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HYDRAULIC ASPECTS OF VEGETATION MAINTENANCE IN STREAMS

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Summary

This paper describes the importance of the underwater vegetation in Danish streams and some of the consequences of vegetation maintenance. The influence of the weed on the hydraulic conditions is studied through experiments in a smaller stream and the effect of cutting channels through the weed is measured. A method for prediction of the Manning's n as a function of the discharge conditions is suggested, and also a working hypothesis for predictions of the effect of channel cutting is presented.

Introduction

Danish streams are typical lowland streams. The streams are meandering through glacial deposits of moraine clay in the eastern part of the country and more sandy soils in the western part. Although the streams are comparatively small most of them have a stable waterflow through the year. The surroundings are almost entirely agricultural land, mostly pastures for cattle.

Due to intensivation of farming methods during this century macrophyte growth in streams has become a severe problem. The heavy growth of plants raises water levels and causes draining systems to stop working and yields from farming to fall drastically. This effect has been accentuated by channelisation of streams making the water systems even more susceptible to macrophytes than before.

Public authorities are responsible for removal of macrophyte vegetation in almost all the streams. Until now this has been done by cutting the weed 1-4 times a year. The removal has been done by clear cutting, and care was taken not to leave any vegetation. The consequences of clear cutting were dramatic alterations of water levels from situations with a dense vegetation to situations without any plants.

Most Danish streams are polluted to some extent either from sewage discharges or from trout farms. The considerable variation in vegetation density during the summer causes organic matters to degrade over either a very short (dense growth) or a much longer (no growth) length of water. This makes oxygen levels fluctuate between intolerable and tolerable levels. Through interaction with the carbonate systems of water macrophyte growth makes the stream more alkaline. The traditional management practice for vegetation has caused bigger fluctuations in pH than necessary, sometimes even making the environment dangerous to stream animals.

Most invertebrates in the streams, especially stoneflies (*Plecopthera*), mayflies (*Emphemerida*), and dragonflies (*Trichopthera*) are delimited in their distribution by the unfavourable oxygen and pH levels caused partly by the above mentioned clear cutting practice for the vegetation management. In addition the method in most cases causes the animals to live in suboptimal densities, because they find themselves in surroundings fluctuating between lots of food and practically no food, between no shelter and ample hideaways.

The commercially most important fish in Danish streams are eels. Like other fishes they have been moving around in the streams due to fluctuating oxygen levels in the environment. The precise effect of this phenomenon is not well known. The salmonid fishes (mostly trout) are territorial during their stream life, and their moving around due to oxygen fluctuations and cover removal causes suboptimal population sizes.

New methods for weed removal have been developed during the last decade. The vegetation is cut during the whole summer to avoid fluctuations in water levels and in biological important water parameters. Clear cutting is also avoided, by regular thinning or channel cutting through the vegetation. The ultimate goal for the management practice is an acceptable water level control and favourable biological conditions.

Optimal strategies for weed management call for rigid hydraulic tools for estimation of the effect on water level and water flow from various stands of underwater vegetation. The objective of this paper is to provide some of the bases for such tools by means of field experiments and measurements.

Field experiments

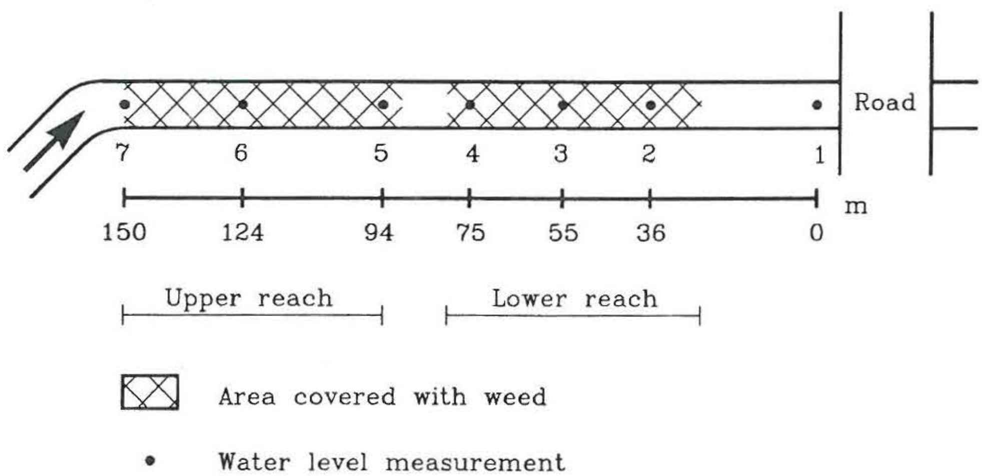

Fig. 1. The reach in Herredsbækken.

The field experiments were carried out in Herredsbækken, a smaller stream near the city Aars in the northern part of Jutland, Denmark. The chosen reach is approximately 150 m long and 2-2.5 m wide. The cross section is almost rectangular. The bottom slope is 0.1-0.2 per cent and during the period of measurement in September 1989 the discharge was approximately 100 l/sec. The average depth was between 0.2 and 0.4 m.

The reach was densily covered with weed totally dominated by *Sparganium simplex*, which is a very commonly found specie in Danish streams. The biomass of the weed was measured as wet weight and was found to be 2.38 kg/m^2 for the upper reach and 1.55 kg/m^2 for the lower reach. The percentage dry matter was found to 7.4 %.

The water level was measured at 7 stations and the flow was found by "velocity area integration", where the velocity was measured at a number of points at the cross section near station no. 3. Approximately 600 m upstream the stream widens into a lake with a 20,000 m^2 large surface. By controlling the outlet from the lake by a weir, the discharge at the reach could be varied in the range from 80 to 450 l/sec.

Four series of measurements were performed, starting with measurements in the undisturbed stream, with an almost uniform distribution of the weed in the cross section. A channel of 0.5 m width (app. 25% of the total width) was cut in the weed and the measurements were repeated. Then the channel was extended to 1.0 m width (app. 50% of total width) and finally all the weed was removed. Between each series the removed weed were sampled and the wet weight was found, from which the removed part of the total biomass could be found to app. 30% for a 0.5 m channel and app. 50% for a 1.0 m channel.

The results were discharge-depth series, Q-h curves, for each station. The results from station no. 4 are shown in Figure 2.

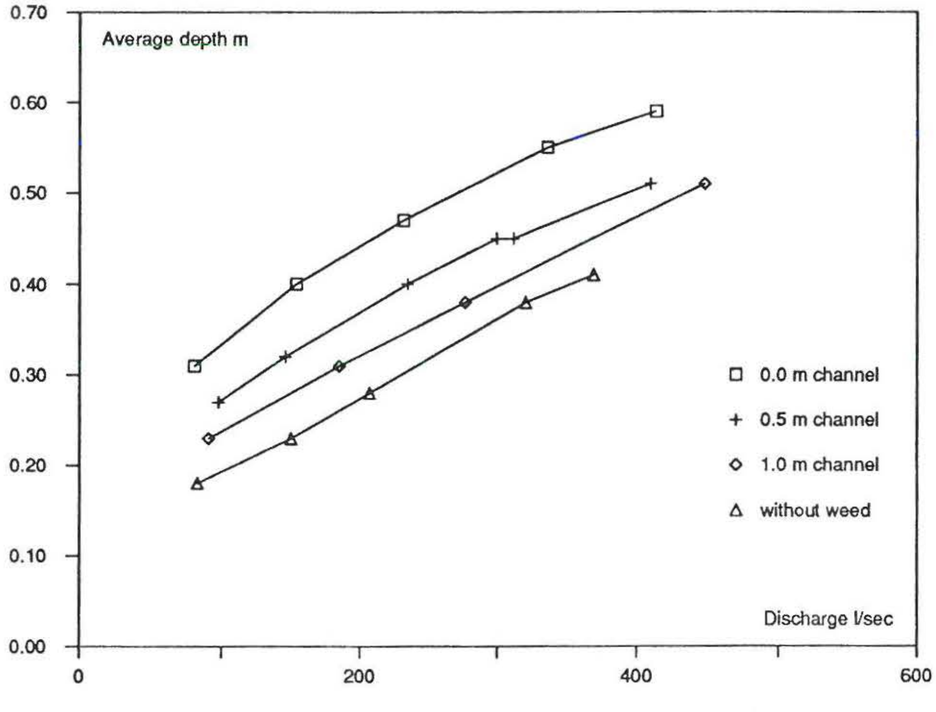

Fig. 2. Measured discharge-depth series in station no. 4.

Hydraulic influence of vegetation

It is well known that the observed Q-h relation in vegetated streams depends on the density of the weed, which easily can be recognised in Figure 2. The double-logaritmic plot of the Q-h data in Figure 3 shows that the effect of the weed decreases with increasing discharge or depth, and a point of intersection between the "weed-curves" and the winter Q-h curve (without weed) seems to exist.

This point of intersection is probably an artificial point, since such a combination of discharge and depth never will occur in the stream. But nevertheless, this point is valuable for construction of other "weed-curves".

Such a point of intersection will not be present in all vegetated streams, since the behaviour of the actual specie of weed can be very different. The *Sparganium simplex* is a plant with very long stems, which due to buoyancy will tend to fill a large part of the cross-section area, but when the discharge is increasing, the depth will increase and the *Sparganium* will bend against the bottom due to the higher velocity and therefore the hydraulic influence of the weed will decrease.

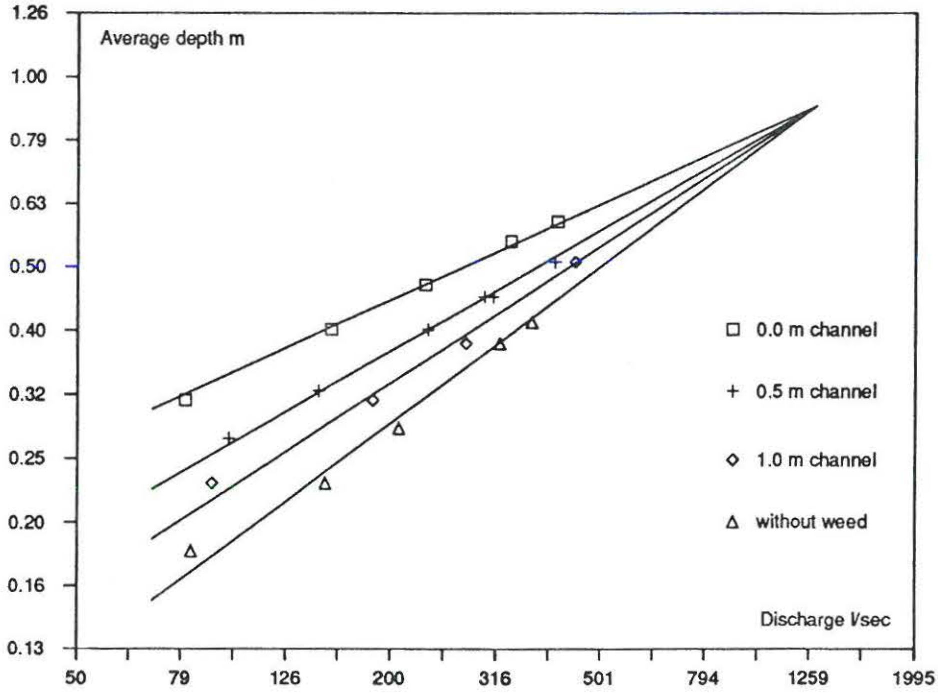

Fig. 3. Measured discharge-depth series in station no. 4. in a double logarithmic plot.

Furthermore, it can be seen from Figure 3 that the effect of cutting a channel through the weed is not proportional to the relative width of the channel, since cutting a channel of app. 25% of the total width will provide app. 50 % of the possible effect at the water level.

This can lead directly to some empirical relation between discharge, depth and relative width of the channel, but if it shall be possible to combine the observed behaviour of this type of weed with mathematical models for streams, it will be much more convenient if this effect is expressed as a kind of variable hydraulic resistance.

Prediction of hydraulic resistance from weed

Hydraulic considerations or calculation in streams are often based on the well known Manning formula:

$$V = \frac{1}{n} R^{2/3} S^{1/2} \quad \text{or} \quad Q = \frac{1}{n} A R^{2/3} S^{1/2}$$

where
- V cross-section average velocity (m/sec)
- Q discharge (m^3/sec)
- A cross-section area (m^2)
- n Manning's n ($sec/m^{1/3}$)
- R hydraulic radius (m)
- S slope of the energy line

It is a generally accepted fact that Manning's n in vegetated streams depends on the product of the average velocity V and the hydraulic radius R, see e.g. Chow 1959 or Larsen et al. 1990. This product is almost similar to the discharge pr. unit width.

From the measured data it is possible to obtain the Manning coefficients, which are shown in Figure 4 as functions of $log(V \cdot R)$, from which the expected dependence is easily recognised.

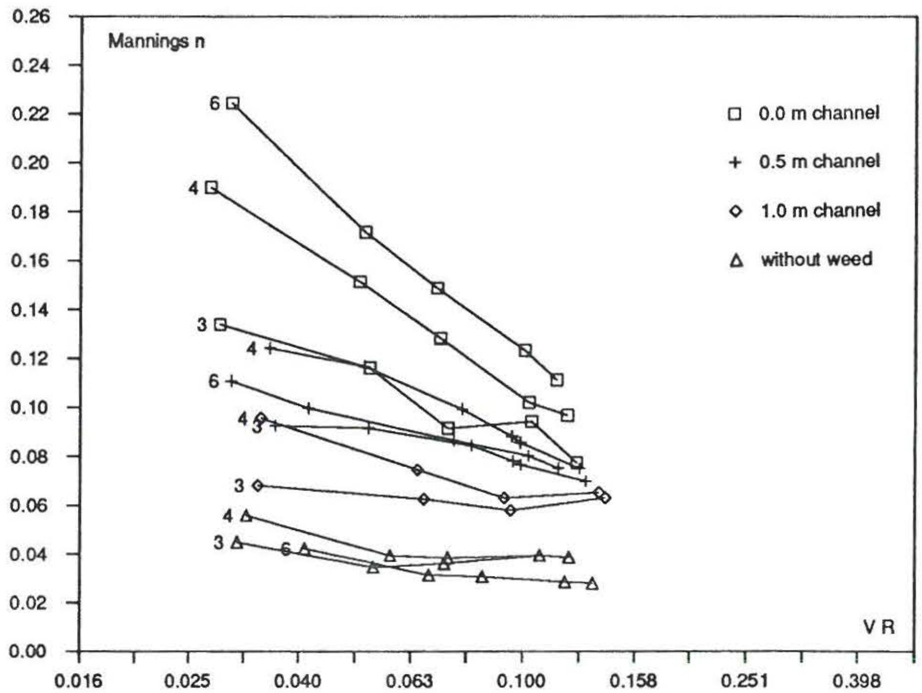

Fig. 4. Measured Manning coefficients.

Figure 4 shows also that all the curves seem to converge for high values of the product $V \cdot R$, which leads to the same conclusions as based on Figure 3, that the hydraulic effect or resistance caused by the weed decreases for increasing discharge rate and even vanishes for very large discharge rates.

This leads to the conclusion that a (perhaps artificial) point of intersection of the curves in Figure 4 can be found. If this point is known, each curve can be constructed if only a few other points on the curve are known (by measurements). The idea is illustrated in Figure 5 where the curves are assumed to be straight lines. Using such a relation would make it possible to include the variation of the Manning coefficient with the discharge rate in for example a mathematical model.

The suggested method can be expanded to include prediction of the effect of cutting channels. In Figure 5 the angle between the basic or winter curve (marked 100) and the curve for the densily weed-covered stream (marked 0) is divided into equal pieces, providing the lines marked 20, 40, 60 and 80. Combining these lines with the measured data from station 4 as shown in Figure 5, indicates some kind of correlation, since the points marked with crosses and diamonds, respectively, represent cutting a channel with a width of app. 25% and 50% of the total width, or removal of app. 30% and 50% of the total biomass. For these data this simple performance seems to give a reasonable prediction of the Manning coefficients.

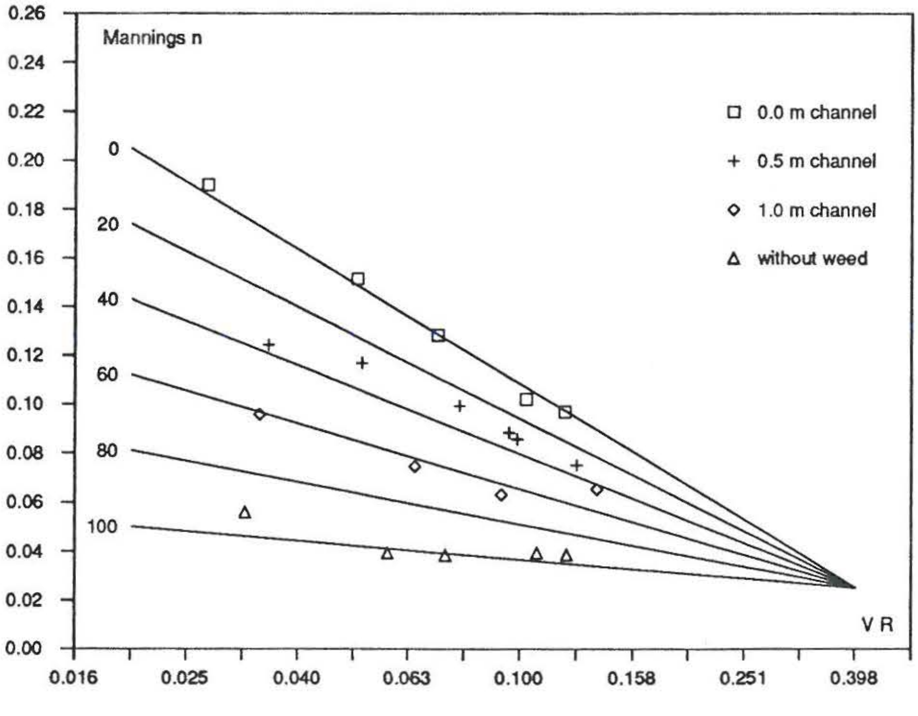

Fig. 5. Prediction of Manning's n for different percentage removal of weed combined with the measured Manning coefficient in station no. 4.

It has to be emphasized that the method for prediction of the effect of channel cutting not has been validated on data from other streams, and therefore it shall only be seen as a "working hypothesis". The relation between Manning's n and $log(V \cdot R)$ is perhaps not always a straight line as suggested in Figure 5, and the division of angle between the 0% and 100% curve into equal pieces is only an initial suggestion. Further investigations need to be made to validate the described method, but the principle can be expected to be usable for other weed species, although intersection point and slope of the lines might be different.

Conclusion

This investigation confirms that underwater vegetation has a significant influence on the hydraulic friction in streams. This effect decreases with increasing discharge rate and even vanishes for very large discharge conditions. The measured relations between the Manning's n and the product $V \cdot R$ of the average velocity and the hydraulic radius indicates that the "weed-curves" converge against a single point. If such a point can be found, it will be possible to obtain the variation of the Manning's n with the product $V \cdot R$ for the actual weed condition, with only a few (one) measurements of Manning's n. Furthermore, the measured data seem to indicate that it will also be possible to predict the effect of cutting a channel in the weed. It has to be mentioned that this suggestion is based on few data and, therefore, it can only be considered as a basis or a "working hypothesis" for further investigations. It can be expected that a similar picture will appear for other species of weed, qualitatively but not quantitatively.

Acknowledgements

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