Journal of the American Mosquito Control Association, 12(2):312–315, 1996

USE OF STREAM WIDTH FOR DETERMINING THE DOSAGE RATES OF *BACILLUS THURINGIENSIS* VAR. *ISRAELENSIS* FOR LARVAL BLACK FLY (DIPTERA: SIMULIIDAE) CONTROL

ALBERT H. UNDEEN[1] AND DANIEL P. MOLLOY[2]

ABSTRACT. Data from several operational black fly abatement programs using *Bacillus thuringiensis* var. *israelensis* (*B.t.i.*) in New York State's Adirondack Mountains were analyzed to determine what the concentration of formulation in the stream might have been if application rates were determined by a stream's width rather than its discharge. There was a high correlation ($|R| = 0.87$) between discharge and width measured at 315 treatment sites. Had the applications been based upon the stream width, 96% of the actual concentrations in the streams would have been within plus or minus a factor of 5 and none exceeding a factor of 10, a range in which *B.t.i.* remains environmentally safe and effective.

Insecticides are applied to streams for the control of simuliid larvae on the basis of discharge, the volume of water passing a point per unit time. Dosage is expressed in terms of concentration (parts formulation per million parts water) of the formulation at the application site over a specified time. Although the calculation of discharge is time consuming, the environmental sensitivity of the lotic habitat of black fly larvae necessitated that great care be taken to avoid overdosages of nonspecific pesticides.

Recent black fly control programs have used microbial insecticides formulated from *B. thuringiensis* var. *israelensis* (*B.t.i.*). At black fly larvicidal concentrations, the toxins produced by this bacterium are highly specific and have little impact on nontarget organisms in streams (Colbo and Undeen 1980, Molloy 1992). Filter-feeding chironomid midge larvae can be adversely impacted at operational dosages, but mortality among other groups of chironomid larvae has been observed only at dosages far in excess of operational treatments (e.g., 20×; Molloy 1992). Mortality was recorded with *Tipula abdominalis* (Tipulidae) at 50 times and with *Arthroplea bipunctata* (Ephemeroptera) at 500 times the recommended dosage (Wipfli and Merritt 1995). Increased drift was observed for *Acroneuria lycorias* (Plecoptera) after treatment with 100 ppm for 120 min (Wipfli and Merritt 1995).

With the best equipment (Lacey and Undeen 1984) or at its greatest simplification (Undeen et al. 1981, Molloy and Struble 1988), measurement of discharge is labor-intensive. Carry (the distance downstream from the treatment point over which the application remains effective) appears to be as closely correlated with stream width as it is with discharge, suggesting that application rates of *B.t.i.* formulations could be based upon stream width alone, without calculating the discharge (Undeen et al. 1984). To obtain equal carry, shallow, slow, and weed-choked streams require a higher dosage than cleaner, swifter, and deeper streams of equal discharge. The variability in concentration resulting from application according to the width of the stream constitutes an automatic dosage adjustment in the appropriate direction (Undeen et al. 1984). However, if the resulting concentrations are too frequently either unacceptably high for environmental safety or too low for efficacy, width would be an unacceptable criterion for dosage.

Black fly abatement programs have been ongoing in the Adirondack Mountains of New York State for more than a decade. More than a dozen townships, covering more than 1,300 km², currently operate such programs during April through June each year. The width and discharge at 315 sites in lowland and mountain streams in the townships of Caroga Lake, Keene, and Colton were analyzed in this study. Discharge was measured in straight stream segments by the method of Molloy and Struble (1988) and streams were treated with a diluted mixture of VectoBac® 12AS (1.2% *B.t.i.*), broadcast by hand, to obtain an initial concentration of 5 ppm for 1 min. Regression analysis was conducted on logarithmic transformation of the width and discharge using SAS GLM regression analysis (ver. 6.04, Cary, NC) (Table 1). Assigning the regression line a value of 5 ppm, the initial 1-min concentration of formulation at each treatment site was calculated assuming that applications had been made according to width rather than discharge (Fig. 1). None of the concentrations would have deviated more than 10-fold from the 5-ppm target concentration (0.5–50 ppm) and less than 4% (11/315) would have been outside the 1–25 ppm range (Table 1). If the New York

[1] Medical and Veterinary Entomology Research Laboratory, Agricultural Research Service, USDA, P. O. Box 14565, Gainesville, FL 32604.

[2] Biological Survey, New York State Museum, The State Education Department, Cultural Education Center, Albany, NY 12230.

Table 1. General linear regression of $\log_{10}$discharge (m/minute) = $\log_{10}$width in meters.

Characteristic	Data from	
	New York	1984 study[1]
n	315	42
Intercept	0.25 ± 0.06	0.58 ± 0.03
Slope	1.80 ± 0.06	1.62 ± 0.07
$\|R\|$	0.87	0.97
Mean discharge (m^3/min)	17.1 ± 2.8	16.8 ± 2.1
Minimum discharge	0.12	0.16
Maximum discharge	554.1	56.9
Mean width	2.2 ± 0.1	2.3 ± 0.3
Minimum width	0.24	0.2
Maximum width	16.5	7.6
5×[2]	6/5	36/0
10×	0/0	4/0

[1] Undeen et al. (1984).
[2] Number of applications in the New York study that would have been higher/lower than the target dosage of 5 ppm by a factor of 5 or 10 if width was used as the sole criterion for treatment.

applications had been based upon the correlation between width and discharge of streams in the 1984 study (Undeen et al. 1984), 4 of the 315 applications would have been over 50 ppm and 36 (11.4%) above 25 ppm (Table 1).

Streams are variable; among other things, streams with larger drainage basins tend to be shallower and slower (Dunne and Leopold 1978). Streams have pools and slow reaches that do not harbor black fly larvae and rapids that do. The mean discharge rate of streams in the 1984 study (Undeen et al. 1984). was only slightly higher than the New York stream average. A similar analysis conducted on black fly streams in Labrador, Newfoundland, Canada, revealed only slightly lower discharge rates (Colbo 1984[3]). The discharge of streams in each of these 3 studies was higher than stream averages generally (Figs. 16–35 of Dunne and Leopold 1978), probably because simuliid larvae inhabit streams, or reaches of streams, that are of higher than average velocity. Published widths of black fly streams were measured at points selected for convenience of calculating discharge, with no attempt being made to obtain widths that were characteristic for the stream. The use of average width of the rapids inhabited by black fly larvae would probably reduce variability. This was noted during the course of extensive field tests conducted in Labrador, Newfoundland, Canada (Colbo 1984[3]). Dosages in that program were based on discharge calculated from stream width measurements and constants based on how full the streams were.

Formulations of *B.t.i.* are applied to small streams over a short period, typically 1 min (Undeen and Colbo 1980, Lacey and Undeen 1984, Molloy and Struble 1989). The toxic particles become increasingly diluted, settle, spread out, and are gradually lost as they move downstream until the concentration is so low that the larvae are no longer affected. Water in contact with the substrate moves more slowly than the main body of the stream. Vegetation and irregular surfaces increase the amount of substrate and add to the surface area that can serve to filter particles from the water. A greater proportion of the flow in a shallow stream is influenced by these factors that slow or stop particles in their passage downstream (Molloy 1990, Tousignant et al. 1995) than in a deeper stream of the same discharge. Predictably, carry is improved by the application of higher concentrations (Lacey and Undeen 1984, Undeen et al. 1984, Molloy and Struble 1989). Dosage based upon the width of the stream takes the method of Colbo (1984[3]) a step farther, discounting discharge altogether. The initial concentration adjusts automatically to stream profile, providing the increased concentration necessary for wide, shallow streams and reduced concentrations acceptable for narrow, deep streams. It is entirely possible that the predictability of carry would be improved when applications are made according to width.

The 10-fold limit was chosen as a theoretical value within which there would be little adverse environmental impact on the high side and, at the low end, the concentration would remain in the effective range. Although these boundaries were never exceeded in this study or the other 2 studies mentioned here, it would still be premature for an operational program to begin treating streams by width. Additional studies are needed to correlate discharge with the mean width of black fly streams in a wider variety of ecological regions. Sites treated according to width need to be carefully evaluated for carry. Variability of the initial dosage when treated by width will also require a reevaluation of the ef-

[3] Colbo, M. H. 1984. Control of black flies (Simuliidae) using *Bacillus thuringiensis* var. *israelensis* (BTI) as a larvicide, with emphasis on the northern programs. Proceedings of the 31st Annual Meeting of the Canadian Pest Management Society, Winnipeg, Manitoba, Canada, August 20–22, 1984. Memorial University of Newfoundland, St. John's, Newfoundland, Canada.

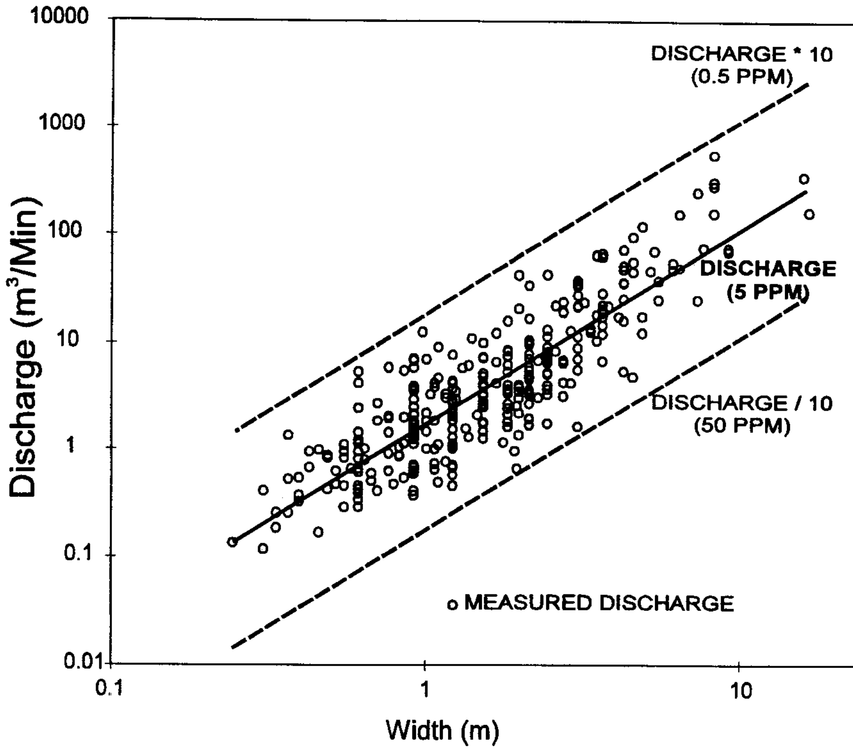

Fig. 1. Correlation between the width and discharge of 315 streams in the Adirondack Mountains of New York State. Midline is the predicted mean discharge (regression equation: $\log_{10}$[discharge] = 1.8 $\log_{10}$[width] + 0.25). The flanking lines are 10 times higher and lower (predicted dosages are in brackets).

fect on nontarget organisms. With an average discharge calculation taking about 20 min (Molloy and Struble 1989), a significant saving in labor could be achieved if these studies reveal that dosages of *B.t.i.* products can be tabulated by stream width (Undeen et al. 1984) rather than discharge.

We are grateful to Susan White for her assistance with data processing and thank Andrea Malik (town of Colton), Bob Spranz (town of Keene), and Ron Staring (town of Caroga) for providing data from their black fly control programs. Contribution 761 of the New York State Museum and Science Service.

REFERENCES CITED

Colbo, M. H. and A. H. Undeen. 1980. Effect of *Bacillus thuringiensis* var. *israelensis* on non-target insects in stream trials for the control of Simuliidae. J. Am. Mosq. Control Assoc. 40:368–371.

Dunne, T. and L. B. Leopold. 1978. Water in environmental planning, p. 644. W. H. Freeman and Co., San Francisco, CA.

Lacey, L. A. and A. H. Undeen. 1984. Effect of formulation, concentration and application time on the efficacy of *Bacillus thuringiensis* (H-14) against black fly (Diptera: Simuliidae) larvae under natural conditions. J. Econ. Entomol. 77:412–418.

Molloy, D. P. 1990. Progress in the biological control of black flies with *Bacillus thuringiensis israelensis,* with emphasis on temperate climates, pp. 161–168. *In:* H. de Barjac and D. Sutherland (eds.). Bacterial control of mosquitoes and black flies: biochemistry, genetics and applications of *Bacillus thuringiensis israelensis* and *Bacillus sphaericus.* Rutgers Univ. Press, New Brunswick, NJ.

Molloy, D. P. 1992. Impact of the black fly (Diptera: Simuliidae) control agent *Bacillus thuringiensis* var. *israelensis* on chironomids (Diptera: Chironomidae) and other nontarget insects: results of 10 field trials. J. Am. Mosq. Control Assoc. 8:24–31.

Molloy, D. P. and R. H. Struble. 1988. A simple and inexpensive method for determining stream discharge from a stream bank. J. Freshwater Ecol. 4: 477–481.

Molloy, D. P. and R. H. Struble. 1989. Investigation of the feasibility of the microbial control of black flies (Diptera: Simuliidae) with *Bacillus thuringiensis* var. *israelensis* in the Adirondack Mountains of New York. Bull. Soc. Vector Ecol. 14:266–276.

Tousignant, M. E., J. L. Boisvert and A. Chalifour. 1995. Loss of *Bacillus thuringiensis* var. *israelensis* larvicidal activity and its distribution in benthic substrates and hyporheic zone of streams. Can. J. Fish. Aquat. Sci. 50:443–451.

Undeen, A. H. and M. H. Colbo. 1980. The efficacy of *Bacillus thuringiensis* var. *israelensis* against black fly larvae (Diptera: Simuliidae) in their natural habitat. J. Am. Mosq. Control Assoc. 40:181–184.

Undeen, A. H., L. A. Lacey and S. W. Avery. 1984. A system for recommending dosage of *Bacillus thuringiensis* (H-14) for control of simuliid larvae in small streams based upon stream width. Mosq. News 44:553–559.

Undeen, A. H., H. Takaoka and K. Hansen. 1981. A test of *Bacillus thuringiensis* var. *israelensis* de Barjac as a larvicide for *Simulium ochraceum,* the Central American vector of onchocerciasis. J. Am. Mosq. Control Assoc. 41:37–40.

Wipfli, M. and R. W. Merritt. 1995. Effects of *Bacillus thuringiensis* var. *israelensis* on nontarget benthic insects through direct and indirect exposure. J. N. Am. Benthol. Soc. 13:190–205.