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*Publication date:*
1991

*Document Version*
Tidlig version også kaldet pre-print

Link to publication from Aalborg University

*Citation for published version (APA):*
Vestergaard , K., Larsen, T., & Frier, J-O. (1991). *Q-h kurver for grødefyldte vandløb*. Aalborg Universitetscenter, Inst. for Vand, Jord og Miljøteknik, Laboratoriet for Hydraulik og Havnebygning.

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## 1 Resumé

Formålet med herværende skrift er at beskrive vandføringsevnen i grødefyldte vandløb ved store vandføringer, som giver oversvømmelsesrisiko. Der angives en metode til beregning af denne vandføringsevne på grundlag af vandføringsmålinger ved normale vandføringer. Hovedkonklusionen er, at den hydrauliske modstand aftager kraftigt med stigende vandføring, - et forhold som kan udnyttes ved skånsom grødeslagning.

## 2 Baggrund/Introduktion

I mange danske vandløb forekommer der en kraftig grødevækst. Grødevæksten kan medføre en betydelig forringelse af vandføringsevnen, hvilket i almindelighed nødvendiggør at foretage grødeslagning. Gennem de senere år er man fra forskellig side blevet opmærksom på de uheldige økologiske effekter ved grødeslagning, og tendensen går i dag mod en mere selektiv og miljøskånsom grødeslagning, se f.eks. Kern-Hansen 1987. For at kunne sikre vandløbenes vandføringsevne på en miljømæssig forsvarlig måde, er det imidlertid nødvendigt at kende grødens indvirkning på vandføringsevnen, f.eks. udtrykt gennem en grødeafhængig hydraulisk modstand.

Man har i en længere årrække løst problemet i forbindelse med permanente vandføringsstationer ved at arbejde med årstidsafhængige Q-h kurver. Grundkurven, eller vinterkurven findes ved potensregression på målte (med propel/vinge) vandføringer og dybder gennem vinterhalvåret. Grødekurverne konstrueres herefter ved hjælp af en enkelt vandføringsmåling i grødesituationen, idet der anvendes en af tre mulige metoder, nemlig *brændpunktmetoden, proportionalmetoden* eller *bundforskydningsmetoden*, se f.eks. Hedeselskabets Hydrometriske Undersøgelser 1987.

Disse empiriske metoder har vist sig anvendelige til afstrømningsmålinger, men i forbindelse med en vurdering af grødeslagningens betydning for oversvømmelsesrisikoen, kunne det være ønskeligt med en mere detaljeret beskrivelse af grødens hydrauliske betydning.

# 3 Projekter på Aalborg Universitetscenter

Instituttet for Vand, Jord og Miljøteknik har gennem årene undervist i vandløbsforhold på akademiingeniøruddannelsen (anlægssektoren) og civilingeniøruddannelsen i miljøteknik. Kurserne har bl.a. omfattet de hydrauliske forhold, herunder indflydelsen fra grøden.

Gennem de senere år er der blevet gennemført en række afgangsprojekter på anlægssektorens miljølinie omhandlende grødens hydrauliske betydning, ofte gennem indfaldsvinklen "miljøvenlig vedligeholdelse", se Schmidt & Madsen 1989, Muldbjerg, 1990 og Jensen et al. 1990. Gennem disse projekter er der blevet genemført en lang række felt- og laboratoriemålinger.

Bl.a. med udgangspunkt i disse målinger, samt supplerende laboratorie- og feltmålinger, har instituttet efterhånden opbygget et kendskab til emnet, som har udmøntet sig i de to vedlagte artikler, Larsen, Frier & Vestergaard 1990 og Larsen, Vestergaard & Frier 1991. Førstnævnte blev i efteråret 1990 præsenteret på en international konference i Wallingford, England, mens sidstnævnte er indsendt til en kommende konference i Madrid.

Det er instituttets hensigt at arbejde videre med emnet i de kommende år, og man har naturligvis et ønske om at formidle den indsamlede viden til det danske område, hvilket bl.a. er formålet med dette skrift. Et andet formål er at indsamle yderligere data fra danske vandløb, således at de i artiklerne opstillede teorier kan diskuteres og videreudvikles.

I det følgende afsnit vil der blive givet et kort resume af de to artikler, hvorefter en metode til beregning af Q-h kurver vil blive skitseret.

# 4 Resumé af resultater

De opnåede resultater er baseret på feltmålinger på en grødefyldt strækning af Herredsbækken ved Års i Himmerland, samt på laboratoriemålinger i en strømrende i vandbygningslaboratoriet på AUC. I begge forsøg var der tale om grødearten Pindsvineknop eller nært beslægtede arter. Endvidere er der inddraget resultater fra floden Bain i England.

Formålet med forsøgene har været at bestemme Manningtallets variation med grødemængden og de hydrauliske forhold, samt at bestemme effekten af at etablere stømrender i grøden. I begge forsøgsrækker har det været muligt at variere vandføringen og således direkte måle Q-h sammenhængen. Ud fra de målte Q-h data har det været muligt at beregne energitabet, og dermed Manningtallet, ved brug af energiligningen for stationære uensformige strømninger, se f.eks. Pedersen 1988.

Forsøgene viser, at der er en tydelig sammenhæng mellem det beregnede "Mannings $n$" (den reciprokke værdi af Manningtallet $M$), og produktet af middelhastigheden $V$ og den hydrauliske radius $R$, se f.eks. fig. 6 og 7 i Larsen, Frier & Vestergaard 1990. Dette er i overensstemmelse med tidligere amerikanske forsøg i græsbegroede kanaler, Chow 1959.

Endvidere fremgår det af målingerne, at Manningtallet for forskellige grødetætheder konvergerer mod grundværdien (vinterkurven) for høje værdier af $VR$, dvs. for store afstrømninger. Dette kan forklares med, at grøden lægger sig mere og mere ned efterhånden som vandføringen, og dermed hastigheden, stiger, og dermed mindskes den hydrauliske modstand forårsaget af grøden, se Mikkelsen 1987. I grænsetilfældet vil grøden ligge fladt hen af bunden og dermed ikke udgøre nogen nævneværdig hydraulisk modstand, dvs. at det aktuelle Manningtal vil svare til Manningtallet for det grødefri vandløb.

Dette leder frem til den i fig. 8 (Larsen, Frier & Vestergaard 1990) foreslåede antagelse, nemlig at der eksisterer et brændpunkt for Mannings $n$. Denne hypotese i kombination med en enkelt bestemmelse af Mannings $n$ i det grødefyldte vandløb kan lede frem til $n$'s variation med afstrømningen ($VR$) for den aktuelle grødesituation. Målingerne i Herredsbækken viser en lineær sammenhæng mellem $n$ og $ln(VR)$, og den i næste afsnit skitserede metode baserer sig netop på en sådan lineær sammenhæng.

Det har envidere vist sig, at en sådan lineær sammenhæng også vil give rimelige estimater for Manningtal ved forskellige bredder af strømrender, se fig. 5 (Larsen, Vestergaard & Frier 1991). Disse resultater bygger dog på et relativt spinkelt grundlag og skal derfor anvendes med nogen forsigtighed.

Alt i alt betyder dette, at man ved en enkelt bestemmelse af Manningtallet i den aktuelle situation, samt udfra kendskab til det omtalte brændpunkt, kan bestemme Manningtallets variation, og dermed f.eks. bestemme den aktuelle Q-h kurve (se næste afsnit) eller basere mere sofistikerede modelberegninger, f.eks. med MIKE 11, på en mere korrekt beskrivelse af energitabet i et grødefyldt vandløb.

# 5 Beregning af Q-h kurver

Givet et brændpunkt $[(VR)_0, n_0]$ og et målt punkt $[(VR)_m, n_m]$, og antag at der eksisterer en lineær sammenhæng mellem $n$ og $ln(VR)$, som vist på fig. 1:

$$n = \frac{1}{M} = \alpha \cdot ln(VR) + \beta \tag{1}$$

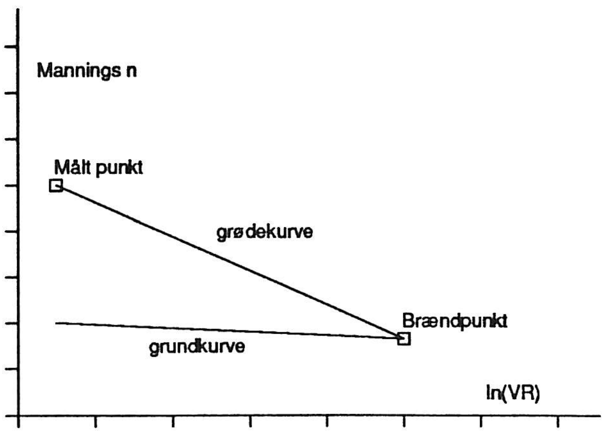


*Fig. 1. Definitionsskitse*

Udfra de to kendte punkter på linien kan parametrene $\alpha$ og $\beta$ bestemmes af:

$$\alpha = \frac{n_0 - n_m}{ln(VR)_0 - ln(VR)_m} \tag{2}$$

$$\beta = \frac{n_m ln(VR)_0 - n_0 ln(VR)_m}{ln(VR)_0 - ln(VR)_m} \tag{3}$$

Endvidere haves kontinuitetsligningen:

$$Q = V \cdot A \tag{4}$$

Hvis der ydermere antages at strømningen kan betragtes som ensformig, dvs. at bundhældningen $I_0$ er lig med energiliniegradienten $I$, da kan Manning-formlen skrives som:

$$V = M\, R^{2/3}\, I_0^{1/2} = \frac{1}{n} R^{2/3}\, I_0^{1/2} \tag{5}$$

Kendes de to parametre $\alpha$ og $\beta$, samt sammenhængen mellem vanddybde og tværsnitsparametrene, hydraulisk radius $R$ og tværsnitsarealet $A$, da kan Q-h kurven findes på følgende vis:

1: Bestem tværsnitsparametrene $R$ og $A$ for en given vanddybde $h$
2: Gæt en middelhastighed $V$, f.eks. $V = 0.3\ m/sek$
3: Beregn Mannings $n$ eller Manningstallet $M$ udfra (1)
4: Beregn en ny middelhastighed af (5)
5: Gentag pkt. 3-4 indtil $V$ er bestemt tilstrækkeligt nøjagtigt
6: Vandføringen $Q$ beregnes af (4)
7: Gentag 1-6 for forskellige værdier af $h$ til bestemmelse af Q-h kurven

I det følgende afsnit vil anvendelsen af metoden blive demonstreret gennem et beregningseksempel.

# 6 Beregningseksempel fra Herredsbækken

I Herredsbækken kendes fem punkter på grundkurven (Q-h kurven i vintersituationen), vist på fig. 2 og i tabel 1.

| | | | | | |
|---|---|---|---|---|---|
| Vanddybde $m$ | 0.15 | 0.20 | 0.25 | 0.35 | 0.38 |
| Vandføring $m^3/s$ | 0.083 | 0.150 | 0.207 | 0.321 | 0.370 |
| Tværsnitsareal $m^2$ | 0.37 | 0.49 | 0.62 | 0.87 | 0.94 |
| Hydraulisk radius $m$ | 0.14 | 0.18 | 0.22 | 0.29 | 0.31 |

*Tabel 1. Målte vinterværdier i Herredsbækken*

Tværsnitsprofilet er tilnærmelsesvist rektangulært med en bundbredde på 2.45 $m$ og den gennemsnitlige bundhældning er bestemt til 1.1 $o/oo$. Manningtallene for de målte Q-h punkter kan da bestemmes til at ligge mellem 22 og 27 $m^{1/3}/sek$.

På baggrund heraf vælges den maksimale værdi af Manningtallet til 30 ($n$=0.33) og brændpunktet antages da at være:

$$[(VR)_o, n_o] = [0.4, 0.33]$$

I sommerhalvåret forekommer der en kraftig grødevækst på strækningen, og i forbindelse med vurderingen af oversvømmelsesrisikoen i den aktuelle grødesituation ønskes Q-h kurven beregnet.

Der foretages en sammenhørende måling af vandføringen $Q$ og vanddybden $h$, dvs. et punkt på den aktuelle Q-h kurve. Følgende bliver målt:

$$Q = 154\ l/sec \qquad og \qquad h = 0.33\ m$$

som via kendskabet til tværsnittets geometri og bundhældningen omregnes til

$$[(VR)_m, n_m] = [0.053, 0.076]$$

Udfra formel 2 og 3 beregnes nu de to kurveparametre $\alpha$ og $\beta$:

$$\alpha = -0.02090 \qquad og \qquad \beta = 0.01418$$

Ved hjælp af iterationsmetoden omtalt i afsnit 5 bestemmes $Q$ for et passende antal $h$-værdier, hvorved Q-h kurven i fig. 2 fremkommer.

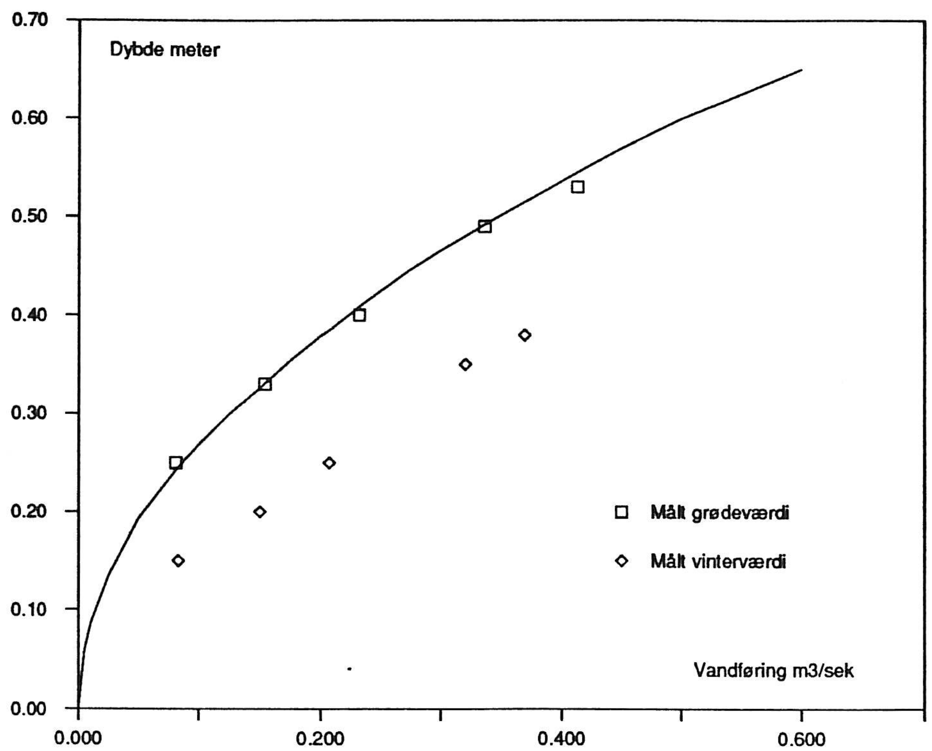


*Fig. 2. Beregnet Q-h kurve og målte Q-h værdier*

Udover det $Q-h$ punkt som blev anvendt til beregningen af kurveparametrene, er vist yderligere fire $Q-h$ punkter fra grødesituationen, se også tabel 2, og det ses at der er opnået en meget fin overensstemmelse mellem de målte værdier og den beregnede kurve.

| | | | | | |
|---|---|---|---|---|---|
| Vanddybde $m$ | 0.25 | 0.33 | 0.40 | 0.49 | 0.53 |
| Vandføring $m^3/s$ | 0.081 | 0.154 | 0.232 | 0.337 | 0.414 |
| Tværsnitsareal $m^2$ | 0.62 | 0.82 | 0.99 | 1.21 | 1.31 |
| Hydraulisk radius $m$ | 0.22 | 0.28 | 0.32 | 0.37 | 0.39 |

*Tabel 2. Målte værdier i grødesituationen*

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# Discharge/Stage Relations in vegetated Danish Streams

by

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## Abstract

This paper describes how the friction in Danish streams varies as function of the vegetation. The major species of vegetation are presented. A series of laboratory and field experiments are described, and a hypothesis for the influence of the vegetation on the Manning's n is discussed.

## Introduction

Danish streams are all typical lowland streams, since the country are totally devoid of rocks or mountains. 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.

Fifty or more different species of macrophytes make up the flora of these streams, but only few are quantitatively important. Among these the sibling species of *Batrachium* or the two monocotyledonts *Glyceria maxima* or *Sparganium simplex* are dominant. *Helodea canadense* or species of *Callitriche* are subdominant with either of the dominant vegetation types.

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 weeds 1-4 times a year. The removal has always been done by clear cutting, and due care was taken not to leave any vegetation.

Presented at International Conference on River Flood Hydraulics, 17-20 September 1990, Wallingford, England

The consequences of clear cutting were dramatic alterations of water levels from situations with a dense vegetation to situations without any plants.

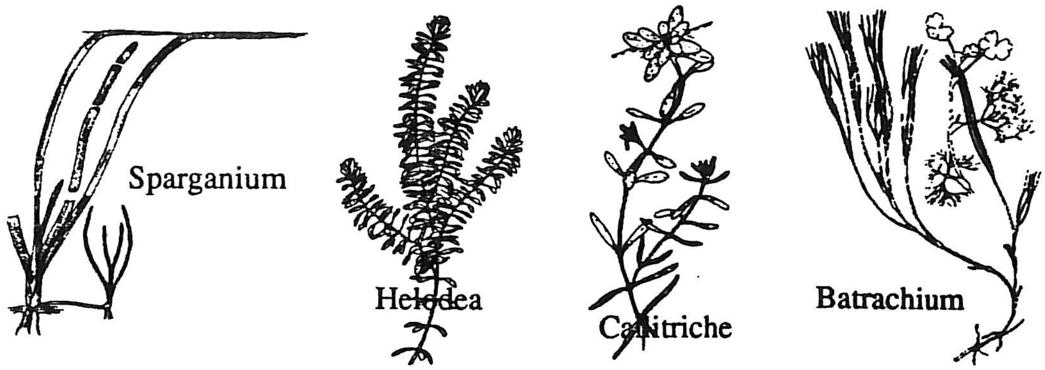


Fig. 1. Dominant species of vegetation in Danish streams

Most danish steams are polluted to some extent either from sewage plants or from trout farms. The big variation in vegetation density during the summer caused organic matters to degrade over either a very short (dense growth) or a much longer (no growth) length of water. This made oxygen levels fluctuate between intolerable and tolerable levels .

Through interaction with the carbonate system of the water macrophyte growth makes the streams more alkaline. The old management practice for vegetation caused bigger fluctuations in pH than necessary, sometimes 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 levels and unfavourable pH levels of danish streams 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 found themselves in surroundings fluctuating between lots of food and practically no food, between no shelter and ample hideaways.

The commercially most important non salmonid fish in danish streams are eels. Like other fishes they have been moving around in the streams due to the fluctuating oxygen levels in the environment. The exact effect of this phenomenon is not well known.

The salmonid fishes (mostly trout) are teritorial during their stream life, and their moving around due to oxygen fluctuations and cover removal causes suboptimal population sizes of these fishes.

New methods for weed removal have been developed during the last decade. The vegetation are 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 a constant water level and constant and favourable biological conditions in the stream in conjunction with a permanent function af the agricultural draining systems.

Optimal strategies for weed management calls 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 basis for such tools by means of a combination of mathematical models, experiments in artificial channels and measurements and experiments in nature.

## Materials and methods

The field experiments was caried out in Herredsbækken, a smaller stream near the city Aars in the nothern part of Jutland. The chosen reach is approximately 150 m long, 2-2.5 m wide. The cross section is almost rectangular. The bottom slope is 0.1-0.2 percent 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 (see figure 3).

The reach in Herredsbækken was densily covered with weed totally dominated by *Sparganium simplex*. The biomass of the weed was measured as wet weight and was found to 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 %.

| | Dry weight g/m$^2$ | Dry matter % |
|---|---|---|
| Flume tank experiment, density I | 390 | 4 |
| Flume tank experiment, density II | 190 | 4 |
| Flume tank experiment, density III | 80 | 4 |
| *Sparganium simplex* - Herredsbæk - September, Area 3 | 120 | 7.4 |
| *Sparganium simplex* - Herredsbæk - September, Area 6 | 180 | 7.4 |
| *Batrachium sp.* - Gryde Å - July, August | 200 | |
| *Batrachium sp.* - Gryde Å - Winter | 40 | |
| *Batrachium sp* - Simested Å - May, Average of 6 areas | 48 | 5.0 |
| *Batrachium sp.* - Fjederholt Å - July, Average for 2 summers | 350 | |

Fig. 2. Biomass density of plants in our experiment and in typical situations in Danish streams. Result from Gryde Å are from Jeppesen and Thyssen (1985). Result from Fjerderholt Å are from Kern-Hansen et al (1980). The rest are own measurements.

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 brook widens into a lake with a 20000 $m^2$ 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.

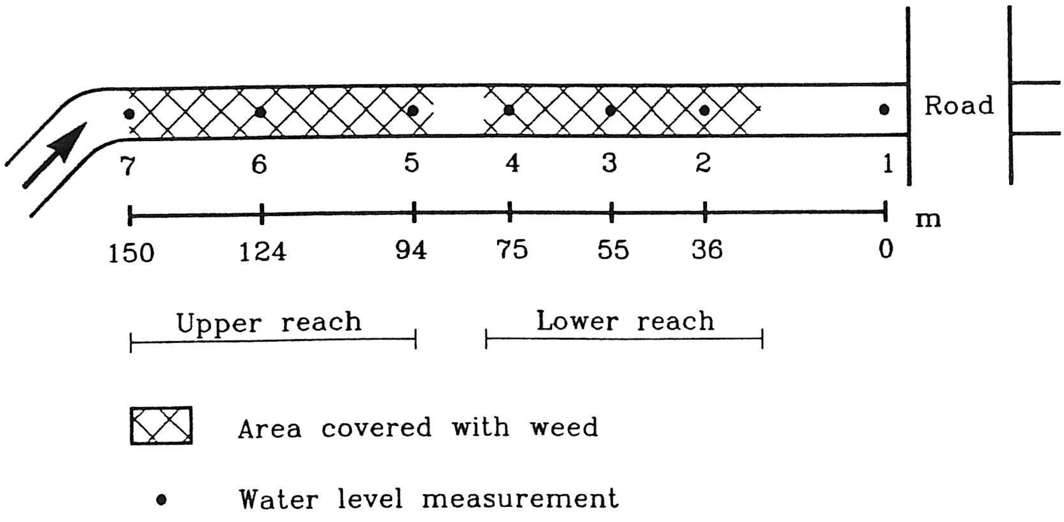


Fig. 3. The reach in Herredsbækken

The results was discharge-depth series for each station. Using a backwater calculation it was possible to obtain the Manning coefficients for each flow-series.

The flume tank experiments in the laboratory at the University of Aalborg was carried out in a 15 m long rectangular flume tank with a width of 30.5 cm.

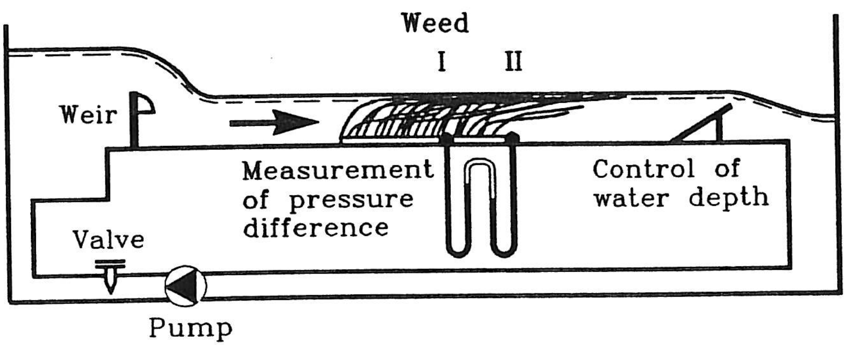


Fig. 4 Flume tank experiment

In this flume tank a 1.5 m long reach with weeds of *Sparganium simplex* was built. Each stem was fixed in a net of metalwire, which afterwards was founded in plaster. The average length of the weed was 81 cm, the specific gravity 802 $kg/m^3$, and the percentage dry matter 4.0 %. The biomass densities of *Sparganium* covered the ranges normally found in Danish streams (see figure 2).

The discharge could be controlled by a valve and was measured by use of a sharp crested weir. The discharge could be varied in a range from 1 to 18 l/sec. The slope of the water surface was measured as a difference in pressure between point I and II (see figure 4). The distance between point I and II was 61.3 cm. The water depth was measured in point I and could be varied in the range from 6 to 22 cm.

The slope of the water surface was measured for a large number of combinations of discharge and depth, then the density of weed was decreased by removing approximately half of the straws, before the measurements were repeated. Measurements were performed for four different densities of weed, and from a backwater calculation the Manning coefficients was found for each combination of discharge, depth and density of weed.

## Hydraulic considerations and results

The main objective of this work was to establish and discuss methods for the determination of discharge/stage relations for vegetated streams. Especially it is relevant to evaluate the flooding risk for streams in the summer period in connection with uncommon high discharges. A typical discharge/stage relation is shown in figure 5.

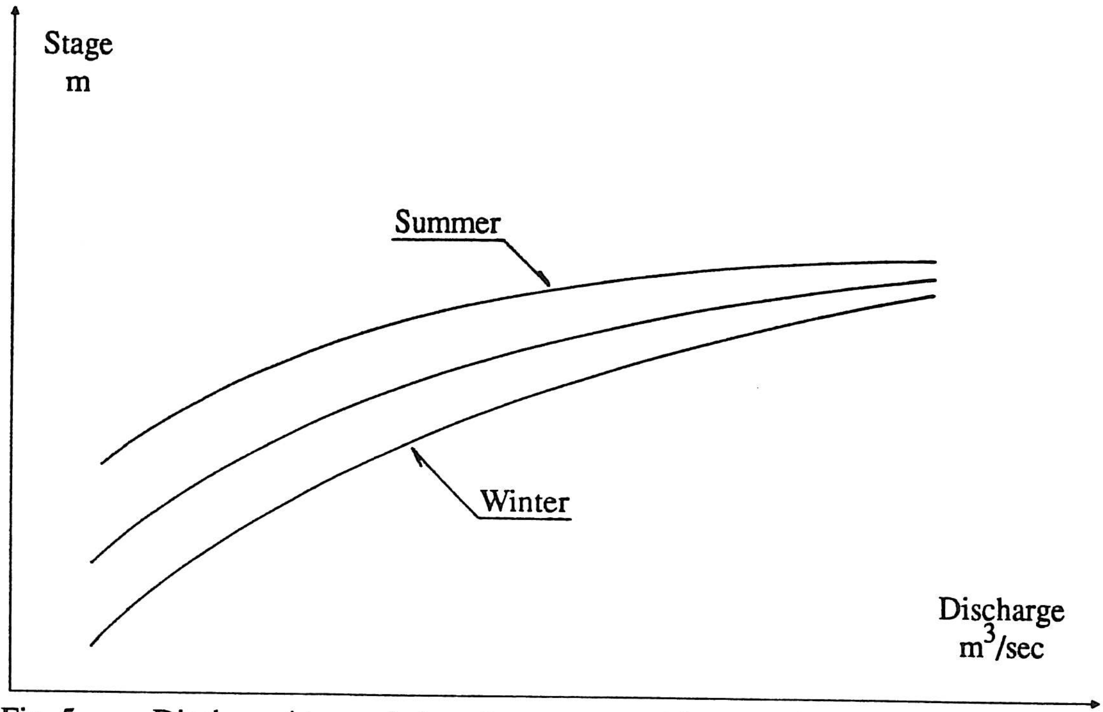


Fig. 5. Discharge/stage relations for a stream with vegetation

It is a generally accepted fact that the friction in vegetated streams and rivers depends on the discharge rate, see e.g. (Chow 1959). Many words could have been spent on discussing which friction equation to use under such circumstances. But this seems to be irrelevant because the physics of the phenomena indicates that a varying friction coefficent would anyhow be necessary. The friction will here be described as the variation of the Manning's n from the well-known Manning equation:

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

where
V is cross-section average velocity [ m/s ]
Q is discharge [ $m^3/s$ ]
A is cross-section area [ $m^2$ ]
n is Manning's n
R is hydraulic radius [ m ]
S is the slope of the energy line [ dimensionless ]

Chow(1959) refers to a number of investigations on grassed channels, which show how the Manning's n depends on the product of V$\cdot$R ( average cross-section velocity times hydraulic radius ).

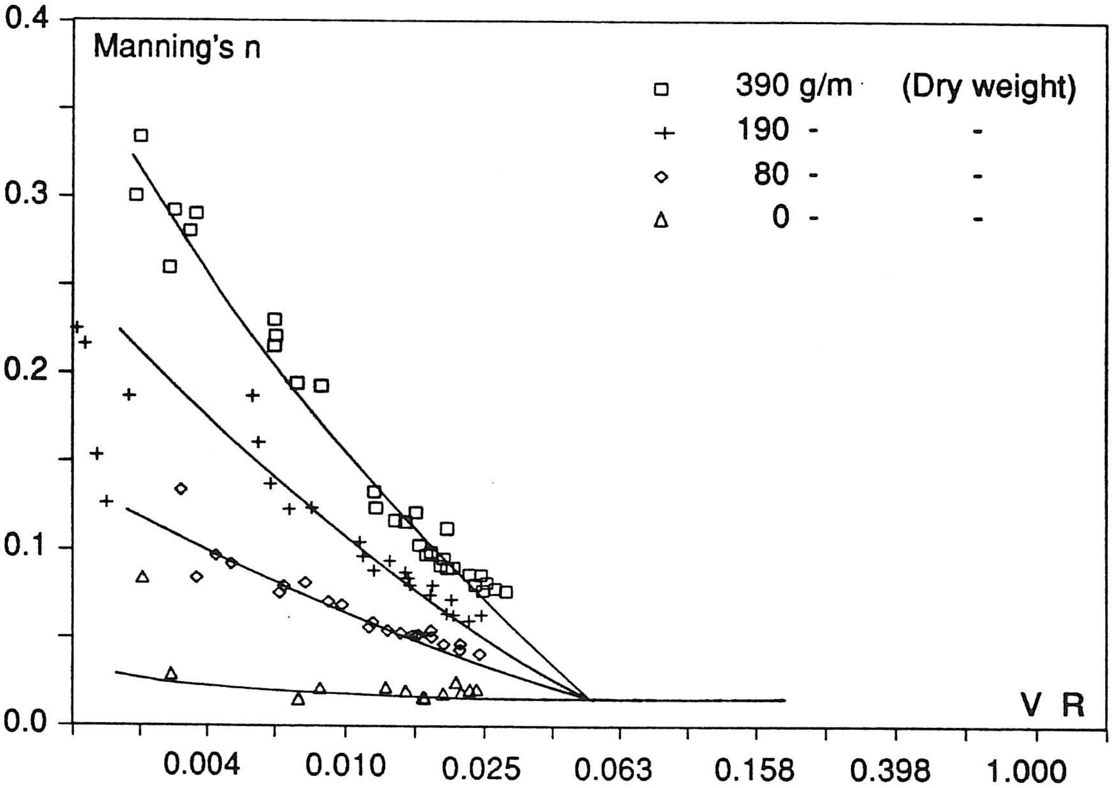


Fig. 6. Results of flume tank experiment.

In this investigation different ways of plotting the results was tried, e.g. n was plotted against discharge, velocity, bottom shear etc. But the conclusion was that plotting n against V• R gave the most consistent results (figure 6).

Figure 6 shows the results the laboratory experiments described . This gives a clear picture how the friction increases with vegetation density and decreases with the product of V• R. It should here be repeated that in the laboratory experiments a large number of independent combinations of V and R were tested. The laboratory results confirm that the product V• R is a reasonable variable in the description of the varying n. Furthermore the results make it probable that the curves converge against one point of intersection. For similarity reasons it cannot be expected that the laboratory results can be directly compared with the field experiment.

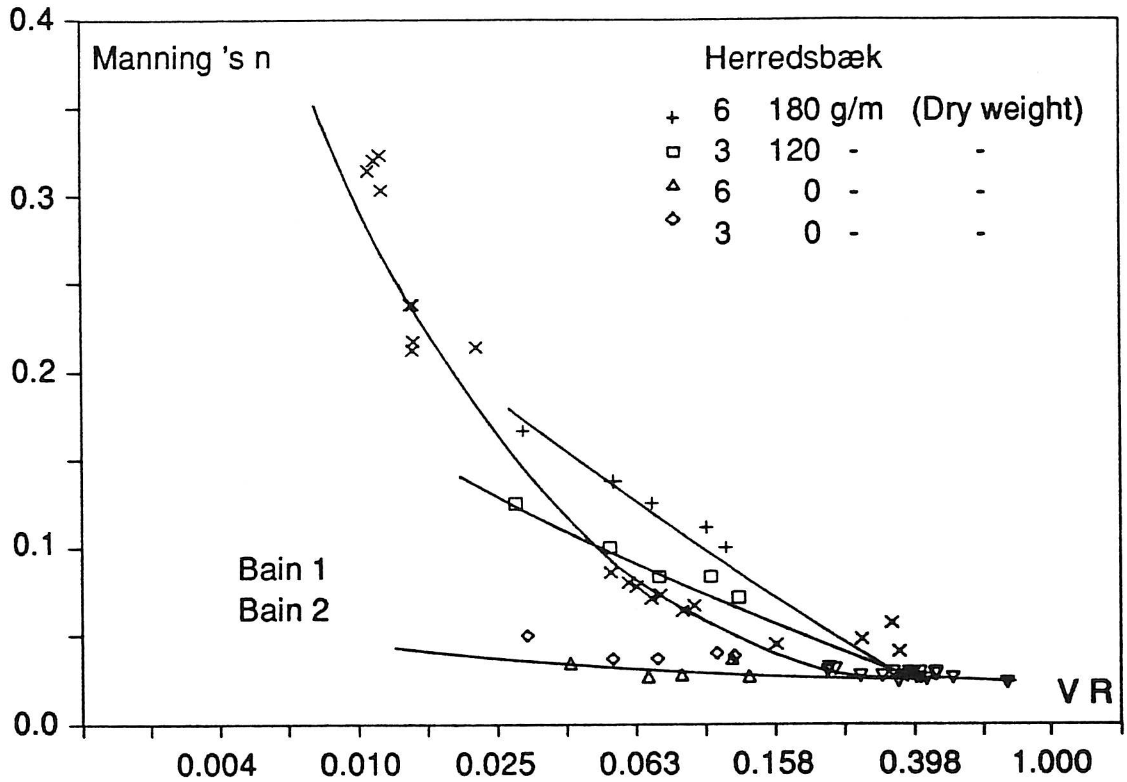


Fig. 7. Results from field experiment in Herredsbækken

Details will not be given here, but it should be mentioned, that the head loss for the small discharge part of the laboratory experiments, where the weed covered all the cross section, was almost proportional to the velocity. This indicates that the flexible and slightly moving plants absorb the turbulence to give an almost laminar friction relation.

The results of the field experiments are plotted on figure 7 together with results published by Powell(1979).

The results of Powell were measurements from River Bain in U.K. for a short rain period in July 1973, where discharge varied over a range from 0.1 to 6 $m^3$/sec. The vegetation was dense and dominated by pondweed *(Potamogeton pectinatus* and *Helodea canadense).* It was reported that approx. 70 %of the river surface was covered by weed. The dry weight of the vegetation was not measured

The field results from U.K. and Denmark show the general dependence of the Manning's n in respect to the product of V• R. In this case V and R were almost 100 % correlated because of the unique discharge/stage relationship during the measurements. This means that the field measurements do not confirm that V• R can be used in general, but fortunately the laboratory results were quite clear on that point.

As a working hypothesis it seem to be probable that the curves have a common point of intersection for a value of V• R= 0.4 $m^2$/s. If this can be taken as a general value for streams of the actual size and type, which covers a wide range of Danish streams, a discharge/stage relation can be established from the basic winter relation and supplemented with one discharge/stage measurement at the actual time. Figure 8 illustrates this principle.

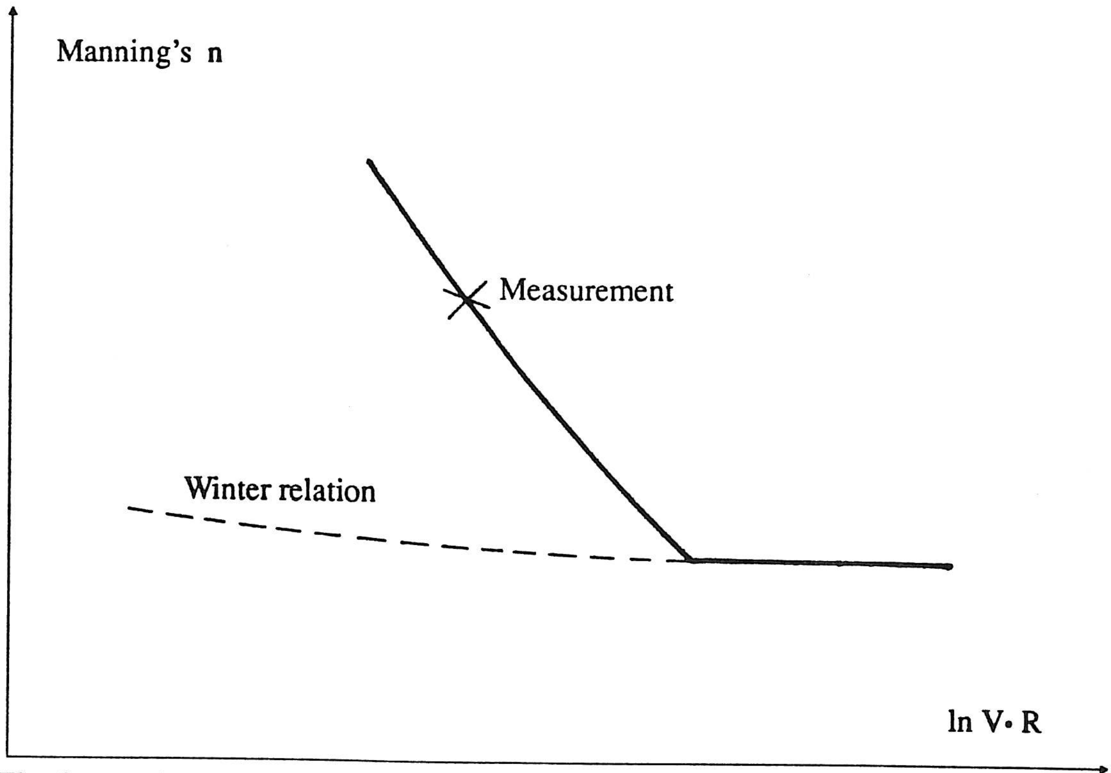


Fig. 8. Actual Manning's n.

In this investigation it was tried, but without succes, to characterize the friction also on the basis of typical plant characteristics with parameters like the dry weight per unit stream bed area (or volume), the plant surface area per stream bed area or the like. A temporary conclusion on this point is, that the actual Manning's n up till now, is the best parameter to characterize the vegetation in this respect. On the other hand the empirical approach taken here can without doubt be improved based on further similarity considerations combined with more data.

## Conclusion

This investigation confirms that vegetation has a significant and often dominating influence on the hydraulic friction in streams. But the effect decreases and even vanishes under high discharge conditions. There seems to be a clear relation between the Manning'n and the actual product V• R of average velocity and hydraulic radius. For discharge conditions, where V• R is greater than 0.4 $m^2$/sec, the friction is no longer influenced by the vegetation. From these general observations, it is possible to establish an actual discharge/stage relation in the vegetated period, based on only a single set of measured discharge/stage values.

Because the functional description of the variation of Manning's n use V• R as the independent variable, the relation is valid not only for uniform flow, but also for backwater and unsteady calculations.

## Acknowledgements

We wish to thank our former students S. A. B. Jensen, N. Olsen, and J. Pedersen for help in the laboratory and measurements of important parameters in Herredsbækken.

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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.

Presented at XXIV IAHR Congress, 9-13 September 1991, Madrid

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

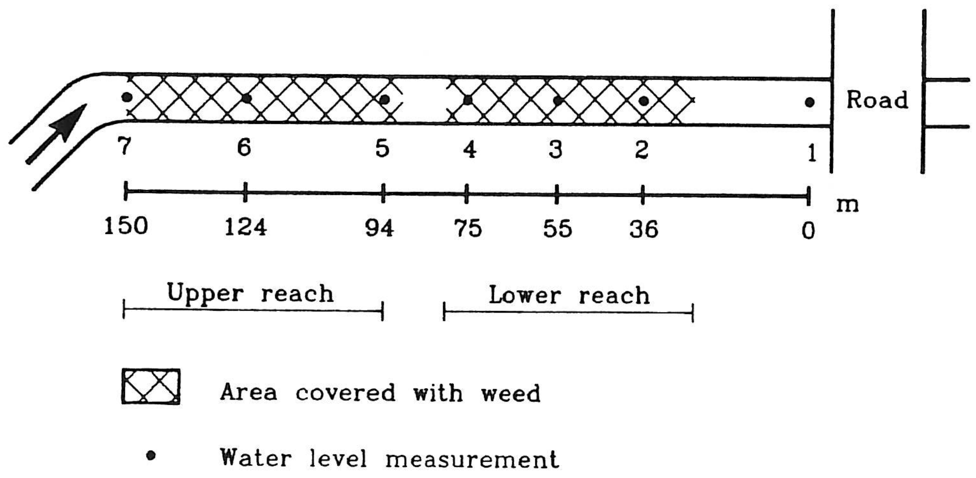


Fig. 1. The reach in Herredsbækken.

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.

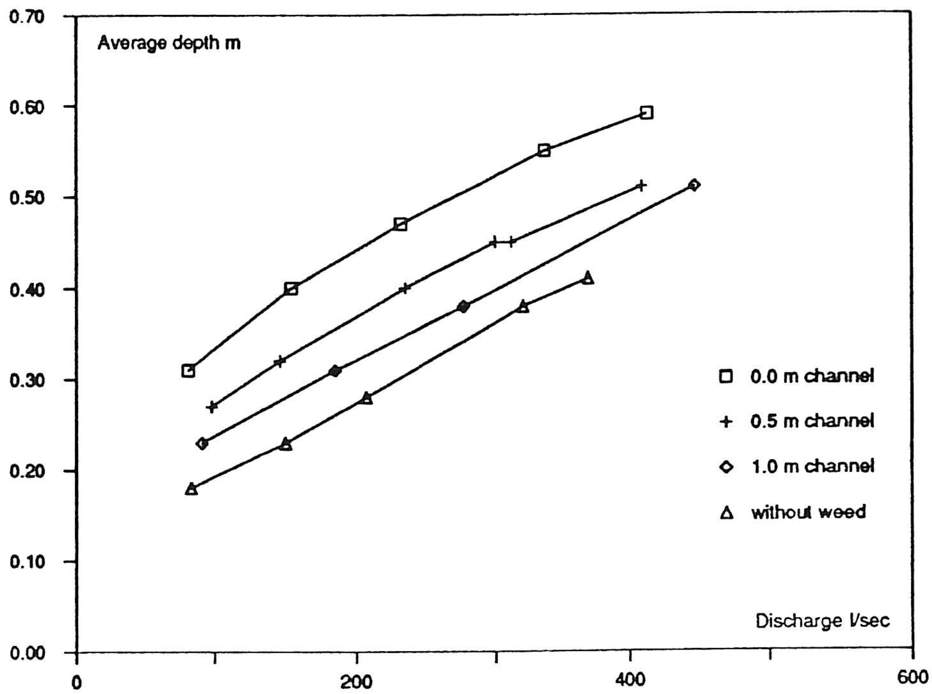


Fig. 2. Measured discharge-depth series in station no. 4.

### 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.

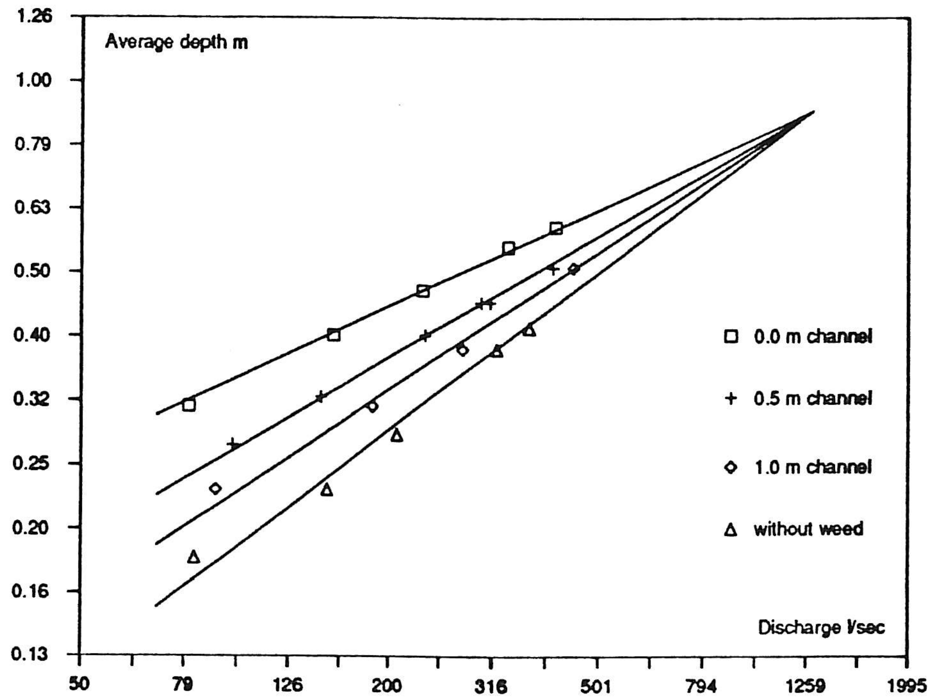


Fig. 3. Measured discharge-depth series in station no. 4. in a double logarithmic plot.

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.

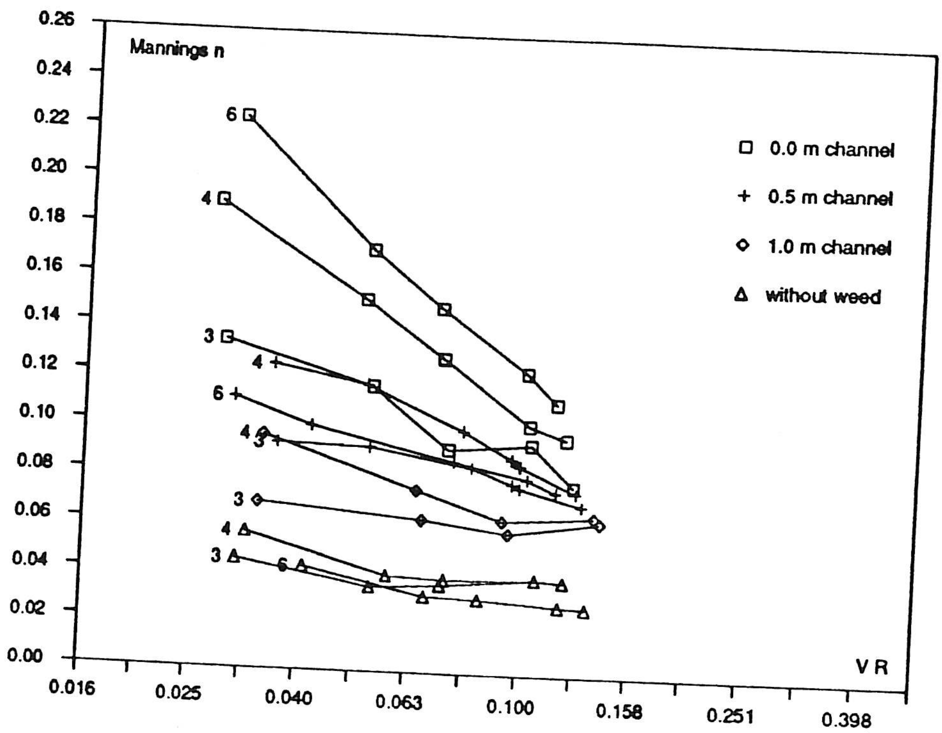


Fig. 4. Measured Manning coefficients.

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.

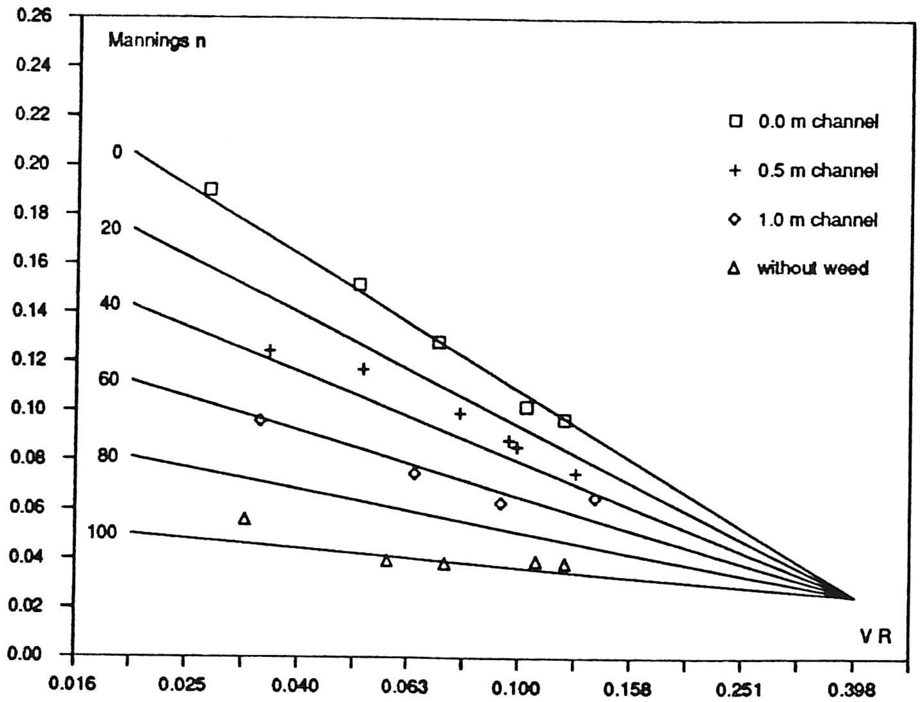


Fig. 5. Prediction of Manning's $n$ for different percentage removal of weed combined with the measured Manning coefficient in station no. 4.

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

We wish to thank our former students S.A.B. Jensen, N. Olsen and J. Pedersen for measurements of important parameters in Herredsbækken.

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# Grødens indflydelse på afstrømningsforholdene i vandløb

*Af Kristian Vestergaard og Torben Larsen, Aalborg Universitetscenter*

I sidste nummer af Vækst gjorde Peter Noe Markmann sig nogle tanker om fremtidens vandløbsvedligeholdelse. Herunder refererede han bl.a. arbejder foretaget ved Instituttet for Vand, Jord og Miljøteknik på Aalborg Universitetscenter (AUC). I denne artikel vil vi forsøge meget kort at give læserne et indtryk af baggrunden for, samt indholdet af disse arbejder.

**Q-h-kurver og Manningformlen**

Til bestemmelse af sammenhængen mellem vandføring og vandstand i vandløbene har man gennem mange år med godt resultat anvendt de såkaldte Q-h-kurver. De gode resultater skyldes i høj grad, at man baserer sig på direkte målinger i det konkrete vandløb. Når det imidlertid drejer sig om at vurdere modstanden i forskellige vandløb kan Q-h-kurverne ikke anvendes, man må i stedet gribe til f.eks. Manning-formlen, som blandt en række forskellige tilsvarende formler er den mest kendte på vore breddegrader.

I Manning-formlen udtrykkes sammenhængen mellem strømningshastighed og længde-/tværsnitsforholdene gennem en konstant faktor – Manningtallet. Denne proportionalitetsfaktor kan relateres til ruheden, som f.eks. i rør er forholdsvis veldefineret. For betonrør vil ruheden typisk være ca. 1 *mm* svarende til et Manningtal på ca. 80 $m^{1/3}/sek.$, mens Manningtallet for gravede kanaler i jord uden bevoksning vil ligge i intervallet 35-50 $m^{1/3}/sek.$ I disse tilfælde virker Manning-formlen fortrinligt, dvs. der kan regnes med et konstant Manningtal for både store og små vandføringer og vanddybder.

**Manningtal i grødefyldte vandløb**

Når Manning-formlen har været benyttet til beregninger i vandløb har det ind imellem givet Manningtal i størrelsesordenen 5-10 $m^{1/3}/sek.$ Dette svarer til ruheder på 270-17000 *meter*!, hvilket naturligvis er noget vrøvl. Dette bunder blot i at gyldighedsområdet for omregning fra Manningtal til ruhed forlængst er overskredet. Endvidere vil det formelle gyldighedsområde for Manning-formlen ofte være overskredet.

I grødefyldte vandløb har man derudover det problem at Manningtallet varierer med årstiden, eller rettere med tætheden, fordelingen og typen af grøde. Dette problem tackler man, f.eks. i forbindelse med afstrømningsmålinger, ved at operere med årstidsafhængige Q-h relationer, som kalibreres på plads gennem vingemålinger.

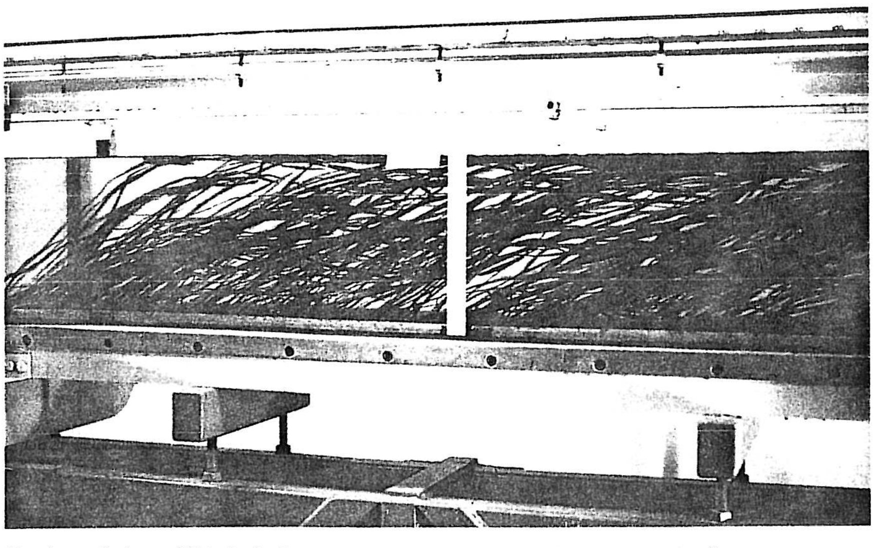
Imidlertid er der yderligere det problem at modstanden varierer med vandføringen og vandstanden. Når vandhastigheden stiger lægger grøden sig mere og mere ned og dermed formindskes den hydrauliske modstand, hvilket betyder at Manningtallet stiger. Hvis man således holder fast ved det Manningtal som er bestemt ved lav vandføring, og benytter dette til at beregne vandstande ved store vandføringer, får man alt for store vandstande. F.eks. kan dette vise sig at have afgørende betydning ved dynamiske beregninger med MIKE 11, hvor man typisk simulerer kortvarende afstrømningsforløb, men med kraftig varierende afstrømning i vandløbet.

**Projekterne på AUC**

Gennem de seneste 4-5 år har der på AUC været arbejdet med ovennævnte problem. Der har været gennemført litteraturstudier, foretaget feltmålinger og målinger i laboratoriet, samt opstillet forskellige modeller til beskrivelse af grødens hydrauliske betydning og betydningen af at etablere strømrender gennem grøden. En række af disse arbejder er gennemført i forbindelse med afgangsprojekter. De forskellige målinger har indtil nu udmøntet sig i to internationale konferenceindlæg, Larsen et al. (1990) og Larsen et al. (1991). En nærmere beskrivelse af de udførte arbejder, samt de to konferenceindlæg findes i Vestergaard et al. (1991), som kan rekvireres ved forfatterne.

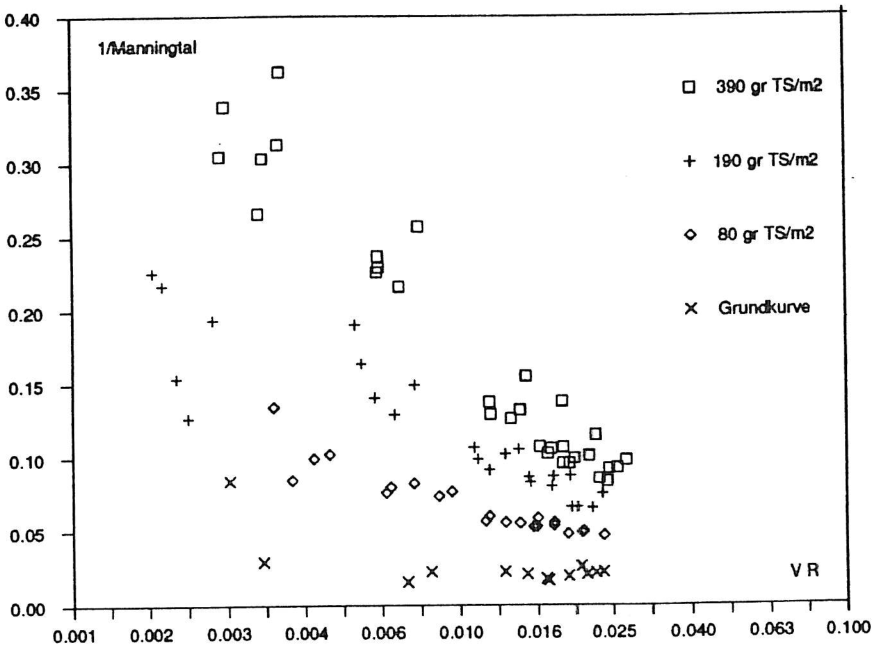
**Resultatet af målingerne**

I denne forbindelse skal blot fremhæves nogle få resultater. I laboratoriet har der været gennemført måling af grødens hydrauliske modstand. Dette foregår i praksis ved at opbygge en kortere grødestrækning i en strømningsrende, som vist på billedet. Grødearten er Pindsvineknop og grøden fasthæftes strå for strå i et metalnet, som herefter faststøbes i gips. Grødetæthed og fordeling er således meget veldefineret. Energitabet, og dermed Manningtallet, bestemmes ved at måle vandspejlsfaldet henover grødebanken ved forskellige kombinationer af vandføring og vandstand. Derefter udtyndes grødebanken og en ny serie målinger ved en anden grødetæthed kan gennemføres osv.



*Grødestrækning af Pindsvineknop opbygget i strømningsrende (90 gr TS/m²).*

Analyse af resultaterne har vist, at der eksisterer en sammenhæng mellem det målte Manningtal og produktet af middelhastigheden $V$ og hydraulisk radius $R$, som vist på figur 1. Af figuren ses, at punktskaren for de enkelte grødetætheder nærmer sig hinanden for store værdier af $V\,R$, dvs. at når vandhastighed eller vanddybde (eller begge) stiger, da aftager den hydrauliske modstand, og Manningtallet nærmer sig værdien for det grødefri tilfælde (grundkurven).




*Figur 1. Målte Manningtal ved forskellige grødetætheder som funktion af produktet V R mellem middelhastighed og hydralisk radius.*

**Beregning af aktuelt Manningtal**

Og det er netop denne observation som ligger til grund for den beregningsprocedure som er foreslået i Vestergaard et al. (1991). Ved brug af denne procedure kan man udfra en enkelt måling af det aktuelle Manningtal, dvs. et enkelt punkt i et diagram som figur 1, bestemme hele variationen af Manningtallet, og dermed gøre det muligt at foretage modelberegninger som tager hensyn til modstandens variation med afstrømningens størrelse. F.eks. kan man beregne Q-h kurven for den aktuelle grødesituation, hvilket vil gøre det muligt at vurdere den aktuelle risiko for oversvømmelse, og dermed evt. iværksætte de nødvendige vedligeholdelsesarbejder – men nu på et mere korrekt hydraulisk grundlag.

**Fortsatte målinger/arbejder**

Arbejdet med at klarlægge grødens hydrauliske betydninger fortsætter ved instituttet. Således er der i skrivende stund netop foretaget nye laboratoriemålinger, og siden foråret har der på en strækning af Simested Å været foretaget kontinuerlige målinger af vandføring og vandspejlskote i et antal stationer, hvilket gør det muligt at foretage en løbende bestemmelse af det aktuelle Manningtal på de mellemliggende strækninger. Resultaterne fra disse målinger er under bearbejdning og forventes at foreligge primo 1992. Endvidere vil der blive udarbejdet forskellige former for EDB-programmel, som formentlig vil kunne erhverves fra samme tidspunkt.

**Afrunding**

Det er vigtigt at gøre sig klart, at strømningsforholdene i et grødefyldt vandløb er komplekse og at der aldrig vil kunne foretages en fuldstændig beskrivelse heraf. Men med de ovennævnte arbejder er vi kommet et langt stykke nærmere en mere korrekt og samtidig funktionel og praktisk anvendelig beskrivelse. Instituttet har et stærkt ønske om at de opnåede resultater formidles til alle interesserede parter og enhver mulighed for udveksling/diskussion af data/resultater vil være velkommen.

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