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FLOW-PROPORTIONAL SAMPLING FROM VARIABLE FLOW CANALS

by

W. Abtew,
L.J. Lindstrom,
and T. Bechtel

Resource Assessment Division
Water Resources Evaluation Department
South Florida Water Management District
West Palm Beach, Florida 33406

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W. Abtew
Sr. Supervising Engineer

L.J. Lindstrom
Division Director

T. Bechtel
Sr. Sup. Env. Scientist

South Florida Water Management District
West Palm Beach, Florida

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Summary:

A water-quality sampling scheme is presented for determining the appropriate volumes of flow needed to trigger sample collection by autosamplers installed at remote canals with variable flows. Flow rates were measured using UVMs (Ultrasonic Velocity Meters) or pump rating curves and water quality samples were collected with the American Sigma 800SL portable water samplers. Historical weekly cumulative flows were analyzed for each of the twelve canals or water control structures monitored. From this analysis, two sampling volumes were determined: one for low flow conditions and the other for high flow conditions. The weekly median cumulative flow was used to calculate a sampling volume for low flow conditions, while the weekly cumulative flow with a 5% exceedence probability was used for high flow conditions. Sampling results from a simulation study of the historical flow data are presented along with a discussion of alternative sampling schemes for site-specific flow measurements.

Keywords: Water quality, Sampling, Nutrients, Runoff

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ABSTRACT

A water-quality sampling scheme is presented for determining the appropriate volumes of flow needed to trigger sample collection by autosamplers installed at remote canals with variable flows. Flow rates were measured using UVMs (Ultrasonic Velocity Meters) or pump rating curves and water quality samples were collected with the American Sigma 800SL portable water samplers. Historical weekly cumulative flows were analyzed for each of the twelve canals or water control structures monitored. From this analysis, two sampling volumes were determined: one for low flow conditions and the other for high flow conditions. The weekly median cumulative flow was used to calculate a sampling volume for low flow conditions, while the weekly cumulative flow with a 5% exceedence probability was used for high flow conditions. Sampling results from a simulation study of the historical flow data are presented along with a discussion of alternative sampling schemes for site-specific flow measurements.

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INTRODUCTION

Inflow and outflow monitoring of an aquatic system is a necessary component in being able to perform hydrologic and constituent mass balance computations. The periodic computation of mass balances is essential to the understanding of sources and sinks and their respective magnitudes, and is commonly required to determine constituent loads and to evaluate the performance of environmental mitigation projects. Water and constituent accounting requires flow measurements and water quality sample collection for determining representative concentrations of the constituents of interest. There are widely accepted schemes for measuring flow rate/volume in canals with and without flow control structures. Flow through structures such as culverts, spillways and pumps can be computed with standard methods of flow computations. Flow through streams without flow control structures can be estimated through stage-discharge (canal rating), slope-stage-discharge or velocity-area methods. Flow velocity through channel systems is measured with flow meters, ultrasonic transducers, floats and tracer solutions. Open-channel formulae are applied to compute discharge through canals, flumes, tunnels and partially filled pipes of regular geometry (Linsley and Franzini, 1979).

Manual grab sampling and automated sampling are commonly used for water quality monitoring. Automatic samplers can be programmed to collect samples at regular time intervals to produce time-discrete samples. To minimize the number of samples for analysis, these time-discrete samples can be composited to produce one time-composite sample. Since constituent concentrations and flow rates usually vary with time, equal-volume (flow-proportional) sampling is needed to produce representative samples. Various flow-proportional sampling schemes have been established to produce more representative constituent concentrations (Steven and Smith, 1978; Rekolainen, et al., 1991; Shih, et al., 1994; Izuno et al., 1996; Tremwell, et al., 1996). A case study from south Florida is presented to evaluate an appropriate methodology for collecting surface water quality samples using automatic samplers in remote canals with variable flow conditions.

METHODOLOGY AND RESULTS

Method

Various methods were evaluated to determine the appropriate sampling volumes for flow-proportional samples retrieved on a weekly basis from twelve different canals or water control structures. The sites, site locations, type of flow-measuring device such as a UVM (Ultrasonic Velocity Meter) and database keys are shown in Table 1. Flow velocity is either measured with a UVM or computed from pump rating curves. Based on stage data, the UVM microprocessor computes cross-sectional area and calculates instantaneous canal discharge using its velocity measurements. Data acquisition and the triggering of the automatic sampler to collect a sample are accomplished with a CR10 data logger using the flow discharge information it receives from the UVM microprocessor.

Flow-proportional sampling is done with an American Sigma 800SL portable water sampler. The sampler at each site, which contains twenty-four (24) bottles of 1-liter capacity, is serviced once a week. Each bottle collects eight (8) 100-ml aliquot (sample) triggered by a predetermined sampling flow volume, giving each sampler the potential to collect 192 samples (aliquots). The weekly cumulative flow volume is expressed as a function of the number of samples or aliquots (N) collected during the week and the sampling flow volume (V_s):

$$V_c = N\ V_s \quad (for N \leq 192) \tag{1}$$

The ideal sampling volume (V_s) is a variable that changes with the weekly cumulative flow volume (V_c) and is expressed as follows:

$$V_s = \frac{V_c}{24 \times 8} \tag{2}$$

All samples collected during the week are composited (mixed) to generate one representative sample with a flow-weighted concentration C_f which can be expressed as follows:

$$C_f = \frac{\sum_{i=1}^{N} C_i}{N} \tag{3}$$

where C_i is the constituent concentration in sample (aliquot) i and N is the number of aliquots collected from equal volume of flow (V_s). The weekly constituent load (L) can be computed as follows:

$$L = V_c \ C_f \tag{4}$$

where V_c is the weekly cumulative flow volume and C_f is weekly flow-weighted mean constituent concentration.

Since more frequent flow-proportional sampling produces more representative constituent concentrations than infrequent flow-proportional sampling, the objective of the sampling scheme is to minimize the sampling (triggering) volume. With the constraints of having only 24 sample bottles and picking up and servicing the automatic sampler on a once-a-week basis, two approaches of setting sampling volumes are suggested.

One method requires establishing sampling volumes for both a high-flow period and a low-flow period, which are to be programmed into the CR10. This can be achieved based on analysis of historical observed flows for each structure. The CR10 can switch between the two sampling volumes based on the instant threshold discharge values set in the program. Representative sampling volumes for both high-flow and low-flow periods can be developed for each site independently. Seven days of cumulative flows were computed for each site from the daily historical flow data in the database and the weekly flows were ranked in descending order. Exceedence probabilities were computed based on the ranking of the weekly flow volumes for the weeks when flow occurred. Figures 1a-c show the probability of exceedence of weekly flow volumes for the various canals and structures.

During high flow periods, the 5% exceedence weekly cumulative flow volume is used to determine sampling volume with equation 2. In this case, there is less than 5% probability that the sampler will be over capacity (all 24 bottles full) before the routine weekly servicing is conducted. For sites where the number of weekly historical flow data sets is small, the maximum value is used to compute the high-flow sampling volume. For low-flow periods, the sampling volume is determined from the weekly median flow volume by using equation 2. Table 2 shows high and low flows with their respective sampling volumes. The constituent loads for each structure can be computed on a weekly basis using equation 4. The previous week's flow volume can be used to determine high or low flow conditions. If the previous week had high flow, the current week would be expected to have high flow and so forth. There may be cases, however, where all the bottles become full before the end of the week, particularly during a sudden transition from a low to a high flow period.

An alternative approach is to obtain a daily remote summary report from the CR10 at each site and determine the sampling volume (V_s) based on the flow rate, the day of the week, the number of bottles filled and the current sampling volume. This approach would yield more aliquots but would also require manpower to follow up on a daily basis to review the summary report and remotely make appropriate changes in the sampling volume. Also, an additional cost of sampling will be incurred because samples associated with similar sampling (triggering) volumes have to be composited and analyzed separately. The CR10 has to register sampling volume continuously on one column to indicate the changes in sampling volume. Therefore, using this method, load can be computed as follows:

$$L = \sum_{m=1}^{M} C_m V_{s_m} \tag{5}$$

where C_m is the mean concentration for a batch of samples with similar sampling volume (V_{sm}) and M is the number of laboratory-analyzed composite samples as well as the number of sampling volumes used in the week. Minimizing the changes in sampling volumes will reduce the number of samples that must be analyzed. Use of this approach may be important where a high-flow event occurs during a low-flow week or vice versa.

The measurement or the flow-rate scan time of the CR10 must be synchronized with the flow and sampling rates. The maximum scan or measurement time (T_m) in minutes before a sample is skipped can be estimated as follows:

$$T_m = \frac{V_s}{Q \times 60} \tag{6}$$

where Q is flow rate in $m^3\ s^{-1}$ and V_s is sampling volume in m^3. Based on equation (2), the maximum scan time without missing large volumes between sampling events for each site is 7.5 minutes. A smaller scan time minimizes the possibility of missing a sampling event. The minimum sampling volume (V_s) is limited by the scan time as follows:

$$V_s \geq 60\ T_m\ Q \tag{7}$$

where V_s is the sampling volume in m^3; T_m is the scan time in minutes and Q is flow rate in $m^3\ s^{-1}$.

The CR10, after scanning each time, could possibly face two alternatives where flow during the scan time is less than or greater than the sampling flow volume. In cases where the volume is less, the CR10 will continue to scan until the sampling volume (V_s) is exceeded when the sampler is activated. If the sampling volume is exceeded and the difference is less than a sampling volume, the sampler should sample once and the difference should be carried on to the next scan time. If the difference is more than a sampling volume (V_s), the sampler should collect samples until the difference is less than a sample volume. An allowance of 5% fluctuation on the sampling volume will make it easier to deal with the scanning time lapse. The sampling volume can be given as a range, $V_s \pm 0.05V_s$. Once an approach is selected and applied, modifications can be made based on additional data and problems observed. The sampling volume(s) used during the week should be registered continuously in the CR10 as one parameter. This will document the sampling volume(s) used during the sampling period. In the case where a change in sampling volume occurs during the week, the technician who services the sampler must be instructed to separately composite the bottles associated with each sampling volume.

In order to minimize the sampling volume misses during scanning time, an internal summation of flow should be performed by the CR10 every minute, using the last scanned discharge (Q) value. Based on the summation of flow, a timely decision can be made on whether to collect a sample or not.

<u>Simulation Results</u>

Simulation of this flow-proportional sampling scheme was performed on historical flow data to evaluate its performance on a weekly basis. Since available flow data were daily averages, a uniform flow rate during each day was assumed. In the simulation, flow volume was computed every two minutes and the data were accumulated. When the flow volume reached the initially declared sampling (triggering) volume, a sample or an aliquot was collected. The sampling (triggering) volume was determined for both low and high flow conditions as discussed earlier (Table 2).

Results of the simulation indicated that the performance of the sampling scheme was site-specific based on the variation of the daily flow rate. In the simulation, the decision to use either the low or high flow sampling volume was based on the previous week's flow conditions. The simulation analysis was applied to two structures, the S190 (spillway) and the S140 (pump and spillway). The average weekly number of samples (aliquots) and standard deviation was 93 (69) and 90 (67), respectively. The number of weeks when the capacity of the sampler was exceeded was 20 out of 400 for S190 and 26 out of 462 for S140. Figure 2 depicts the S190 simulated weekly number of samples (aliquots), the average number of samples for the historical period and the maximum capacity of the sampler.

SUMMARY

Efficient flow-proportional sampling at remote sites with variable flows can be achieved by programming a CR10 data logger and automatic sampler in response to current and preceding week flow rates. Statistical analysis of historical flow data can provide a means of calculating minimum sample trigger volumes with the least chance of under utilizing or overflowing the automatic samplers. Variable sample trigger volumes corresponding to current flow rates improve the sampling scheme. Additional improvements in the sampling scheme can be gained with complex programming if there is sufficient memory in the data logger.

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Table 1. Site locations, UVM type and DBKEYs

SITE	DBKEY	Location	UVM type/PUMP Rating
G136	15195	C139 Basin	USGS Accusonic
L3BRS	16245	EAA*	AFFRA
NFEED	16754	Western Basin	AFFRA
S150	15041	EAA/WCA 3A#	USGS Accusonic
WFEED	16752	Western Basin	AFFRA
S352	13031	EAA/WCA 3A	AFFRA
USSO	16749	EAA	AFFRA
L3BRN	16243	C139 Basin	AFFRA
S8	15040	EAA/Miami Canal	Pump Rating
S9	15015	C-11$/WCA 3A	Pump Rating
L28U (N. of S140)	06752,06753	WCA 3A	USGS Accusonic
L28IN (S. of S190)	04524,13043,15987	Western Basin	USGS Accusonic

* Everglades Agricultural Area
$ C-11 Canal
# Water Conservation Area 3A

Table 2. Weekly flow volumes and sampling volumes for high flow and low flow conditions

SITE	Maximum ha-m (ac-ft)	5% Exceedence ha-m (ac-ft)	High Flows Sampling Volume m^3x10^3 (ft^3x10^3)	Median ha-m (ac-ft)	Low Flows Sampling Volume m^3x10^3 (ft^3x10^3)
G136	800 (6484)	308 (2497)	16 (567)	69 (556)	3.6 (126)
L3BRS	2170 (17581)	1731 (14029)	90.1 (3183)	98.2 (796)	5.1 (181)
NFEED	432 (3504)	355 (2881)	18.5 (654)	81 (659)	4.2 (145)
S150	1436 (11639)	1239 (10046)	64.5 (2280)	287 (2330)	15 (529)
WFEED	1256 (10185)	1256 (10185)$	54.6 (1931)	35 (282)	1.8 (64)
S352	1294 (10489)	1049 (8507)	54.6 (1930)	318 (2581)	16.6 (586)
USSO	409 (3311)	409 (3311)$	21.3 (751)	87.5 (709)	4.6 (160)
L3BRN	2774 (22477)	1538 (12465)	80.0 (2829)	115 (931)	6.0 (211)
S8	6160 (49931)	3275 (26547)	169.8 (6000)	627 (5085)	32.5 (1150)
S9	2848 (23093)	1529 (12394)	79.5 (2810)	582 (4719)	30.3 (1070)
S140	2056 (16669)	1096 (8885)	57.0 (2016)	177 (1438)	9.2 (326)
S190	2610 (21153)	868 (7037)	45.3 (1600)	136 (1100)	7.1 (250)

$ maximum flow used due to smaller size of data

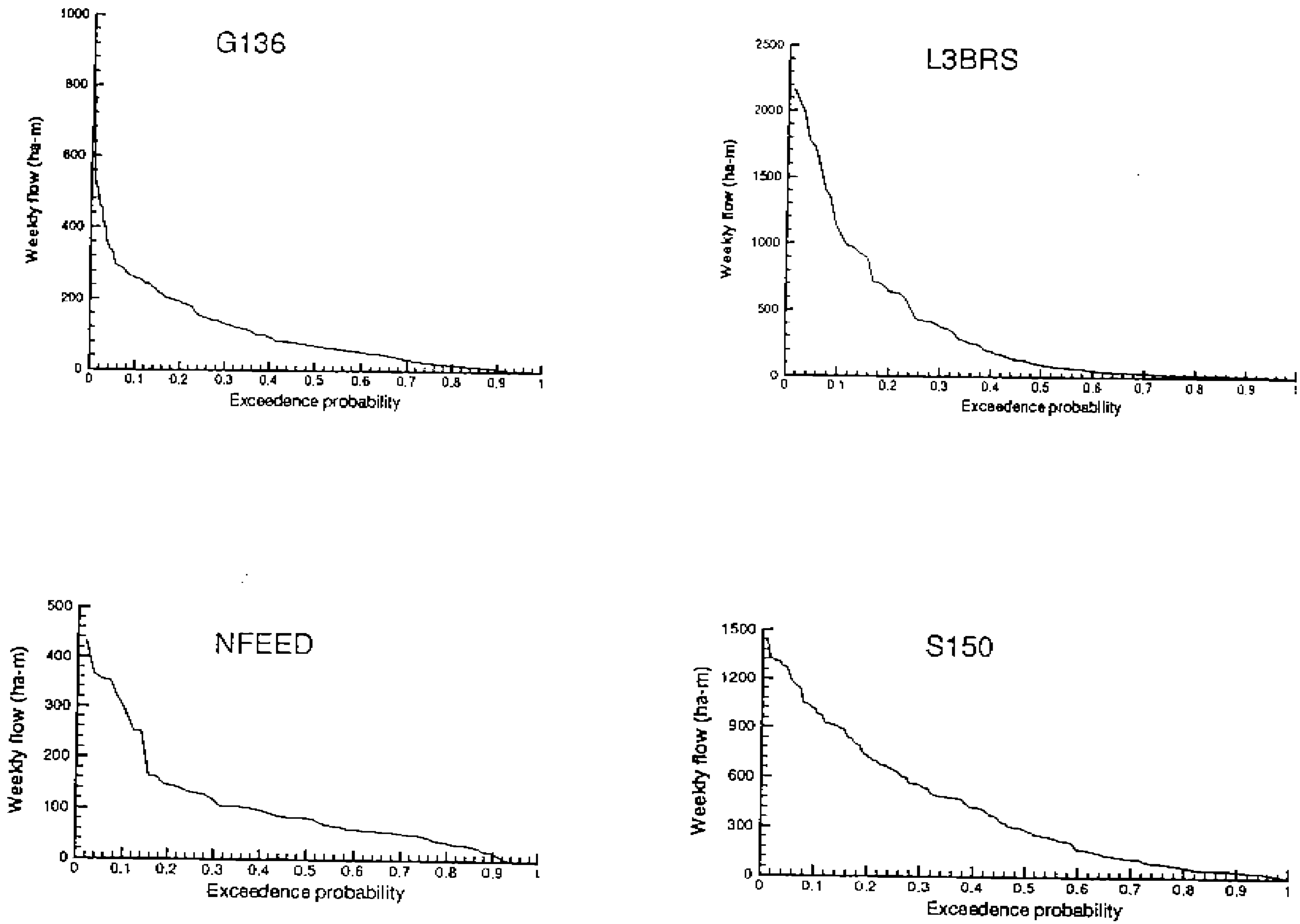

Figure 1a. Weekly flow exceedence probability (G136, L3BRS, NFEED and S150)

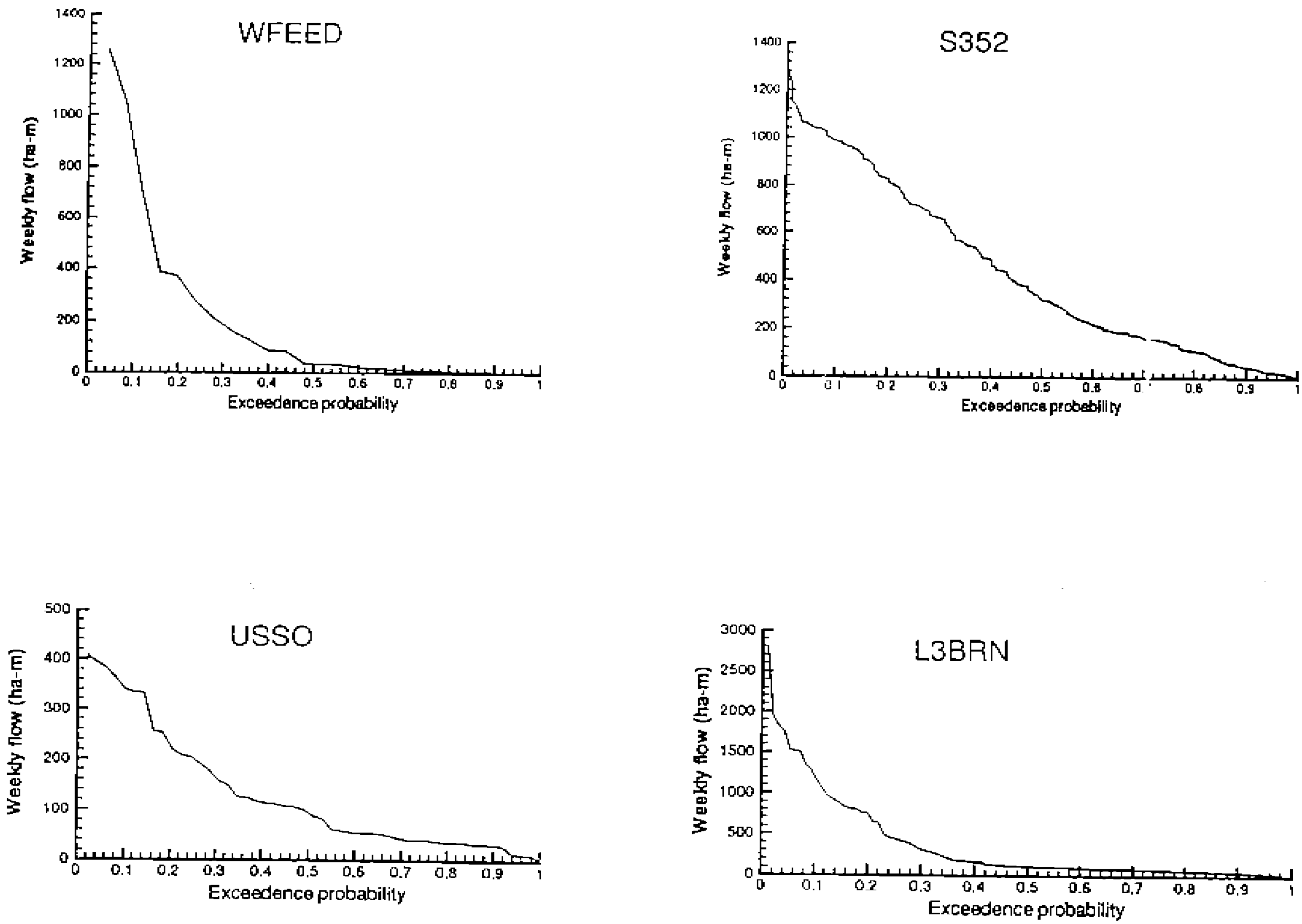

Figure 1b. Weekly flow exceedence probability (WFEED, S352, USSO and L3BRN)

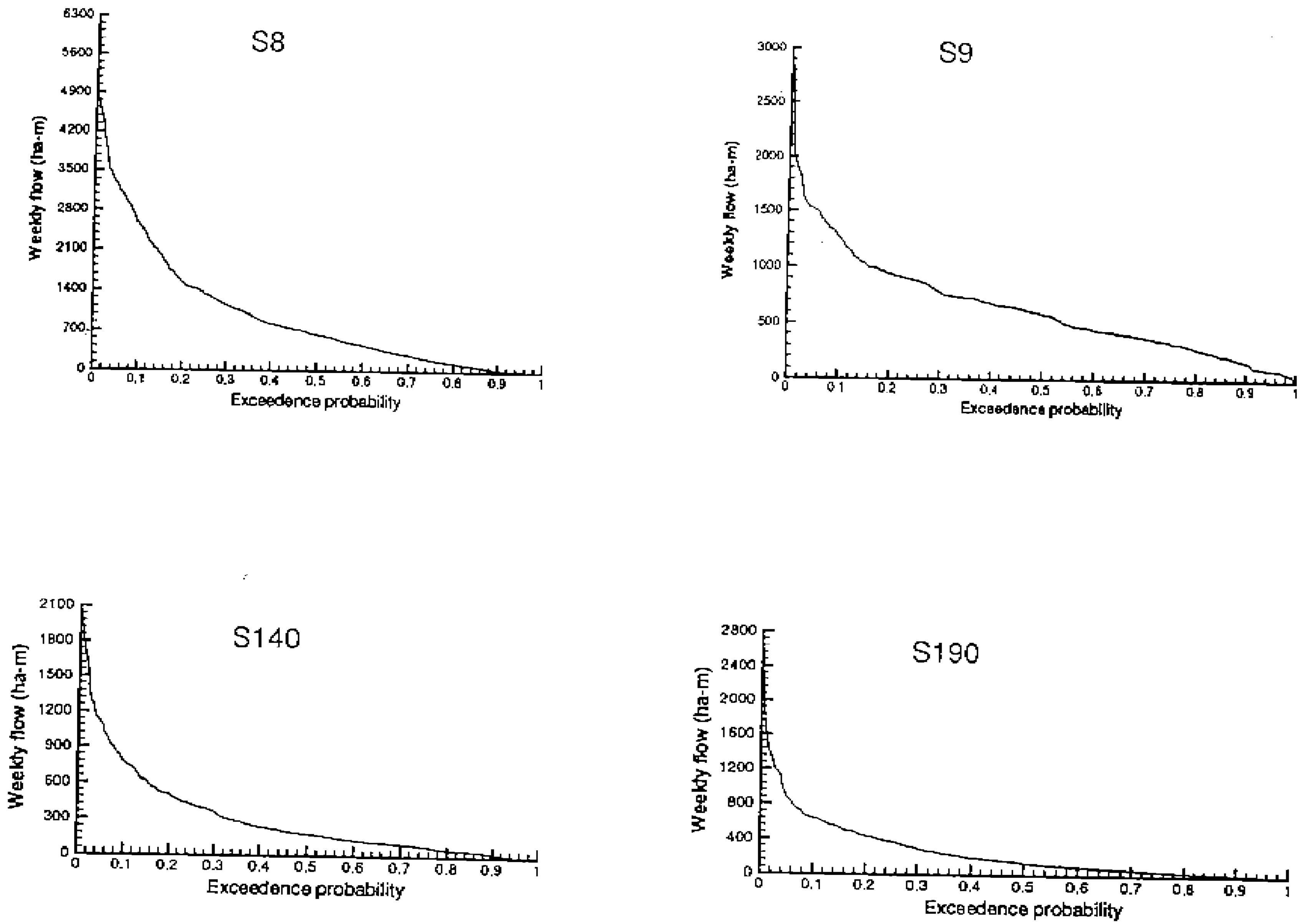

Figure 1c. Weekly flow exceedence probability (S8, S9, S140 and S190)

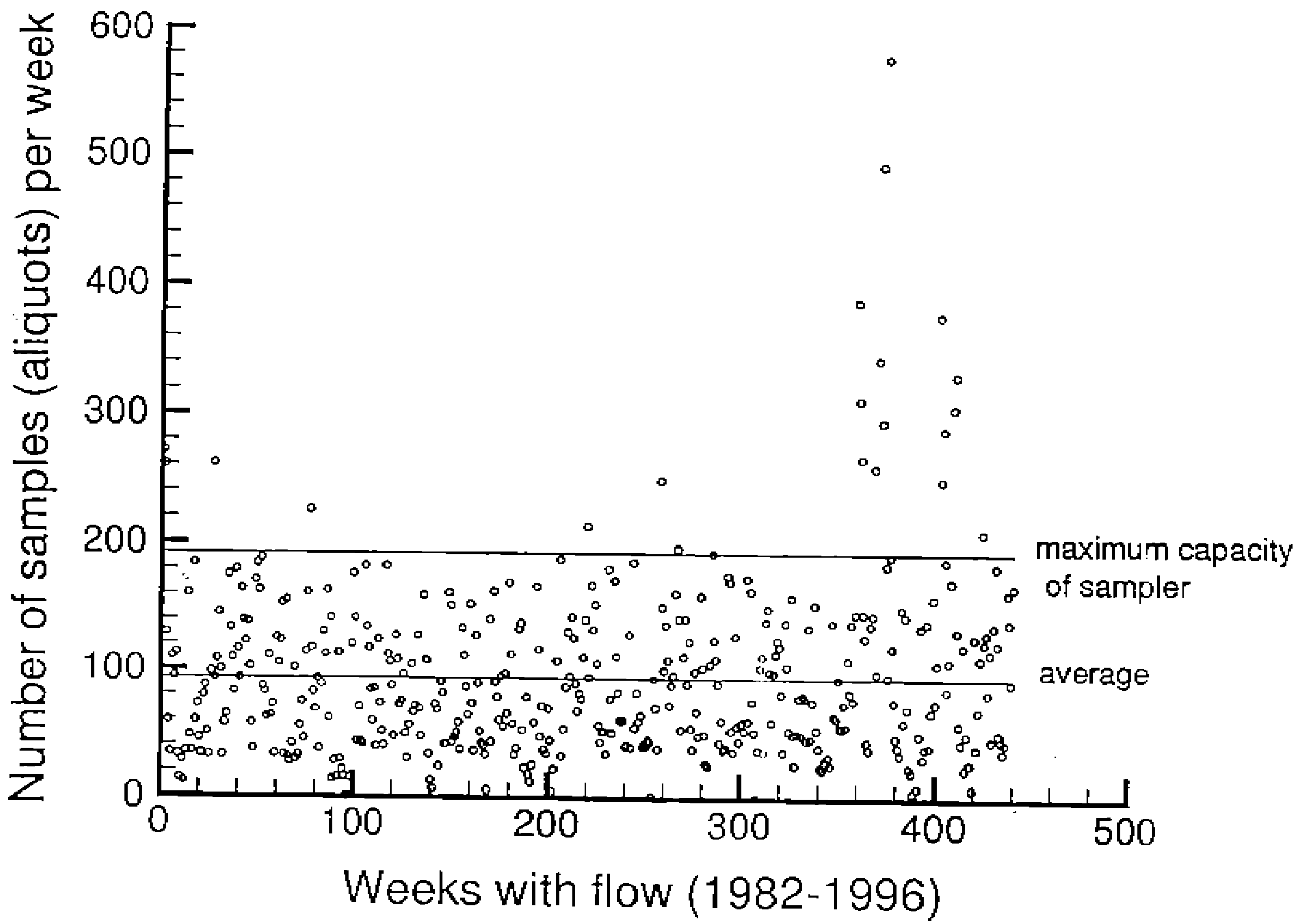

Figure 2. Weekly simulated number of samples for S190