NATIONAL WATER RESEARCH INSTITUTE

INSTITUT NATIONAL de RECHERCHE sur les EAUX

CONSIDERATIONS ON THE HYDRAULIC AND SAMPLING EFFICIENCY OF BEDLOAD SAMPLERS

Peter Engel

NWRI CONTRIBUTION 90-131

MANAGEMENT PERSPECTIVE

Bedload samplers are used by the Water Survey of Canada (WSC) and other agencies to measure the rate of transport of sediment moving near the bed in sand bed and gravel bed rivers. The samplers do not collect bedload at the true rate because their presence alters the flow pattern and the bedload movement. As a result, the sampling efficiency of the sampler is much less than 100%. In addition the hydraulic characteristics of the sampler changes as the sediment accumulates within it resulting in a decrease in the hydraulic efficiency. Both the hydraulic and sampling efficiency are important indicators of the performance of bedload samplers. An appreciation of the link between the two efficiencies is important in the design of better bedload samplers. This report was prepared in support of the Sediment Survey Section of the WSC in Ottawa.

Dr. J. Lawrence
Director
Research and Applications Branch

PERSPECTIVE DE GESTION

Les échantillonneurs de charge de fond sont utilisés par la Division des relevés hydologiques du Canada et par d'autres organismes pour mesurer la vitesse de transport des sédiments à proximité du fond, dans des rivières à fonds de sable et de gravier. Les échantillonneurs ne prélèvent pas la charge de fond à la vitesse réelle car leur présence modifie l'écoulement et le mouvement de la charge de fond. Par conséquent, l'efficacité de l'échantillonnage est bien inférieure à 100 %. De plus, les caractéristiques hydrauliques de l'échantillonneur varient à mesure que les sédiments s'y accumulent, ce qui entraîne une réduction de l'efficacité hydraulique. L'efficacité hydraulique et l'efficacité de l'échantillonnage sont deux indicateurs importants du rendement des échantillonneurs de charge de fond. Il est important d'évaluer la relation qui existe entre les deux efficacités pour concevoir de meilleurs échantillonneurs de charge de fond. Le présent rapport a été préparé pour la Section de l'étude des sédiments de la Division des relevés hydrologiques du Canada.

Dr. J. Lawrence
Directeur
Direction de la recherche et des applications

SUMMARY

Existing data were reviewed to compare the hydraulic and sampling efficiency of the WSC basket type bedload sampler. Using dimensional analysis, a link between the hydraulic efficiency and the sampling efficiency was developed. Results show the relative reduction in the hydraulic and sampling efficiency as sediment accumulates in the sampler. Observations regarding the importance of the hydraulic efficiency in improving the sampling efficiency are made.

RÉSUMÉ

Les données existantes ont été revues dans le but de comparer l'efficacité hydraulique et l'éfficacité de l'échantillonnage de l'échantillonneur de charge de fond à panier de la Division des relevés hydrologiques du Canada. A l'aide d'une analyse dimensionnelle, nous avons établi une relation entre l'efficacité hydraulique et l'efficacité de l'échantillonnage. Les résultats mettent en évidence la réduction relative de l'efficacité hydraulique et de l'efficacité de l'échantillonnage à mesure que les sédiments s'accumulent dans l'échantillonneur. L'importance de l'efficacité hydraulique pour améliorer l'efficacité de l'échantillonnage est soulignée.

TABLE OF CONTENTS

1.0 INTRODUCTION

Basket type bedload samplers are used by the Water Survey of Canada (WSC) and other agencies to measure the rate of transport of bed material in gravel bed streams. The difficulty in the use of the samplers arises from the fact that they trap less than the amount of material that would pass had the sampler not been there. The basic problem is that the flow passing through the sampler is subject to hydraulic losses and these increase as the sampler fills up with sediment. In addition, the presence of the sampler on the stream bed alters the flow patterns and bedload movement in the sampler's vicinity. As a result samplers must be calibrated to determine their trapping efficiency under the different conditions that affect them.

The sampling efficiency of the WSC basket type sampler was determined by Engel and Lau (1980), Engel and Lau (1981) and Engel (1982). The hydraulic efficiency of the sampler was determined by Engel (1986). In this report, a preliminary attempt is made to establish the link between the hydraulic efficiency and the sampling efficiency, using data from Gibbs (1973) and Engel (1982, 1986). The work is being conducted as part of the continuing research support provided to the WSC by the Research and Applications Branch at the National Water Research Institute, Burlington, Ontario.

2.0 REVIEW OF SAMPLER CHARACTERISTICS

2.1 Hydraulic Efficiency

The hydraulic efficiency, as defined by Hubbel (1964) is defined as

$$E_H = \frac{U_S}{U_O} \times 100\% \qquad (1)$$

in which E_H = the hydraulic efficiency in percent, U_S = the average velocity of the flow through the sampler entrance and U_o = the average velocity through the same area of the streambed had the sampler not been there. The WSC basket type sampler is basically a rectangular cage composed of a frame covered with wire screen, having one entire side open which serves as the intake. The basket is suitably mounted on a tubular frame as shown in Figure 1. One can expect that such a rectangular configuration should have a hydraulic efficiency less than 100% even when no sediment has yet entered. As the bed material is carried into the sampler, the hydraulic resistance to the flow increases which would be reflected by a decrease in the entrance velocity and thus a decrease in the hydraulic efficiency.

It has been shown by Engel (1986) that the hydraulic efficiency can be expressed in dimensionless form as

$$E_H = f \left[\frac{V_D}{V_t}, \frac{U_o}{\sqrt{gh}} \right] \tag{2}$$

where h = the average depth of the flow, g = the acceleration due to gravity, V_D = the volume of sediment trapped in the sampler, V_t = the total volume of the sampler and f denotes a function. Tests conducted by Engel (1986) were plotted as E_H vs. $U_o/\sqrt{gh}$ with V_D/V_t as a parameter in Figure 2. The plot shows that E_H is independent of $U_o/\sqrt{gh}$ and therefore E_H is a function of V_D/V_t only. The variation of E_H as a function of V_D/V_t is given in Figure 3. A smooth curve was drawn through the plotted points to facilitate the analysis. The curve clearly shows that, when the sampler is empty, the hydraulic efficiency is about 90% and decreases as the accumulated sediment volume in the sampler increases. When the sampler is about 1/2 full, the hydraulic efficiency is reduced to about 65%.

The above results show that for a given basket type sampler, the hydraulic efficiency depends only on the percentage of the sampler's volume occupied by the trapped material. Therefore, equation (2) may be reduced to give

$$E_H = f_1 \left[\frac{V_D}{V_t} \right] \quad (3)$$

Clearly, the rate of change in hydraulic efficiency should depend on the rate of accumulation of material in the bedload sampler.

2.2 Sampler Catch

The amount of material trapped in a sampler depends on the sampling time, flow conditions, bed material properties, geometric characteristics of the sampler and the initial hydraulic efficiency of the sampler. As the sampler fills up, the rate at which it traps sediment must slow down because the hydraulic efficiency decreases as the volume of trapped material increases. It has been shown by Engel (1982) that the percent of sampler volume filled with sediment can be expressed in the dimensionless functional form

$$\frac{V_D}{V_t} = f_2 \left[\frac{t_* U_*}{L_b}, \frac{\rho U_*^2}{\gamma_s D_{50}}, \frac{D_{50}}{L_a}, \psi \right] \quad (4)$$

where t_* = the length of time to trap one bedload sample, U_* = the shear velocity, L_b = the length of the sampler, L_a = the height of the sampler, ρ = the density of the water, γ_s = the submerged specific weight of the sediment,

D_{50} = the median bedload particle size, ψ = the particle size distribution factor given as D_{84}/D_{16} and f_2 denotes a function.

Data from Gibbs (1973) were used to compute the dimensionless variables in equation (4). For the data selected, values of D_{50}/L_a and ψ were virtually constant at 0.085 and 4.9 respectively. As a result equation (4) can be reduced for this particular case to the simpler form

$$\frac{V_D}{V_t} = f_3 \left[\frac{t_* U_*}{L_b}, \frac{\rho U_*^2}{\gamma_S D_{50}} \right] \qquad (5)$$

where f_3 denotes another function. Values of V_D/V_t were then plotted as a function of $t_* U_*/L_b$ in Figure 4. The plot shows that V_D/V_t increases with t_* U_*/L_b in all cases and that the rate of increase in V_D/V_t decreases as $t_* U_*/L_b$ increases. It is also apparent that for a given value of $t_* U_*/L_b$ the relative sampler catch increases as the mobility number $\rho U_*^2/\gamma_S D_{50}$ increases. Therefore, for a given sampling time t_*, the amount of material deposited in the sampler depends on the rate of bedload transport since this is known to be strongly dependent on the mobility number.

2.3 Sampling Efficiency

The sampling efficiency of the sampler is defined by Hubbel (1964) and Engel and Lau (1980) as the ratio of the measured transport rate to the actual transport rate at the sampling location if the sampler had not been there. This can be expressed as

$$E_s = \frac{q_s}{q_b} X\ 100\% \qquad (6)$$

where q_s = the bedload transport rate determined with the sampler, q_b = the actual bedload transport rate and E_s = the sampling efficiency in percent. Using dimensional analysis Engel (1982) developed a general functional relationship for the sampling efficiency given as

$$E_s = \phi \left[\frac{t_* U_*}{L_b}, \frac{\rho U_*^2}{\gamma_s D_{50}}, \frac{D_{50}}{L_a}, \psi \right] \qquad (7)$$

where ϕ denotes a function and the other variables have already been defined. Data from Gibbs (1973) were used to examine the sampling efficiency. For the data used ψ was constant at 4.9 and thus equation (7) can be reduced to

$$E_s = \phi_1 \left[\frac{t_* U_*}{L_b}, \frac{\rho U_*^2}{\gamma_s D_{50}}, \frac{D_{50}}{L_a} \right] \qquad (8)$$

where ϕ_1 denotes another function.

The sampling efficiency ES was plotted as a function of $t_* U_*/L_b$ with $\rho U_*^2/\gamma_s D_{50}$ and D_{50}/L_a as parameters in Figure 5. The plot shows that the efficiency decreases as $t_* U_*/L_b$ increases. This is because as $t_* U_*/L_b$

increases, the accumulated sample volume represented by V_D/V_t increases with the result that the hydraulic efficiency decreases. When $t_*U_*/L_b < 25$, the rate at which E_s decreases as t_*U_*/L_b increases is quite significant. When $t_*U_*/L_b >$ 25, the rate of change in E_s, as t_*U_*/L_b increases, becomes smaller. The fact that the data collapse to form a single curve, indicates that the mobility number is not very important in determining the sampling efficiency. The single curve also implies that D_{50}/L_a is not very significant over the range of particle sizes used. Additional work by Engel (1982) has shown that E_s is independent of D_{50}/L_a for values of $D_{50}/L_a > 0.048$.Therefore, for the present data set, equation (8) can be reduced to

$$E_s = \phi_2 \left[\frac{t_*U_*}{L_b} \right] \qquad (9)$$

where ϕ_2 denotes a function.

3.0 LINK BETWEEN THE HYDRAULIC AND SAMPLING EFFICIENCY

It has been established that the hydraulic efficiency E_H and the sampling efficiency E_s decrease as t_*U_*/L_b increases. Examination of equations (3) and (5) shows that the hydraulic efficiency can be expressed as

$$E_H = F \left[\frac{t_*U_*}{L_b}, \frac{\rho U_*^2}{\gamma_s D_{50}} \right] \qquad (10)$$

where F denotes a function. Therefore, the dimensionless variable t_*U_*/L_b may be considered to be the link between E_H and E_S. A convenient way to reveal the relative behaviour of the sampling and hydraulic efficiency is to plot each as a function of t_*U_*/L_b with $\rho U_*^2/\gamma_S D_{50}$ as a parameter as shown in Figure 6. The plot represents values of E_H and E_S for the same flow conditions. The sampling efficiency, as observed in Figure 5, can be represented by a single curve, indicating that for this data set the sampling efficiency is independent of D_{50}/L_a and the mobility number $\rho U_*^2/\gamma_S D_{50}$. In contrast to this, as expected from equation (10), the data for the hydraulic efficiency are seen to be dependent on the mobility number.

When $\rho U_*^2/\gamma_S D_{50} = .074$, values of E_H decrease virtually linearly from the maximum hydraulic efficiency of 90% (ie: when the sampler is empty) to a value of 85.5% when t_*U_*/L_b is equal to about 85. Comparison of E_H with E_S indicates that for values of $t_*U_*/L_b < 30$, the sampling efficiency decreases much faster than the hydraulic efficiency. For values of $t_*U_*/L_b > 30$ the rates of reduction in E_H and E_S are virtually the same.

When $\rho U_*^2/\gamma_S D_{50} = 0.123$ the rate of decrease in E_H is significantly greater than that observed with the lower mobility number. This behaviour must be attributed to the fact that the rate of accumulation of sediment in the sampler is much greater, resulting in a larger value of V_D/V_t in a shorter period of time. It can be seen from Figure 4, that the rate of increase in the accumulation given as V_D/V_t tends to decrease as t_*U_*/L_b increases. As a result, one can expect a gradual decrease in the rate of decline of E_H as values of t_*U_*/L_b become larger than about 30.

Further examination of Figure 6, shows that for a given value of t_*U_*/L_b the hydraulic efficiency decreases as the mobility number increases. This rate of change increases as t_*U_*/L_b increases. It is also important to note the large difference between the hydraulic and sampling efficiency. The reason for this is that the bedload transport is very sensitive to the shear stress on the sediment particles. This means that very small changes in the flow intensity through the sampler can have a very significant effect on the movement of bedload through the sampler. Therefore as the sampler fills up, the increased blockage to the flow by the accumulating sediment and the resultant loss in flow intensity result in the relatively low sampling efficiency experienced with the basket type sampler. Novak (1957) and Helley and Smith (1976) have sought to overcome this difficulty by developing stream lined samplers. The shape was such that a pressure difference between the front and the rear of the sampler was created which increased the rate of flow through the sampler, thereby offsetting some of the internal resistance. As a result of these improvements, hydraulic efficiencies greater than 100% were achieved. Test, by Engel (1983) on the VUV sampler developed by Novak (1957), showed that sampling efficiencies were significantly larger than those obtained with the basket type sampler.

4.0 CONCLUSIONS

4.1 The hydraulic efficiency has been found to be dependent on the percent accumulation of bedload in the sampler. For a particular type of bed material, the percent volume of trapped bedload depends on the two dimensionless variables $t_* U_* / L_b$ and $\rho U_*^2 / \gamma_s D_{50}$. The percent volume increases as these two dimensionless variables increase, resulting in a corresponding decrease in the hydraulic efficiency of the basket sampler.

4.2 When $D_{50}/L_b > 0.048$ the sampling efficiency for the basket sampler depends only on the dimensionless variable $t_* U_* / L_b$. The sampling efficiency decreases as $t_* U_* / L_b$ increases. This decrease in sampling efficiency is due to the increase in the percent volume of trapped bedload.

4.3 The decrease in sampling efficiency for the basket sampler corresponds to an accompanying decrease in the hydraulic efficiency. The sampling efficiency is always smaller than the hydraulic efficiency. There is a large difference between the two efficiencies and this is due to the fact that the rate of movement of the bedload is very sensitive to the flow intensity. For a given value of $t_* U_* / L_b$, the difference between the two efficiencies decreases as the mobility number increases. Improvement in the sampling efficiency can be obtained by improving the hydrodynamic shape of the sampler, thereby increasing the hydraulic efficiency.

4.4 The hydraulic efficiency cannot be used to replace the sampling efficiency. Instead the hydraulic efficiency is merely an index of the potential performance of a bedload sampler.

REFERENCES

Engel, P. and Y.L. Lau. 1980. Calibration of Bedload Samplers. Journal of the Hydraulics Division, ASCE, Vol. 106, No. 10. Proceedings 15725, pp. 1677-1685.

Engel, P. and Y.L. Lau. 1981. The Efficiency of Basket Type Bedload Samplers. Erosion and Sediment Transport Measurement, Proceedings of the Florence Symposium, IAHS Publication No. 133, pp. 27-34.

Engel, P. 1982. Characteristics of the WSC Basket Type Bedload Sampler. Hydraulics Division, National Water Research Institute, Canada Centre for Inland Waters, Burlington, Ontario, Canada.

Engel, P. 1983. Sampling Efficiency of the VUV Bedload Sampler. Hydraulics Division, National Water Research Institute, Canada Centre for Inland Waters, Burlington, Ontario, Canada.

Engel, P. 1986. On the Hydraulic Efficiency of the WSC Basket Type Bedload Sampler. National Water Research Institute, Canada Centre for Inland Waters, NWRI Contribution 86-105.

Gibbs, C.J. 1973. Model Study of the Basket Type Bedload Sampler. M.Sc. Thesis, University of Alberta, Edmonton, Alberta, Canada.

Hubbel, D.W. 1964. Apparatus and Techniques for Measuring Bedload. USGS Water Supply Paper No. 1748, U.S. Government Printing Office, Washington, D.C., U.S.A.

Helley, E.J. and W. Smith. 1971. Development and Calibration of a Pressure - Difference Bedload Sampler. Open File Report, USGS,Menloe Park, California.

Novak, P. 1957. Bedload Meters - Development of a New Type and Determination of their Efficiency with the Aid of Scale Models. IAHR 7th General Meeting, Lisbon Portugal, Transaction. Vol. 1, pp. A9-1 - A911.

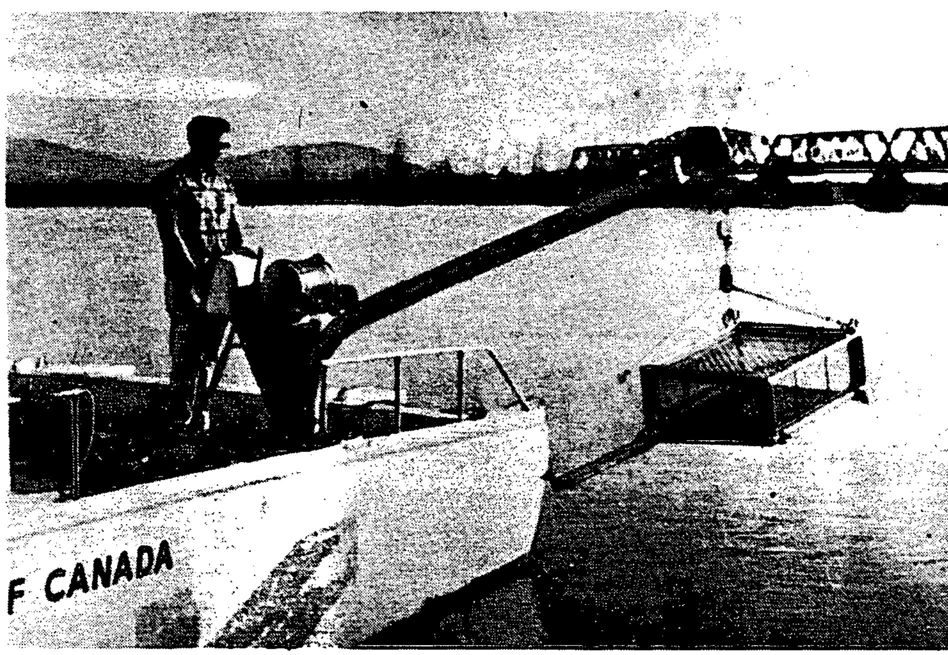

Figure 1. W.S.C. Basket Sampler

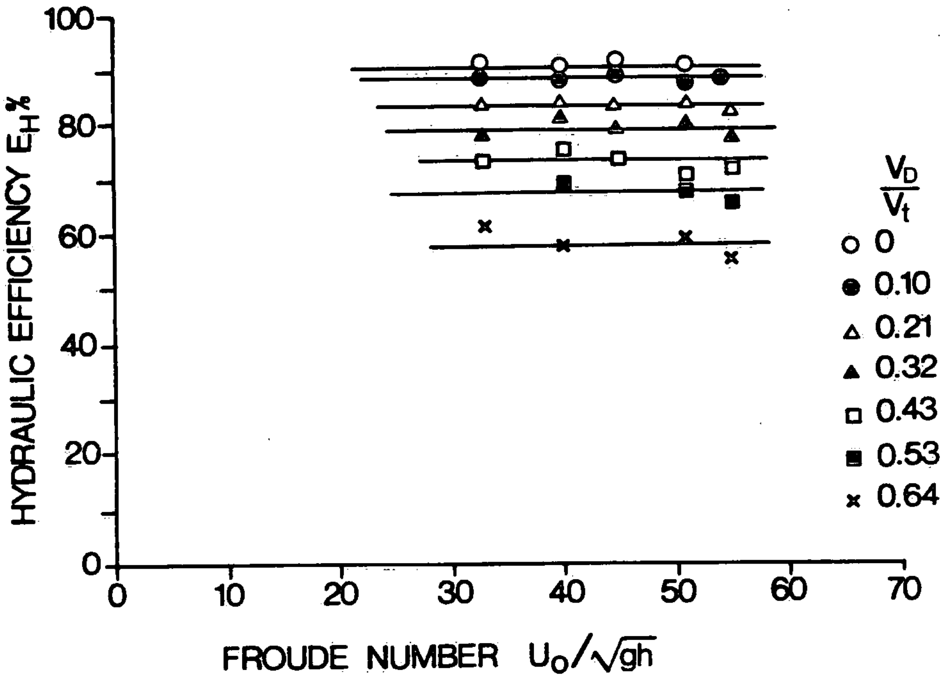

Figure 2 Effect of Froude Number on Hydraulic Efficiency

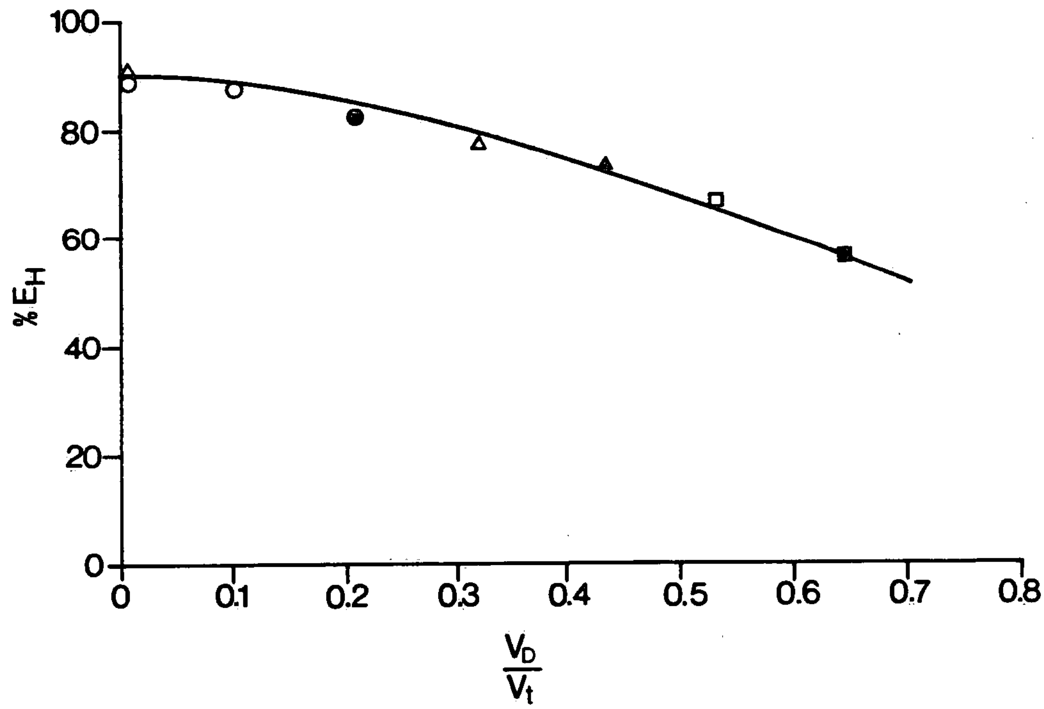

Figure 3 Variation of Hydraulic Efficiency

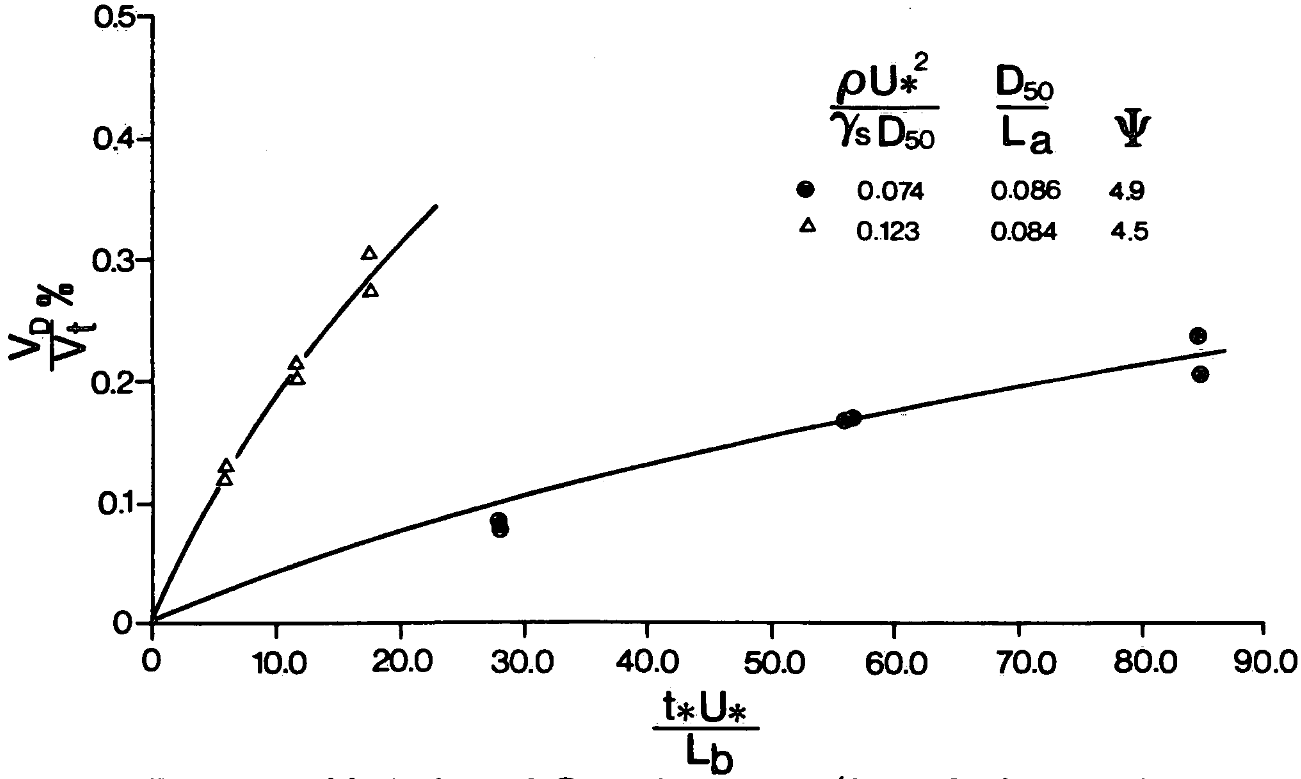

Figure 4 Variation of Sampler Catch (from Gibbs, 1973)

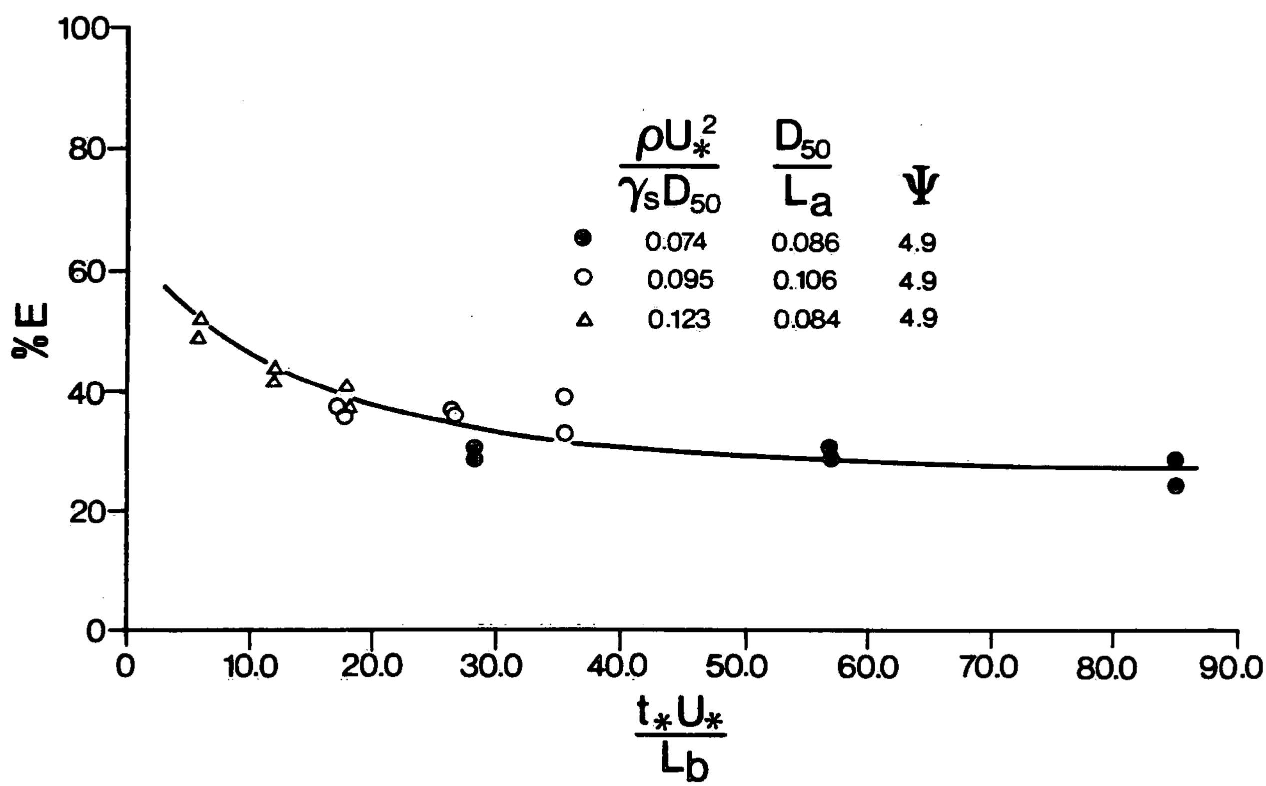

Figure 5 Variation of Sampling Efficiency (from Gibbs, 1973)

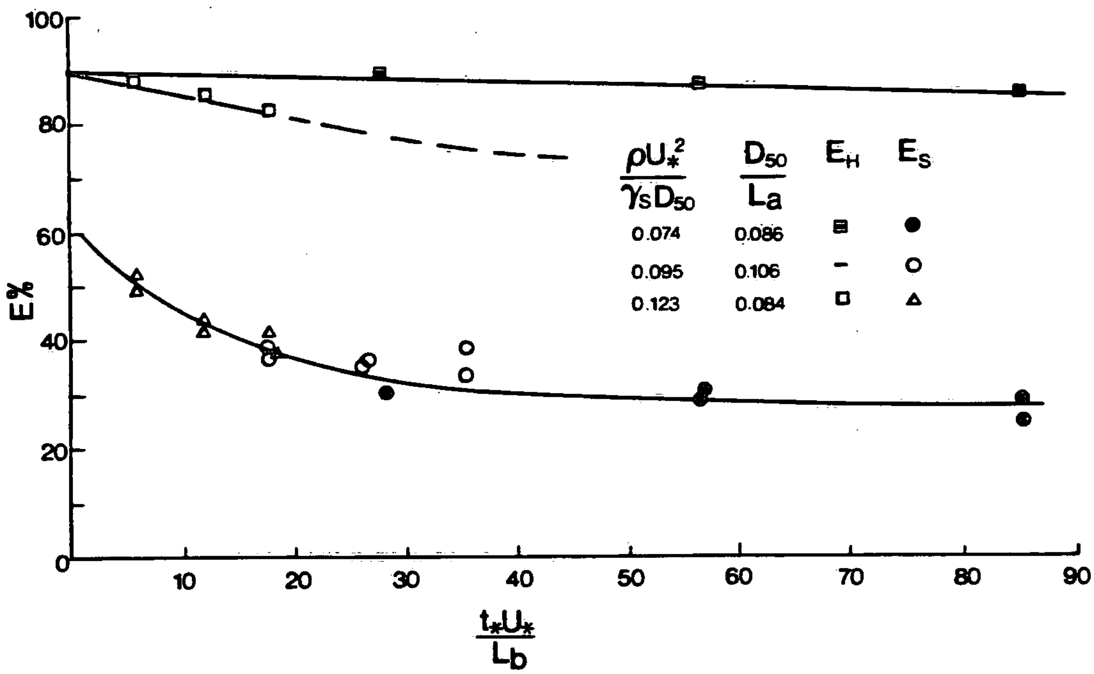

Figure 6 Variation in Hydraulic and Sampling efficiency

NATIONAL WATER RESEARCH INSTITUTE
P.O. BOX 5050, BURLINGTON, ONTARIO L7R 4A6

Environment Canada | Environnement Canada

Canada

INSTITUT NATIONAL DE RECHERCHE SUR LES EAUX
C.P. 5050, BURLINGTON (ONTARIO) L7R 4A6

Think Recycling!

Pensez à Recycling!