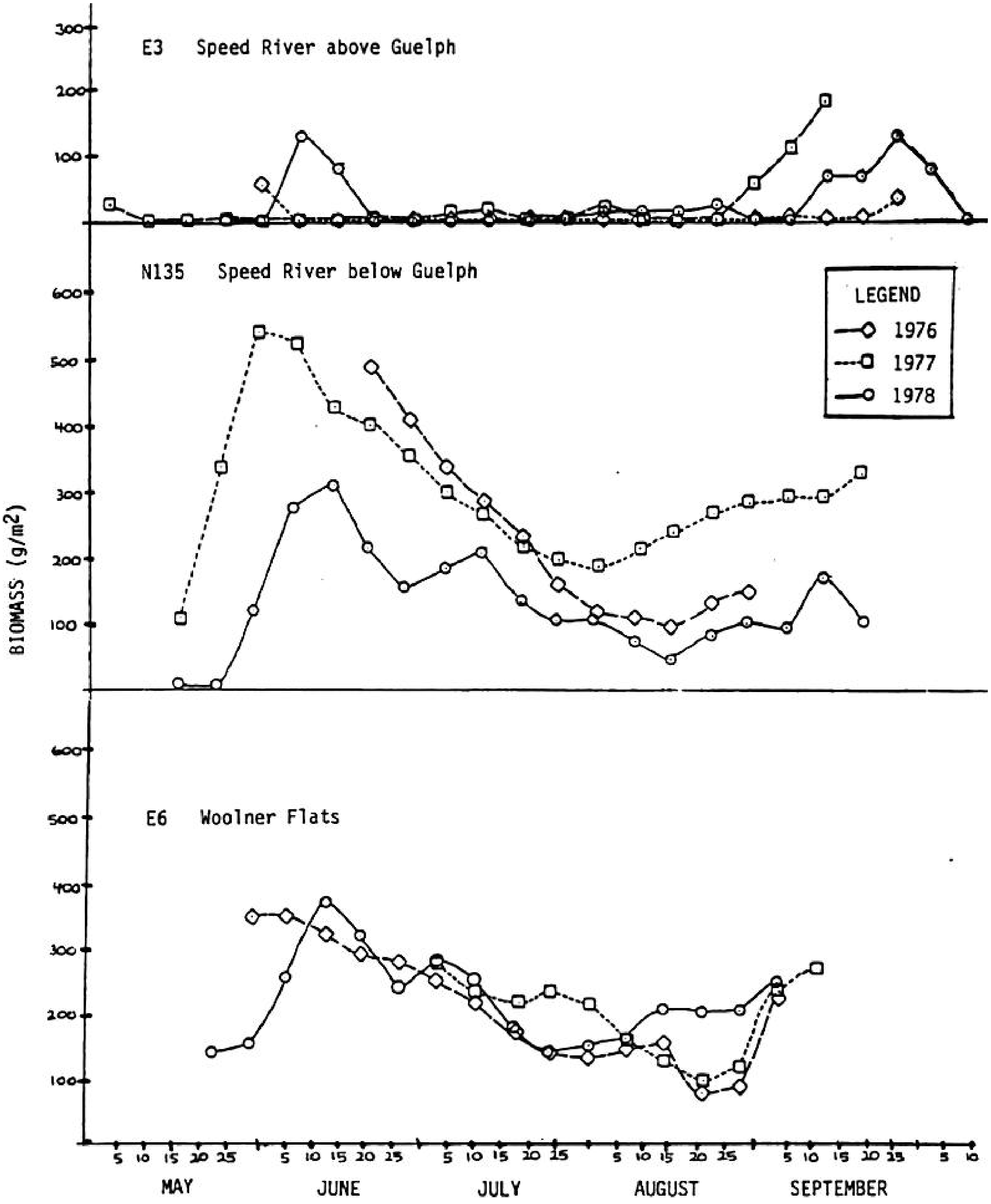

Figure 2: Continuous monitoring data: Estimated Biomass vs. Time.

Periphyton (a velvety growth of smaller algal growth forms commonly found on rocks in a stream) may also be important. Their density is best estimated by completely scraping several rock samples of known surface area and having the sample analyzed for volatile mass. An alternative procedure involves placing suitable, easily handled units, such as floor tiles in the stream, allowing periphyton to grow and determining mass at intervals. Periphyton does not usually influence stream DO sufficiently to warrant study. If, however, this does not appear to be the case, tests using light and dark dome respirometers *in situ* will be of use (2)(6).

D. Study Plans

The following tables summarize the field programs for two levels of study. The descriptive study plan (Table 1) would provide the data needed to determine whether an aquatic plant problem exists. By considering the results of such a study, the character of the stream bed in terms of substrate suitability and the level of plant productivity compared with that of other similar streams, a biologist can evaluate the potential for further plant proliferation in the study stream. Note that ideally the study plan should be implemented when (1) plants are near peak growth, (2) sunny, warm conditions prevail, and (3) near baseflow conditions are found in the stream.

The intensive study plan summarized (Table 2) requires that an additional monitoring station be established at the head of the study reach, that light be measured and that water quality monitoring be intensified. In addition, sediment oxygen demand should be measured. The in situ dome respirometer method is recommended for this work (6). The intensive study plan will provide a comprehensive data set which may be used to calibrate the ECOL1 model. The modelling approach is further discussed below.

TABLE 1: DESCRIPTIVE STUDY PLAN.

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. - Re-aeration coefficients - Dissolved oxygen - Biomass estimates
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
Substrate mapping	during biomass survey	- Rough sketch only to determine potential plant range.
Biomass chemistry	5 samples from along the weed bed.	- Phosphorus concentration in plants indicates the degree of nutrient limitation.
Water quality	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, velocity and flow rate.	At each change in flow	- Necessary in Odum's productivity analysis and estimation of nutrients flux.

TABLE 2: INTENSIVE STUDY PLAN

TASK	FREQUENCY OR DISTRIBUTION	USE OR INTERPRETATION
DO-Temp monitoring	Continuouslyfor1full week at each end of the study reach but not more than3 hrs. time of travel apart.	- Total community productivity and respiration from Odum's analysis. - Re-aeration coefficients - Dissolved oxygen - Total biomass estimate
Biomass survey	3 quadrats cropped at each transect. Transects should be about 100-200 metre intervals. <u>Major species should be identified along with % of the total.</u> Cropping should be repeated if survey lasts longer than1 week.	- Biomass density - Species distribution
Biomass chemistry	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, 3N,BOD_5, SS or Turbidity)	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 K_e and establish relationship. - Variability characteristics
Flow, velocity/time of travel, staff Ht.	At each major flow change	- Odum's analysis - Used in ECOL1
Substrate mapping	ONCE	- Establishing area subject to plant growth or SOD
SOD	3-4 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.

E. Simulation Modelling

If an intensive study program has been successfully completed the requirements will have been met for the application of the ECOL1 model. This model can be used as a subroutine in either a steady state or dynamic modelling framework. In terms of application, the main difference in the two approaches is the time frame of the model. In steady state modelling a representative 24-hour period is modelled, whereas longer periods, for example the growing season, may be modelled using the dynamic model.

A summary of the data requirements is given in Table 3 below.

1. Steady State Modelling

In waste assimilation studies a steady state DO-BOD model is used to establish waste loading guidelines which will ensure that acceptable levels of minimum DO are met under critical streamflow and temperature conditions. The MOE DO model (7) considers plant respiration to be a constant (areal) rate and varies plant photosynthesis according to a sine wave within-day variation. In the ECOL1 modelling approach this photosynthesis and respiration algorithm is replaced with a compartmentalized plant process approach. Aside from this difference the model treats the processes of BOD decay and re-aeration in a form identical to the MOE DO-BOD model, modelling a representative one-day period.

2. Dynamic Modelling with ECOL1

Dynamic modelling involves the integration of the ECOL1 program as a subroutine with a controlling program which accounts for the processes other than plant dynamics occurring simultaneously in the reach. The main advantage of a dynamic modelling approach is that it allows the modeller to "grow" the aquatic plant community through the simulated growing season and explore the effects of various management strategies on e.g. the peak biomass reached. Rather than simply using a set of design conditions of stream flow and temperature, dynamic modelling also has the capability of accepting

TABLE 3: Modelling Data Requirements.

DATA REQUIRED	MODEL TYPE: Steady-State	Dynamic	COMMENTS
River schematic	X	X	
Air temperature		X	
Storm data		X	If modelling storm effects
STP Data:			If modelling STP effects
Quality	(mean)	(2-hrly)	
Quantity	(mean)	(2-hrly)	
Sunlight intensity		X	
Sunlight duration	X	X	
Sunrise time	X	X	
Streamflow	X	X	
Hydraulic Relationships	X	X	
Muskingham coeff.		X	
Local inflow coeff.		X	
Boundary cond.'s	X	X	
ECOL1 constants	X	X	5 per plant species
Biomass	(Design)	(Starting)	
Phosphorus in plants	"	“	
Org. N/Tot. N	X	X	
Inhibition factor	X	X	From calibration
pH characteristics		X	For unionized NH_3 calculation
BOD_{ult} / BOD_5 ratio	X	X	

variable input flows and water quality. Thus, for example, instead of simply using mean values, STP within-day variation can be included, to better approximate real conditions. Data requirements can be only marginally greater than for steady state modelling, but increase with the complexity of the system being modelled and the management variables being tested.

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