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NWRI CONTRIBUTION NO. 95-70

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MANAGEMENT PERSPECTIVE

Urban areas are important sources of the non-point source (NPS) pollution. To mitigate the impact of urban pollution on the downstream water quality, the so-called Best Management Practices (BMPs) have been introduced to urban stormwater management. Among such BMPs, stormwater detention ponds have become particularly common.

The present study estimates pollutant inventories in different compartments of four stormwater management ponds in the Greater Toronto Area. The results show the impact of land use on the water and sediment quality in these impoundments, with the ponds in industrial/commercial catchments having the highest heavy metals concentrations, followed by the ponds in the residential areas. The deleterious effects of restricted water circulation and the subsequent problems associated with eutrophication are apparent from elevated levels of toxic ammonia in the water column, which at times reached or exceeded the levels recommended by the Canadian Water Quality Guidelines (CCREM,1987) in ponds receiving runoff from residential and industrial areas.

Pollutant inventories in water and sediments of these ponds are important for pond maintenance and for evaluation of their effectiveness in pollutants removal. Effective performance of these ponds should enhance the water quality in a number of streams discharging into Lake Ontario along the Toronto Waterfront and thereby contribute to the development of a remedial strategy for this Great Lakes Area of Concern.

SOMMAIRE À L'INTENTION DE LA DIRECTION

Les zones urbaines sont d'importantes sources de pollution non ponctuelle. Pour atténuer l'impact de la pollution urbaine sur la qualité de l'eau en aval, on a défini des pratiques appelées Best Management Practices (pratiques de gestion optimales) pour la gestion des eaux pluviales. Le recours à des déversoirs d'orage est une solution particulièrement fréquente à ce chapitre.

L'étude actuelle dresse l'inventaire estimatif des matières polluantes présentes dans les divers compartiments de quatre bassins de retenue dans la région du grand Toronto. Les résultats montrent l'impact de l'utilisation des terres sur la qualité de l'eau et des sédiments dans ces bassins récepteurs, ceux des entreprises commerciales et industrielles présentant les concentrations de métaux lourds les plus élevées, suivi de ceux situés dans les zones résidentielles. Les effets nocifs d'une faible circulation de l'eau et les problèmes d'eutrophisation qui y sont associés sont manifestes dans les niveaux élevés d'ammoniac toxique dans la colonne d'eau. À certains moments, ces niveaux atteignaient et même dépassaient les concentrations indiquées par les Recommandations pour la qualité des eaux au Canada (CCMR 1987) dans les bassins recevant les eaux de ruissellement des zones résidentielles et industrielles.

Il est important de dresser l'inventaire des matières polluantes dans l'eau et dans les sédiments de ces bassins pour pouvoir en assurer l'entretien et pour évaluer l'efficacité de la dépollution qui s'y déroule. Un rendement efficace de ces bassins devrait entraîner une amélioration de la qualité de l'eau dans un certain nombre des tributaires du lac Ontario qui se déversent le long du secteur riverain de Toronto, et contribuer à la mise au point d'une stratégie de rétablissement pour ce secteur préoccupant des Grands Lacs.

ABSTRACT

Stormwater detention ponds are one of the management options designed to reduce pollution of the receiving water bodies by urban runoff. Many such structures are operated in the Greater Toronto Area. A seasonal survey of four stormwater detention ponds was conducted to estimate the inventories of heavy metals and phosphorus in bottom and suspended sediments. The concentrations of heavy metals in suspended and bottom sediments suggest that land use has the most profound impact on the quality of suspended and deposited sediments, with the pond in an industrial/commercial catchment having the highest metals concentrations, followed by ponds located in the residential catchments. The suspended sediment data suggest that the removal of heavy metals in these reservoirs may not be adequate. Apart from land use, the magnitude of runoff and seasonal conditions impacted the sediment and water quality in these ponds. The deleterious effects of restricted water circulation during the dry summer conditions and under the winter ice cover are apparent from the elevated levels of ammonia-N, sometimes reaching or exceeding the levels recommended by the Canadian Water Quality Guidelines CCREM 1987) for the protection of aquatic life.

RÉSUMÉ

Le recours à des déversoirs d'orage constitue l'une des options de gestion permettant de réduire la pollution des plans d'eau par les écoulements urbains. Cette pratique est couramment utilisée dans la région du Grand Toronto. On a procédé à une enquête saisonnière dans quatre bassins de retenue dans le but d'évaluer la quantité de métaux lourds et de phosphore dans les sédiments de fond et en suspension. D'après les concentrations de métaux lourds constatées dans les sédiments en suspension et dans les dépôts, l'utilisation des terres se répercute profondément sur la qualité de ceux-ci, le bassin de retenue en zone industrielle et commerciale montrant les plus grandes concentrations de métaux lourds, suivi de celui situé en milieu résidentiel. Les données sur les sédiments en suspension portent à croire que l'élimination des métaux lourds de ces bassins pourrait être insuffisante. Exception faite de l'utilisation des terres, l'importance de l'écoulement et les conditions saisonnières se répercutaient sur la qualité de l'eau et des sédiments de ces bassins. Les teneurs élevées d'azote ammoniacal, qui peuvent à l'occasion atteindre, voire dépasser, les valeurs indiquées par les Recommandations pour la qualité des eaux au Canada (CCMR 1987) pour la protection des espèces aquatiques, ne laissent aucun doute quant aux effets nocifs de la faible circulation de l'eau pendant les périodes sèches de l'été et sous le couvert de glace en hiver.

INTRODUCTION

Urban stormwater has long been recognized as a major source of non-point source (NPS) pollution. Stormwater runoff from urban areas is a major pathway of chemicals from land into the receiving waters, where it limits and impairs beneficial uses. Consequently, methods for stormwater control have been introduced and among these, stormwater management ponds have become particularly popular. The early ponds were designed as flood control structures, but more recent designs attempt to mitigate the effects of urban pollution as well (Marsalek et al. 1992). At present, many municipalities within the Great Lakes Basin, including Metropolitan Toronto, Ontario, operate these facilities in their jurisdictions. Properly designed and operated stormwater ponds profoundly impact water quality in receiving waters, by reducing loadings of nutrients, heavy metals and organic contaminants.

Capture of sediments is one of the principal roles of these ponds in controlling urban pollution (Marsalek et al. 1992, Whipple, 1979). Since many environmentally important contaminants are associated with the sediments, their fate and transport is ultimately governed by the fate of sediments entering these ponds. Several factors influence the storage and transport of sediment-associated pollutants. For instance, retention in the ponds is largely controlled by the pond size and catchment hydrology, particularly the magnitude of runoff discharge, which affects the residence time of particles in the pond. Biochemical processes influence P and N cycling in the ponds and subsequent export and/or immobilization of these nutrients. Sorting of particles through physical fractionation also effects the residence time of particles in the pond by allowing for rapid settling of coarser particles, while extending the residence time of fine particles in the water column and thereby increasing the chances for their export to the receiving waters.

Although numerous estimates of pollutant loadings from urban sources have been produced (Ellis 1989, Marsalek 1990, Marsalek and Schroeter 1988, Schroeter 1983), little is known about the inventories of pollutants in the stormwater detention ponds and their dynamics.

Yet, such information is of paramount importance for a proper maintenance of these ponds, evaluation of their effectiveness in pollutant removal, and development of improved designs.

This study presents the findings of seasonal survey of four stormwater detention ponds in the Greater Metropolitan Toronto Area. As the chemical composition of urban runoff is effected by land use (Hall and Anderson 1988) the selection of the ponds had to consider a variety of urban settings, whereby the ponds would receive runoff from regions with various land use. The study concerned itself with nutrients and heavy metals, which represent two important groups of contaminants in urban runoff. The specific objective of the study was to evaluate the inventories of these pollutants in water and sediment compartments of the selected stormwater detention ponds, in order to assess the pollutants fate and transport prior to entering the receiving waters. This was accomplished by investigating the water quality and the suspended and bottom sediments geochemistry in the four stormwater ponds studied.

MATERIALS AND METHODS

Sampling sites and sample collection

Water samples, suspended and bottom sediments were collected from four Metropolitan Toronto detention ponds situated in areas with commercial, industrial, residential and open space land uses. The sampling dates were selected to reflect any characteristic seasonal variances.

The following detention ponds were surveyed: Colonel Samuel Smith, Tappscott, Heritage Estates, and Unionville; their locations are shown in Fig. 1. The Col. S. Smith Reservoir is situated in Etobicoke at the bottom of Kippling Ave., adjacent to Lake Ontario. This pond receives runoff primarily from industrial and commercial lands and from a major highway, Queen Elizabeth Way. The catchment area of this pond extends over 340 ha (Dutka et al. 1994a). The Tapscott Reservoir is located in Scarborough and is adjacent to the Rouge River which flows into Lake Ontario. The reservoir is situated in the area zoned for agricultural uses (AG zoning permits, City of Scarborough, personal communications). With the largest catchment area (384 ha), this reservoir receives runoff from open spaces (golf course). The Heritage Estates Reservoir is located in a residential area in Richmond Hill and discharges into the Don River. The Unionville Reservoir is situated in Markham and discharges into the Rouge River. The last two reservoirs drain catchments (20 and 11 ha, respectively) with typical residential developments.

The sample collection techniques were the same for all reservoirs. Sampling was carried out near the inlet, outlet, and if the conditions permitted, in the middle of individual reservoirs. Early spring sampling trips allowed us to sample the beginning (March 26) and the end of snowmelt (March 29, April 1) at the Heritage and Col.S. Smith reservoirs. Tapscott reservoir was sampled at the end of snowmelt (March 29) only, whereas an early spring sampling of the Unionville pond was logistically unfeasible. Water samples from the mid-column were pumped directly into 2 L Nalgene bottles using a 5C-MD Marsh submersible pump. Temperature, pH, turbidity, conductivity and dissolved oxygen concentrations were recorded to aid data interpretation.

Except for the mid-winter sampling, dewatered suspended sediments were collected in conjunction with water samples using a continuous-flow Westfalia centrifuge system. Centrifugation was carried out at a flow rate of 6 L/min, a rate which compromises between a good recovery efficiency and time required to obtain a sufficient quantity of particulate material. Centrifuged samples were transferred as a slurry to precleaned glass jars, frozen and subsequently freeze-dried.

Bottom sediments were collected using an Eckman dredge on all sampling occasions at all sampling sites. Approximately top 2 cms were collected for analysis. These samples were processed and analyzed in a similar manner as the suspended sediments.

Water samples were kept at 4°C until arrival to the laboratory, where they were split for chemical analyses. Water samples used for total dissolved P (TDP) analyses were filtered through 0.45 μm cellulose acetate membrane filters. The whole and filtered water samples used for P analysis were preserved with 1 mL of 30% H_2SO_4 per 100 mL of sample and those used for metal analysis were preserved with 1mL of 1:1 HNO_3 per 250 mL of sample.

Sample Analysis

Water samples were analyzed by the National Laboratory for Environmental Testing (NLET) for total suspended solids (TSS), chloride, total heavy metals, total phosphorus (TP), total dissolved P (TDP), nitrate/nitrite (NO_3 + NO_2), ammonia (NH_3) and total Kjeldal nitrogen (TKN) using standard methods (Environment Canada, 1979). Chlorophyll *a* was measured in water samples collected in August of 1993, using the procedure of Burnison (1980), utilizing dimethyl sulfoxide (DMSO) extractant.

Suspended and bottom sediments were analyzed for carbon, forms of phosphorus and for metals. Concentrations of non-apatite inorganic P (NAI-P) and apatite-P were determined using the sequential extraction of Williams et al. (1976) and Mayer and Williams (1981). 0.1 N NaOH/1.0 N NaCl extraction of Williams et al. (1980) was used to measure bioavailable P (BAP), a surrogate measure of P taken up by algae estimated from bioassays. Total P in sediments or total particulate P (TPP) was determined by the ignition of samples at 550°C and subsequent 16-h 1 N HCl extraction. Total carbon (TC) and organic carbon (OC) in suspended and bottom sediments were determined with a LECO-12 Carbon Determinator using a two temperature (575°C, 1371°C) dry combustion method.

Total concentrations of metals in suspended and bottom sediments were determined by microwave digestion of samples with aqua regia under 125 psi pressure, followed by atomic absorption. Sediments with known metals concentrations and the NBS standard were used for quality control assurance.

RESULTS AND DISCUSSION

Water Chemistry

The water quality data presented in Tables 1 and 2 show a high degree of variability in water chemistry for all the ponds surveyed. Although the obtained data series are relatively short, seasonal patterns emerge. The highest concentrations of chlorides in the water column were measured in the winter (February sampling) when the ponds were under a complete ice cover. Conductivity, which correlates closely (r=0.986) with chloride concentrations, was also highest at this time of year, suggesting that chlorides may be the major contributors to dissolved solids concentrations in winter urban runoff. Highest chloride concentrations were measured in the Unionville pond, followed by the Col. S. Smith and Heritage ponds. Road salt is obviously the source of chlorides in the ponds in the residential areas. The data in Table 1 show little difference between the inflow and outflow chloride concentrations, indicating ineffective removal of dissolved solids. This has important implications for the fate of dissolved nutrients (TDP, NO_3+NO_2 and NH_3) entering the receiving waters via these structures. Indeed, the levels (Table 1) of inflow and outflow TDP, NO_3+NO_2 and NH_3 are not substantially different, which is consistent with findings of Randal et al. (1982) and Hey (1982). It is generally acknowledged (Marsalek et al., 1992) that ponds are not very effective in removal of dissolved constituents, unless they are designed as extended detention ponds, with significant chemical uptake (particularly nutrients) by aquatic plants. In general, nitrate is the most stable form of combined nitrogen and along with the TDP plays a significant role in stimulation of the aquatic plant growth.

At the Unionville and Heritage ponds, the undetectable dissolved oxygen levels and consequent release of ammonia from sediments were associated with the winter ice cover. This is reflected in the elevated ammonia-N concentrations (Table 1) in these residential ponds. The NH_3-N levels in the water column of the Unionville and Heritage ponds (Table 1) reached values of 0.490, 0.602 mg/L and 0.381, 0.357 mg/L, respectively. These concentrations exceed the levels for protection of aquatic life (CCREM 1987, IJC 1978) and the U.S. EPA Guidelines (U.S. EPA

1985). The U.S. EPA found ammonia to be toxic to many aquatic organisms, with un-ionized ammonia (NH_3) being the principal toxic form. The concentration of un-ionized NH_3 is a function of pH, temperature and total ammonia concentration in the water column.

Elevated concentrations of NH_3-N were also observed in the summer at the Heritage and Unionville ponds, where anoxic conditions prevailed at the sediment-water interface. Decomposition of nitrogenous organic matter, which includes terrestrial and aquatic plants, is likely the source of ammonia in sediments. Although no oxygen depletion was observed in the water column of the Col. S. Smith Reservoir, the concentrations of NH_3-N were higher in May and August than on the other survey occasions. Oxygen depletion at the sediment-water interface of the Heritage and the Unionville ponds in August may be the consequence of high primary productivity and the resulting accelerated oxygen consumption due to the decomposition of the organic matter in sediments. Prolific algal growth was observed at both of these ponds in the summer and poor trophic conditions were confirmed by high chlorophyll levels in these ponds. Chlorophyll *a*, which is a photosynthetic pigment common to green plants and is a good measure of algal abundance in aquatic systems, was highest at the Heritage pond (31.4 μg/L), followed closely by the Unionville pond (29.4 μg/L). The chlorophyll concentrations indicate eutrophic-hypereutrophic conditions (Wetzel 1975, Dobson 1981) in both ponds. Substantially lower chlorophyll levels, 9.3 and 2.7 μg/L were measured in the Col. S. Smith and Tapscott reservoirs, respectively.

No clear consistent areal pattern is evident in concentrations of the total Kjeldal nitrogen (TKN), a combined measure of organic N and ammonia in the water column. Likewise, no discernable trend from inlet to outflow was detected in the TP concentrations in the individual ponds. Since more than half (on average 65%) of the TP in water column is in the particulate form, the results suggest low efficiency of particulate P removal and/or additional input of particulate P to the water column by resuspension of bottom sediments due to currents caused by high flows, wind-induced circulation, or pressurized flow under the ice cover.

The highest input of suspended sediments, as indicated by the TSS data (Table 1), was associated with the initial stages of the snowmelt period (Heritage, March 26) and snowmelt with rainfall (Col. S. Smith, April 1). Generally, no large differences in TSS concentrations between the inlet and the remaining reservoir were seen. The lack of a significant difference between the inlet and outlet TSS concentrations was also confirmed statistically by the *t*-test, with *t* values ranging between 0.332 and 0.896, for n=6 to 14, suggesting low removals of fine suspended particulates. Although sediment removal efficiencies are lower for short detention times (Marsalek et al.1992), that is when runoff flows are high, a 91% drop in TSS concentrations was observed at the Heritage pond on April 1, when rain runoff and snowmelt carried the highest sediment loads (Table 1). This observation may be explained by high inputs of coarse material, of high settling velocity, derived from physical scouring of streets by runoff from snowmelt and intensive steady rain. TSS concentrations correlated strongly (r=0.98, 0.99, respectively) with Al and Fe concentrations in water, suggesting terrigenous input of particles, derived from the erosion within the catchment.

The highest heavy metal concentrations in water were found in the Col. S. Smith reservoir, where Cu and Zn exceeded the Provincial Water Quality Objectives (PWQO) most of the time (Table 2). The Heritage pond exhibited the second highest metal concentrations, with Cu frequently exceeding the PWQO and Zn exceeding the Objectives at the inlet during the spring snowmelt. Elevated Cu concentrations were observed at Unionville during the fall sampling (Nov.11), when a continuous rain resulted in scouring of streets and a significant input of street dust. Although the TSS and heavy metals were strongly correlated, the simple correlations explained only between 24-68% of the variance in the heavy metals concentrations. A stepwise multiple regression, relating the concentrations of heavy metals to Al and Fe concentrations, most improved the correlations:

$$[Zn] = -0.083\,[Al] + 0.075\,[Fe] + 7.232 \qquad r=0.812$$

$$[Pb] = -0.014\,[Al] + 0.013\,[Fe] - 0.390 \qquad r=0.921$$

$$[Cu] = -0.012\,[Al] + 0.013\,[Fe] + 3.792 \qquad r=0.702$$

$$[Ni] = -0.002\,[Al] + 0.002\,[Fe] + 0.741 \qquad r=0.936$$

Such good relations between the heavy metals and Al, Fe may be explained by adsorption of these metals onto Fe-oxides and clay particles of which Al and Fe are part. Better correlation may also be due to the exclusion of non-Fe and Al bearing land-derived components such as quartz, dolomite, asphalt etc., which play a minor role in the metal binding, yet may constitute a substantial portion of urban dust. These components are typically included in the TSS values.

Suspended and Bottom Sediments Geochemistry

Contaminants enter urban runoff from natural sources (vegetal matter, soil erosion) and from the anthropogenic sources (industry, fertilizers, traffic and roof runoff). Because many metals and nutrients occur naturally, their anthropogenic enrichment can be defined only in relation to background or natural concentrations (Colman and Sanzolone, 1992).

To determine the relative level of metal contamination as opposed to the natural occurrence, sediment metal data collected from reservoirs receiving runoff from industrial/commercial (Col. S. Smith) and residential (Heritage, Unionville) catchments are compared to the data from the Tapscott reservoir, which represents an open space catchment. A similar approach was used by Hall and Anderson (1988) in their study of urban runoff. The relative level of contamination is assumed to be significant, if it exceeds the mean + 2 standard deviations of the reference (green space) metal values. Similar criteria were used to show the heavy metals contamination of stormwater and street sediments (Hall and Anderson 1988) and river sediments (Oliver and Agemian 1974). The data (Table 3) show the highest levels of metals contamination in suspended sediments from the Col. S. Smith Pond which drains an industrial/commercial area. In this pond, the mean concentrations of Zn, Pb, Cu, Cd, Ni and Cr in suspended sediments (Table 3) were greater than the mean + 2 standard deviations for the suspended sediments from the Tapscott Reservoir. The sources of industrial waste in this pond include a metal working plant, which at times contributes significant quantities of Zn, P and oil and grease to runoff (The Metropolitan Toronto and Region Conservation Authority 1993). The presence of a sludge-like material, probably originating from the metal working plant, was reported (The Metropolitan Toronto and Region Conservation Authority 1993) for this area. The

Unionville Pond ranked second with Pb, Cu and Cd concentrations exceeding the criteria, while only Cu exceeded the criteria at the Heritage Pond. These data are consistent with the previous research which identified Pb, Zn and Cu as main pollutants in suspended sediments from urban areas (O'Neil 1979). The data also indicate that bottom sediments of the Col. S. Smith Pond, are similarly the most contaminated (Table 4).

As seen from Figs. 2 - 5, metals concentrations in suspended sediments were higher than those in bottom sediments. Except for Pb, the differences between the mean metal (Mn, Zn, Cu, Ni and Cr) concentrations in suspended and bottom sediments were significant (*t*-test) at the 5% significance level (α=0.05). No substantial decrease in metals concentrations in suspended sediments was observed between the inlets and outlets of the ponds (Figs. 2 -5), suggesting continuous transport of heavy metals through these structures, during the sampling episodes. In view of the fact that heavy metals tend to associate with fine grained particles, and coarser particles settle preferentially in stormwater detention ponds, the removal of heavy metals in these ponds, with short detention times, may not be adequate. Concentrations of heavy metals in suspended sediments higher than those in bottom sediments also provide evidence for relation between the sediments size distribution (Dutka et al. 1994b) and their metal content. Thus, our results point to almost uninterrupted passage of fine clay particles through these structures into receiving water bodies, under the conditions studied.

Using an abrupt drop in organic C and metals concentrations (unpublished core data), the depth of fine grained sediments enriched in heavy metals was arbitrarily determined for the Col. S. Smith reservoir to be about 4 cm. Assuming a uniform distribution of deposited sediments, and considering the 2,657 m^2 area of the pond (The Metropolitan Toronto and Region Conservation Authority 1993), the estimated volume of sediment enriched with heavy metals is about 106 m^3.

Comparison of TPP concentrations (Figs. 6-9) shows an enrichment of P in suspended sediments, relative to bottom sediments. These differences are largely due to significantly higher BAP concentrations in suspended sediments than those in bottom sediments. The BAP is the most labile portion of the particulate P and, depending on the source material, it accounts for 60-75% of the NAI-P. Particles produced by autotrophic production in the water column (Mayer 1985, Mayer and Manning 1989) and fine grained eroded soil particles with weakly bound P (Sharpley and Smith 1992, Menzel 1980) have generally higher BAP and lower apatite-P concentrations. Conversely, detrital coarser particles have lower BAP and higher apatite-P concentrations, as apatite is a heavy mineral and tends to be associated with coarser particles of detrital origin. Thus, apatite-P which is negatively correlated with organic C ($r=-0.848$, $n=44$), is a reasonably good indicator of sediment sources. Higher apatite-P concentrations accompanied by lower organic C concentrations suggest input of land-derived material of mineral nature. As seen from Figs. 6-9, the composition of bottom sediments with significantly higher ($t=4.26$, $n=94$) apatite-P concentrations and lower ($t=6.23$, $n=93$) organic C concentrations is more representative of terrigenous material (Dean et al. 1993) than that of suspended sediments.

During the dry conditions in the summer, or under the winter ice cover, these small-sized stagnant waters with only restricted water circulation become anoxic and nutrient fluxes from sediments add to the external nutrients loadings. There is a sufficient P pool in sediments within the NAI-P, and particularly the BAP category (Figs. 6-9), to release substantial quantities of P into the overlying water and so contribute to problems associated with eutrophication.

CONCLUSIONS

In all surveyed ponds the water quality was highly variable and changed as a result of the magnitude of runoff and seasonal conditions within the ponds. Land use within the catchment of these ponds had a profound effect on the water and sediment quality. The variation in the suspended and bottom sediments geochemistry appears to be affected by a combination of site location in relation to the pollution sources, organic matter and clay content which is, similarly to water quality, determined largely by the magnitude of runoff and seasonal conditions within the pond and the watershed. The survey clearly showed elevated levels of heavy metal contaminants (Pb, Cu, Zn, Cd) in the ponds receiving runoff from industrial/commercial and residential areas. No obvious decrease in nutrient or metal concentrations in suspended particulates between the inlets and outlets of these structures was apparent, suggesting uninterrupted passage of fine-grained particles through the ponds. Hence, under the conditions studied, the ponds have only limited ability for removing the sediment-associated contaminants.

The geochemical data presented in this study are significant, as they provide the agencies responsible for management of urban detention ponds with information required for selecting the disposal methods for bottom sediments of these ponds and improving their design to better mitigate the impacts of urban non-point pollution.

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Table 1. Water quality parameters in stormwater detention ponds

Pond Name	Site	Sampling Date	TSS mg/L	Cl mg/L	TP mg/L	TFP mg/L	TKN mg/L	NO_3/NO_2 mg/L	NH_3 mg/L
Heritage	Inlet	92/11/11	13.6	21.6	0.0667	0.0286	0.754	0.829	0.181
	Middle	92/11/11	16.0	22.0	0.0657	0.0260	0.687	0.818	0.167
	Outlet	92/11/11	15.6	21.5	0.0737	0.0277	0.747	0.817	0.178
	Middle	93/02/26	1.8	244.0	0.0220	0.0097	0.741	1.140	0.381
	Middle	93/02/26	1.2	232.0	0.0216	0.0092	0.759	1.020	0.357
	Inlet	93/03/26	169.0	151.0	0.6601	0.4795	1.630	0.855	1.082
	Outlet	93/03/26	157.0	345.0	0.2606	0.1722	0.961	2.120	0.006
	Inlet	93/03/29	22.4	63.4	0.1892	0.0650	0.939	1.250	0.046
	Outlet	93/03/29	14.4	102.0	0.1745	0.1081	0.643	1.150	0.307
	Inlet	93/04/01	267.0	183.0	0.3165	0.0343	1.340	1.380	0.200
	Outlet	93/04/01	23.5	199.0	0.1275	0.0535	1.050	1.610	0.004
	Inlet	93/05/04	5.0	238.0	0.0318	0.0092	0.526	0.982	0.146
	Middle	93/05/04	6.2	239.0	0.0409	0.0104	0.560	1.010	0.159
	Outlet	93/05/04	6.6	241.0	0.0354	0.0096	0.556	1.020	0.143
	Inlet	93/08/19	9.6	49.4	0.0607	0.0169	0.898	0.019	0.320
	Middle	93/08/19	10.0	48.8	0.0755	0.0172	1.090	0.045	0.384
	Outlet	93/08/19	8.8	49.9	0.0471	0.0128	0.908	0.019	0.234
S.Smith	Inlet	92/10/14	8.8	135.0	0.1666	0.1436	0.455	1.420	0.174
	Middle	92/10/14	6.4	192.0	0.1066	0.0677	0.737	1.060	0.206
	Outlet	92/10/14	6.0	175.0	0.1158	0.0748	0.754	0.942	0.005
	Middle	93/02/26	3.2	617.0	0.0452	0.0288	0.479	0.881	0.092
	Inlet	93/03/26	26.0	338.0	0.1154	0.0547	0.819	1.010	0.261
	Inlet	93/04/01	119.0	211.0	0.1787	0.0411	1.090	1.400	0.013
	Outlet	93/04/01	79.0	173.0	0.1279	0.0321	0.788	0.970	0.135
	Inlet	93/05/07	12.8	167.0	0.1020	0.0127	0.853	0.864	0.326
	Middle	93/05/07	10.4	177.0	0.0982	0.0104	0.801	0.857	0.307
	Outlet	93/05/07	11.6	170.0	0.1030	0.0129	0.786	0.851	0.322
	Inlet	93/08/16	24.0	36.8	0.1319	0.0783	0.786	1.353	0.319
	Middle	93/08/16	21.6	39.2	0.1323	0.0782	1.010	1.276	0.330
	Outlet	93/08/16	17.6	40.1	0.1275	0.0786	0.578	1.654	0.017
Tapscott	Inlet	92/09/02	0.5		0.0235	0.0188			
	Middle	92/09/02	34.0		0.0703	0.0217			
	Outlet	92/09/02	53.0		0.0906	0.0164			
	Inlet	93/02/25	66.8	206.0	0.0573	0.0071	0.275	1.600	0.055
	Middle	93/02/25	30.8	209.0	0.0361	0.0073	0.208	1.130	0.044
	Outlet	93/02/25	4.6	216.0	0.0128	0.0051	0.208	1.720	0.034
	Inlet	93/03/29	49.2	92.9	0.1137	0.0328	0.513	0.981	0.076
	Outlet	93/03/29	23.2	81.7	0.0881	0.0274	0.470	0.751	0.172
	Inlet	93/05/06	39.2	105.0	0.0731	0.0085	0.454	1.010	0.111
	Middle	93/05/06	22.0	105.0	0.0491	0.0087	0.453	0.970	0.089
	Outlet	93/05/06	25.6	103.0	0.0554	0.0078	0.407	1.030	0.071
	Inlet	93/08/18	14.8	58.7	0.0525	0.0132	0.847	0.203	0.160
	Middle	93/08/18	36.8	58.3	0.1441	0.0124	1.610	0.442	0.244
	Outlet	93/08/18	42.5	59.7	0.1782	0.0119	1.930	0.272	0.258
Unionville	Inlet	92/11/12	57.0	28.4	0.1360	0.0594	0.931	0.809	0.262
	Middle	92/11/12	10.5	71.8	0.0913	0.0376	1.150	0.809	0.403
	Outlet	92/11/12	42.5	59.5	0.1434	0.0293	5.550	0.846	0.324
	Middle	93/02/25	12.0	1071.0	0.1660	0.0276	1.850	0.728	0.490
	*	93/02/25	14.0	1201.0	0.1420	0.0180	1.690	0.491	0.602
	Inlet	93/05/05	18.2	280.0	0.0822	0.0140	0.552	0.339	0.234
	Middle	93/05/05	18.0	280.0	0.0935	0.0197	0.587	0.321	0.269
	Outlet	93/05/05	18.2	279.0	0.0746	0.0195	0.901	0.330	0.233
	Inlet	93/08/17	19.2	98.2	0.0890	0.0368	1.050	0.352	0.179
	Middle	93/08/17	17.6	98.8	0.0885	0.0354	1.180	0.092	0.396
	Outlet	93/08/17	5.2	101.0	0.0526	0.0243	0.828	0.118	0.178

* Site between inlet and outlet

Table 2. Concentration of metals in water column of four stormwater detention ponds

Pond Name	Site	Sampling Date	Al µg/L	Fe µg/L	Mn µg/L	Zn µg/L	Pb µg/L	Cu µg/L	Ni µg/L
Heritage	Inlet	92/11/11	551	603	51.3	7.9	0.8	7.3	1.2
Heritage	Middle	92/11/11	627	677	56.2	8.5	1.1	3.0	1.2
Heritage	Outlet	92/11/11	663	718	58.8	9.8	0.9	3.1	1.4
Heritage	Middle	93/02/26	33	74	133.0	7.9	0.2	2.8	0.8
Heritage	Middle	93/02/26	28	74	145.0	8.5	0.2	2.7	1.1
Heritage	Inlet	93/03/26	2840	3890	204.0	50.2	7.9	32.2	4.0
Heritage	Outlet	93/03/26	2130	2460	199.0	28.0	3.2	17.8	2.7
Heritage	Inlet	93/03/29	464	593	50.1	21.0	1.3	14.2	0.9
Heritage	Outlet	93/03/29	485	586	58.9	28.6	0.8	7.8	0.9
Heritage	Inlet	93/04/01	7910	9770	203.0	77.7	12.6	24.5	8.2
Heritage	Outlet	93/04/01	1030	1140	77.3	25.0	1.6	10.3	1.6
Heritage	Inlet	93/05/04	78	107	9.6	1.9	0.2	2.8	0.6
Heritage	Middle	93/05/04	75	112	9.4	1.6	0.2	3.0	0.7
Heritage	Outlet	93/05/04	89	127	9.6	1.7	0.2	3.2	0.8
Heritage	Inlet	93/08/19	65	106	49.0	2.9	0.2	1.9	0.6
Heritage	Middle	93/08/19	60	105	46.7	2.1	0.2	1.7	0.6
Heritage	Outlet	93/08/19	64	104	40.6	1.6	0.2	1.7	0.6
S.Smith	Inlet	92/10/14	250	401	33.1	49.5	3.4	12.8	2.1
S.Smith	Middle	92/10/14	86	327	78.6	31.2	1.0	7.2	1.9
S.Smith	Outlet	92/10/14	80	247	69.2	31.1	1.1	21.0	1.8
S.Smith	Middle	93/02/26	101	155	75.0	17.5	0.2	5.1	0.9
S.Smith	Inlet	93/03/26	750	1100	132.0	68.0	4.2	11.8	2.7
S.Smith	Outlet	93/03/26	901	1360	154.0	86.0	5.7	13.7	3.3
S.Smith	Inlet	93/04/01	2190	4420	190.0	153.0	25.9	32.9	6.0
S.Smith	Outlet	93/04/01	1800	3290	138.0	113.0	19.3	24.7	4.7
S.Smith	Inlet	93/05/07	248	464	96.3	41.6	3.0	11.0	2.2
S.Smith	Middle	93/05/07	69	123	25.0	18.6	0.2	5.3	1.4
S.Smith	Outlet	93/05/07	214	430	95.6	35.5	2.3	9.8	2.0
S.Smith	Inlet	93/08/16	536	1020	66.0	72.9	8.9	18.8	2.5
S.Smith	Middle	93/08/16	528	987	64.8	69.7	8.6	18.6	2.5
S.Smith	Outlet	93/08/16	535	1010	65.9	72.2	8.8	19.7	2.6
Tapscott	Inlet	92/09/02	48	107	13.1	12.3	0.2	3.8	0.5
Tapscott	Middle	92/09/02	887	1290	112.0	7.3	1.3	5.5	1.5
Tapscott	Outlet	92/09/02	1180	1690	97.8	12.0	1.6	4.7	1.7
Tapscott	Inlet	93/02/25	806	1110	45.6	25.5	2.1	2.9	1.4
Tapscott	Middle	93/02/25	481	664	45.3	17.2	0.8	2.4	0.7
Tapscott	Outlet	93/02/25	80	208	27.4	13.7	0.2	1.2	0.2
Tapscott	Inlet	93/03/29	1120	1410	125.0	16.0	1.8	5.2	1.6
Tapscott	Outlet	93/03/29	647	770	108.0	9.8	0.6	3.0	1.2
Tapscott	Inlet	93/05/06	1100	1650	181.0	13.1	1.8	3.1	1.6
Tapscott	Middle	93/05/06	570	931	165.0	6.8	0.7	2.1	1.2
Tapscott	Outlet	93/05/06	768	1200	158.0	11.4	1.2	2.7	1.9
Tapscott	Inlet	93/08/18	262	493	99.6	3.6	0.7	1.8	0.7
Tapscott	Middle	93/08/18	760	1130	133.0	11.8	1.1	2.5	1.3
Tapscott	Outlet	93/08/18	826	1280	148.0	9.9	1.4	2.5	1.3
Unionville	Inlet	92/11/12	1340	1680	57.4	38.9	6.4	17.1	2.1
Unionville	Middle	92/11/12	204	280	31.4	6.1	0.3	11.7	1.4
Unionville	Outlet	92/11/12	881	1110	53.8	20.9	3.6	18.9	1.9
Unionville	Middle	93/02/25	64	142	248.0	6.3	0.2	3.6	0.8
Unionville	*	93/02/25	162	337	375.0	4.5	0.2	2.8	0.6
Unionville	Inlet	93/05/05	366	624	16.8	3.6	0.7	1.9	1.3
Unionville	Middle	93/05/05	328	600	17.0	3.8	0.7	1.8	1.3
Unionville	Outlet	93/05/05	370	629	17.3	3.8	0.5	1.9	1.3
Unionville	Inlet	93/08/17	488	680	64.1	8.1	2.4	4.0	1.4
Unionville	Middle	93/08/17	567	719	65.3	9.0	1.4	4.5	1.4
Unionville	Outlet	93/08/17	172	267	36.2	3.1	0.3	2.9	0.9

* Site between inlet and outlet

Table 3. Relative heavy metals contamination of suspended sediments

	Tapscott	Heritage	C.S.Smith	Unionv.
	means			
Mn				
mean	1894	1803	1356	960
2std	2868			
sum	4762			
Zn				
mean	244	282	1077	245
2std	68			
sum	312			
Pb				
mean	57.5	61.1	265	83
2std	11			
sum	68.5			
Cu				
mean	44.4	58.9	215	65.5
2std	10.4			
sum	54.8			
Cd				
mean	2.11	2.32	6.22	2.98
2std	0.5			
sum	2.61			
Ni				
mean	34.8	29.8	49.7	31.2
2std	10.2			
sum	45			
Cr				
mean	36.1	29.3	55.2	34.5
2std	10.2			
sum	46.3			

Table 4. Relative heavy metals contamination of bottom sediments

	Tapscott	Heritage	C.S.Smith	Unionv.
		means		
Mn				
mean	491	481	693	377
2std	114			
sum	605			
Zn				
mean	178	146	610	98
2std	38			
sum	216			
Pb				
mean	46.2	46	202	48
2std	9			
sum	55.2			
Cu				
mean	34	32	151	30
2std	10.2			
sum	44.2			
Cd				
mean	2.01	2.26	4.16	2
2std	0.34			
sum	2.35			
Ni				
mean	30.1	26.3	45.2	22.7
2std	8			
sum	38.1			
Cr				
mean	24	24.1	45.3	21.2
2std	8.2			

LIST OF FIGURES

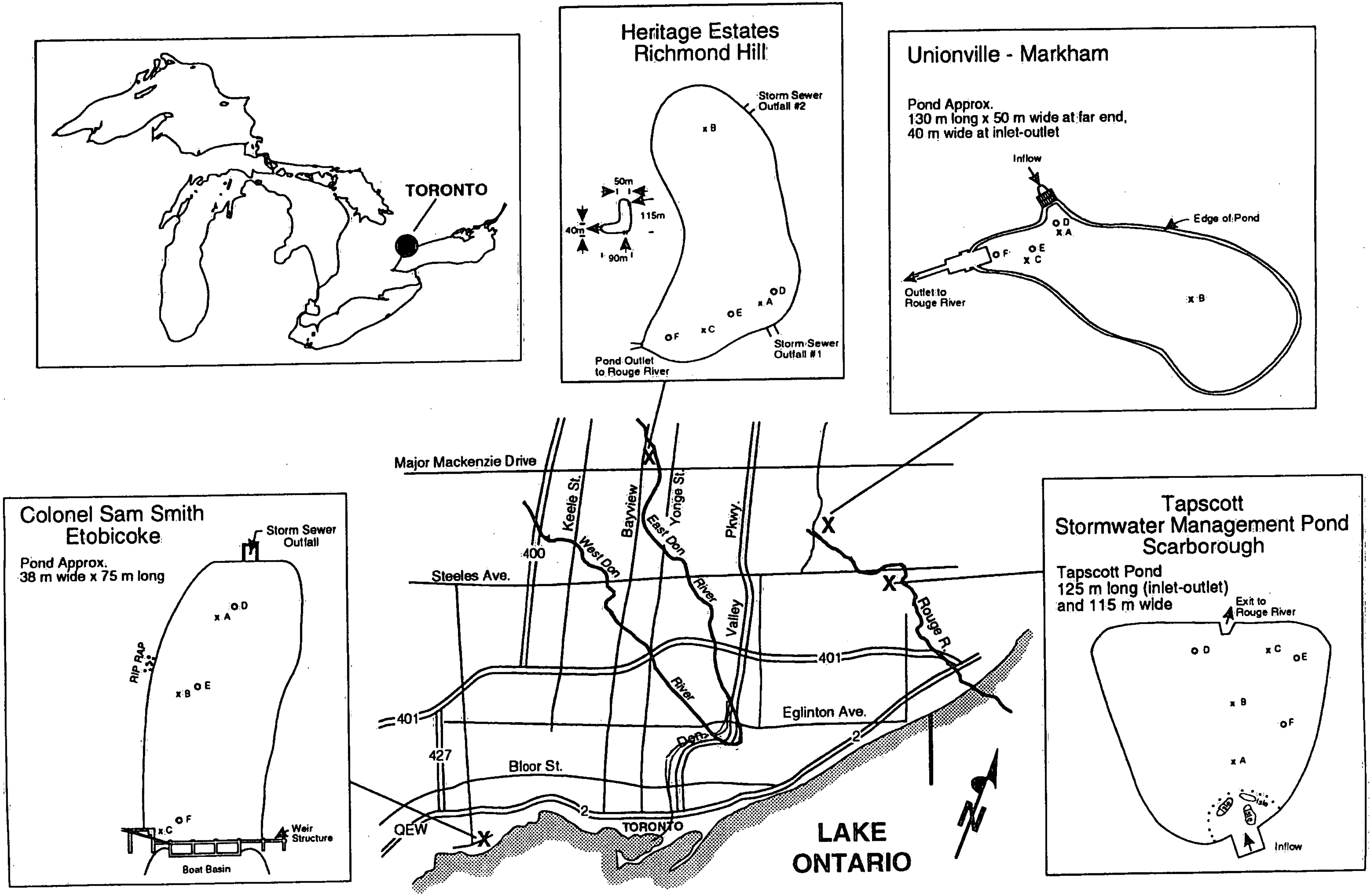

TORONTO
Heritage Estates
Richmond Hill
Storm Sewer Outfall #2
50m
115m
40m
90m
x B
o D
x A
o E
x C
o F
Storm Sewer Outfall #1
Pond Outlet to Rouge River
Unionville - Markham
Pond Approx.
130 m long x 50 m wide at far end,
40 m wide at inlet-outlet
Inflow
Edge of Pond
o D
x A
o E
x C
o F
x B
Outlet to Rouge River
Colonel Sam Smith
Etobicoke
Pond Approx.
38 m wide x 75 m long
Storm Sewer Outfall
o D
x A
RIP RAP
x B
o E
o F
x C
Weir Structure
Boat Basin
Major Mackenzie Drive
Keele St.
Bayview
Yonge St.
Pkwy.
400
West Don
East Don
River
Valley
Steeles Ave.
Rouge R.
401
River
Eglinton Ave.
427
Bloor St.
Don
2
QEW
TORONTO
LAKE
ONTARIO
N
Tapscott
Stormwater Management Pond
Scarborough
Tapscott Pond
125 m long (inlet-outlet)
and 115 m wide
Exit to Rouge River
o D
x C
o E
x B
o F
x A
Isle
Inflow

Fig. 1

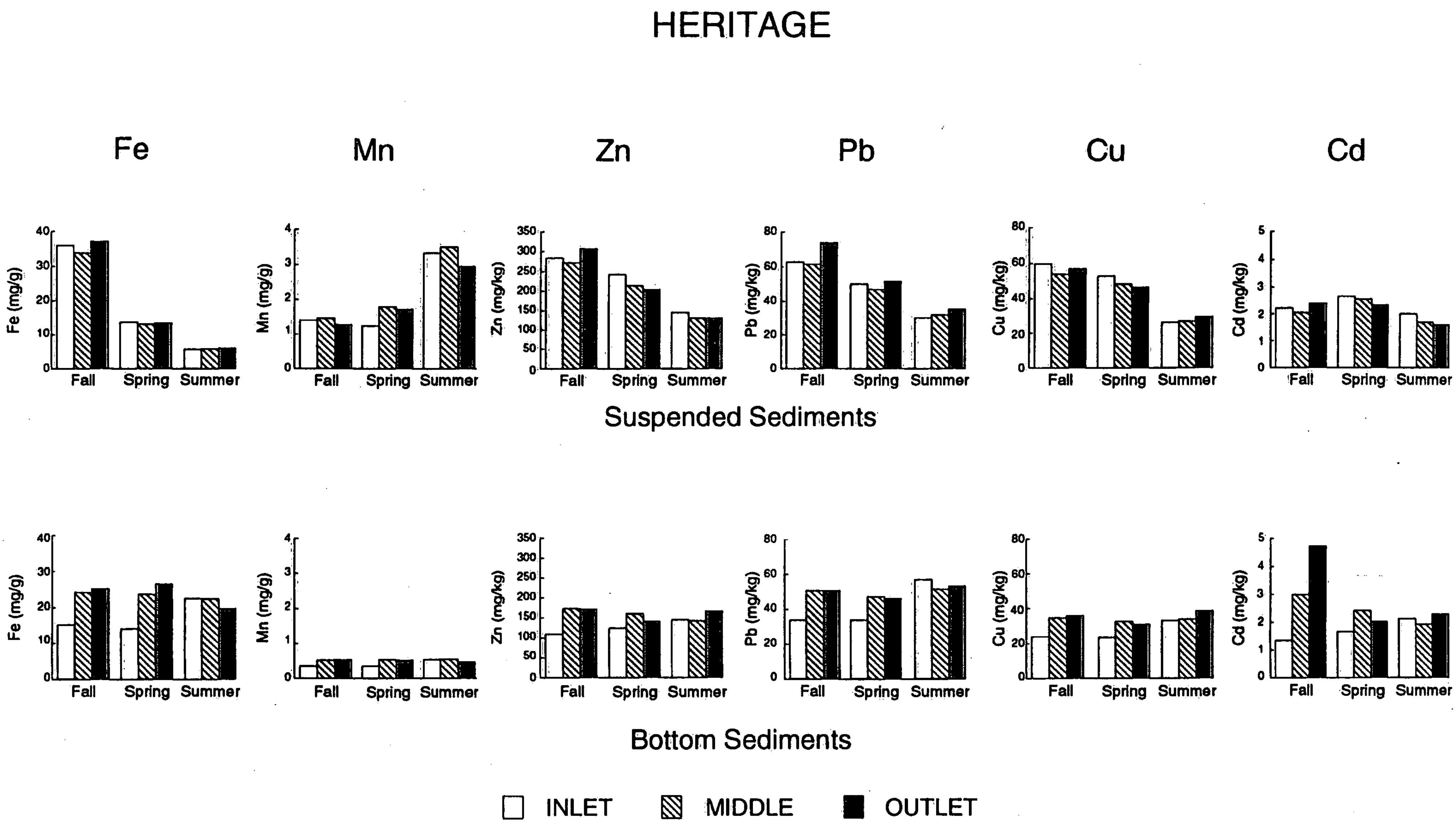

HERITAGE
Fe
Mn
Zn
Pb
Cu
Cd
Fe (mg/g)
Mn (mg/g)
Zn (mg/kg)
Pb (mg/kg)
Cu (mg/kg)
Cd (mg/kg)
Fall
Spring
Summer
Suspended Sediments
Bottom Sediments
INLET
MIDDLE
OUTLET

Fig. 2

SAMUEL SMITH

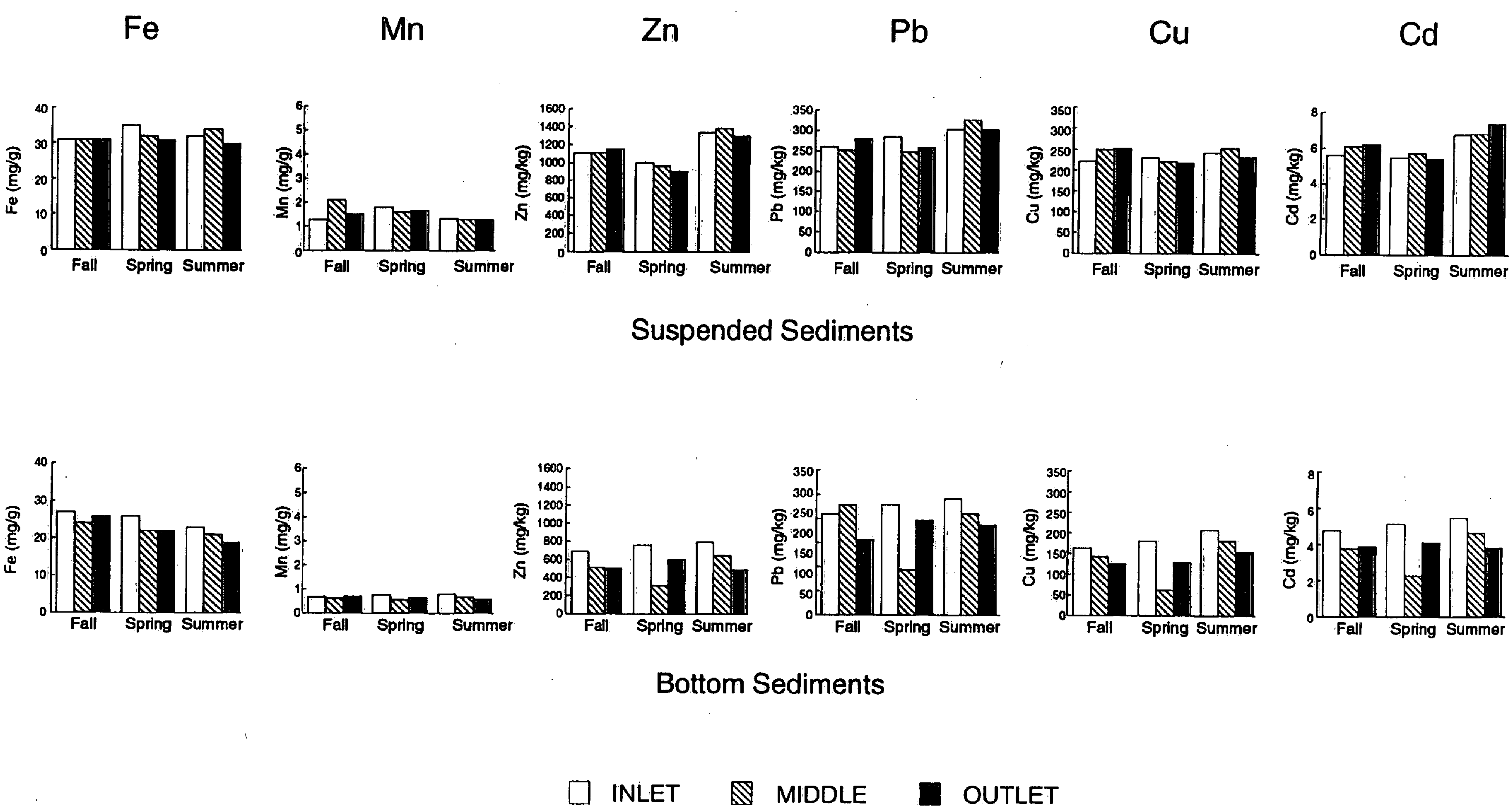


Fig. 3

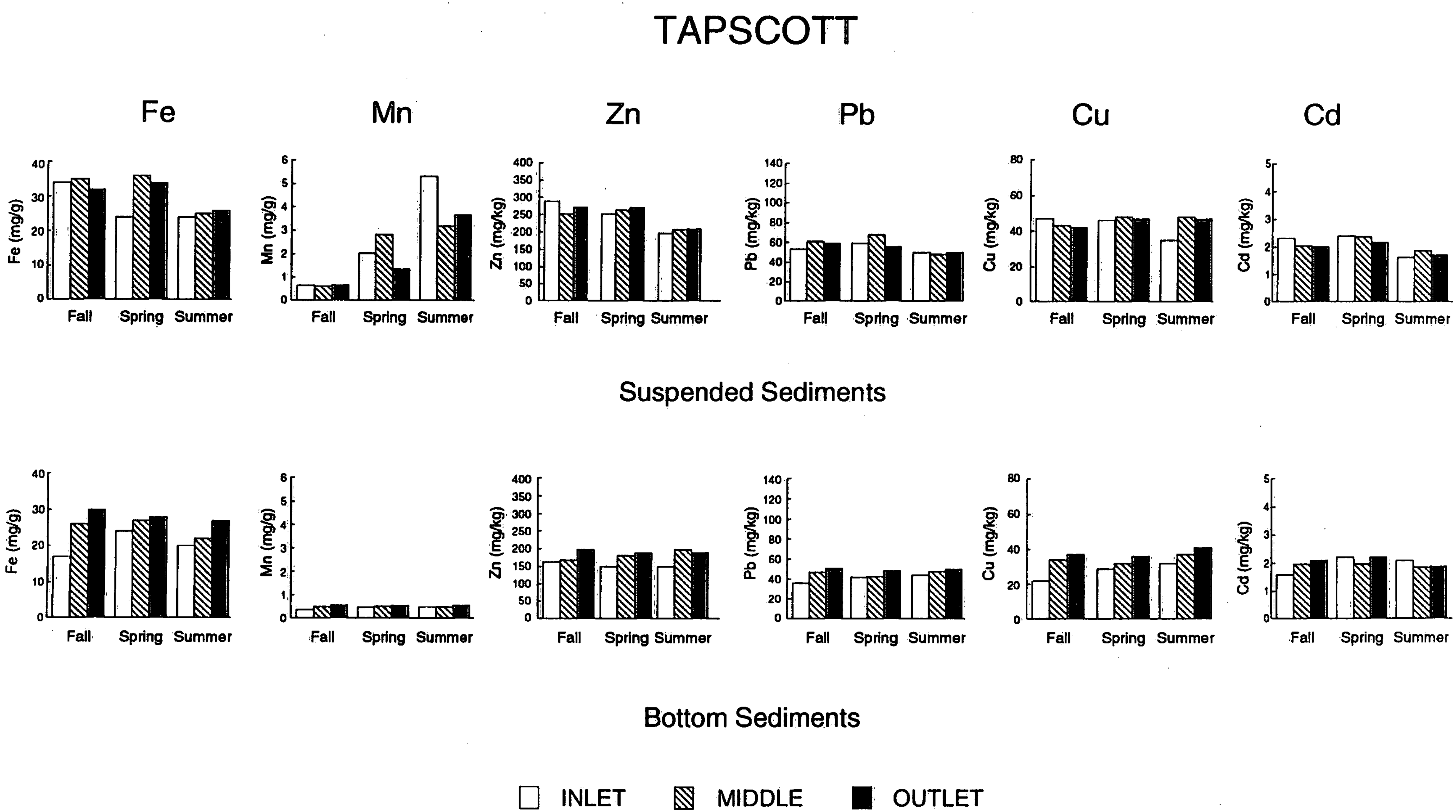
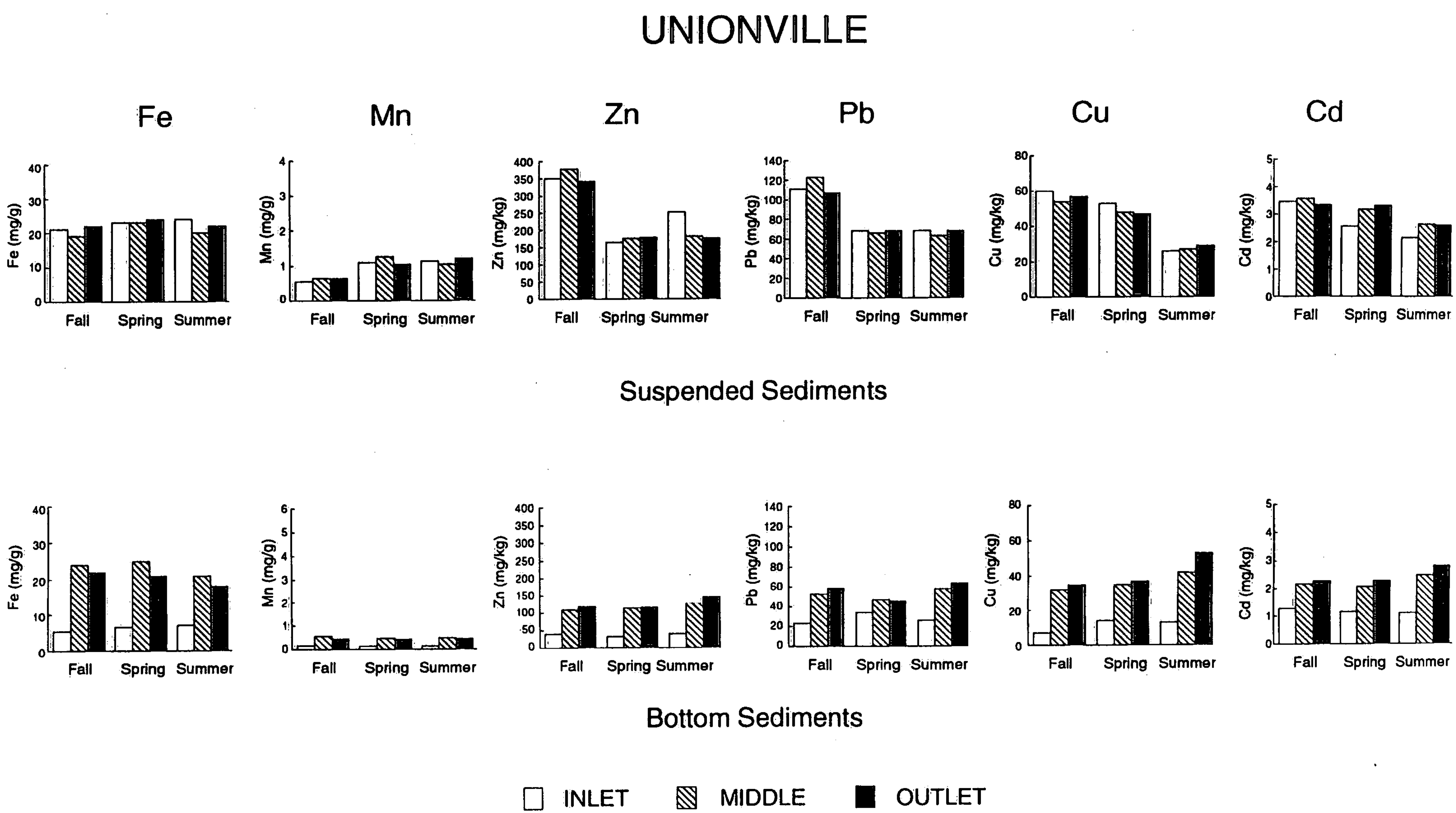

TAPSCOTT
Fe
Mn
Zn
Pb
Cu
Cd
Fe (mg/g)
Mn (mg/g)
Zn (mg/kg)
Pb (mg/kg)
Cu (mg/kg)
Cd (mg/kg)
Fall
Spring
Summer
Suspended Sediments
Bottom Sediments
INLET
MIDDLE
OUTLET

Fig. 4



UNIONVILLE
Fe
Mn
Zn
Pb
Cu
Cd
Fe (mg/g)
Mn (mg/g)
Zn (mg/kg)
Pb (mg/kg)
Cu (mg/kg)
Cd (mg/kg)
Fall
Spring
Summer
Suspended Sediments
Bottom Sediments
INLET
MIDDLE
OUTLET

Fig. 5

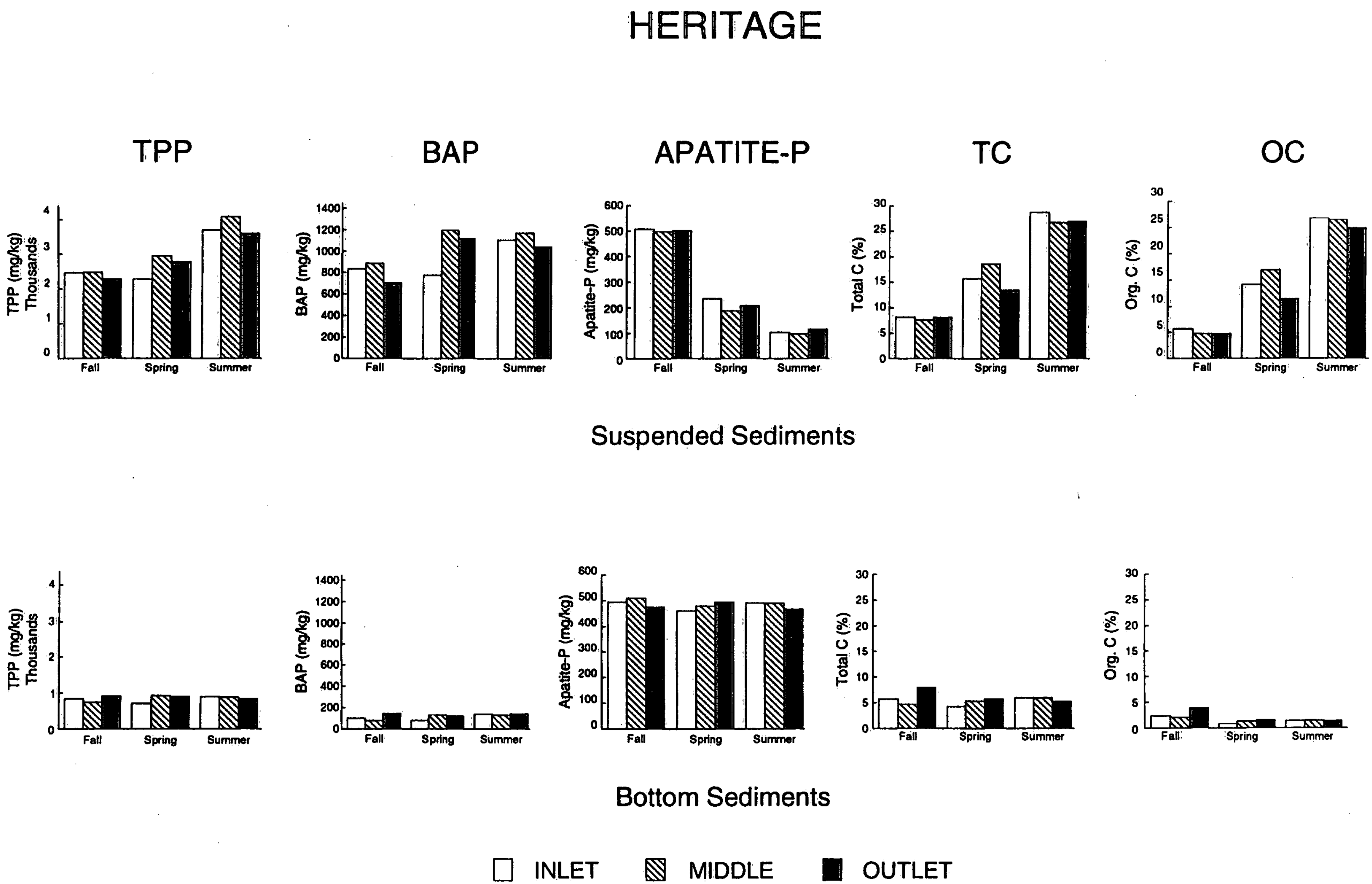

HERITAGE
TPP
BAP
APATITE-P
TC
OC
TPP (mg/kg) Thousands
BAP (mg/kg)
Apatite-P (mg/kg)
Total C (%)
Org. C (%)
Fall
Spring
Summer
Suspended Sediments
Bottom Sediments
INLET
MIDDLE
OUTLET

Fig. 6

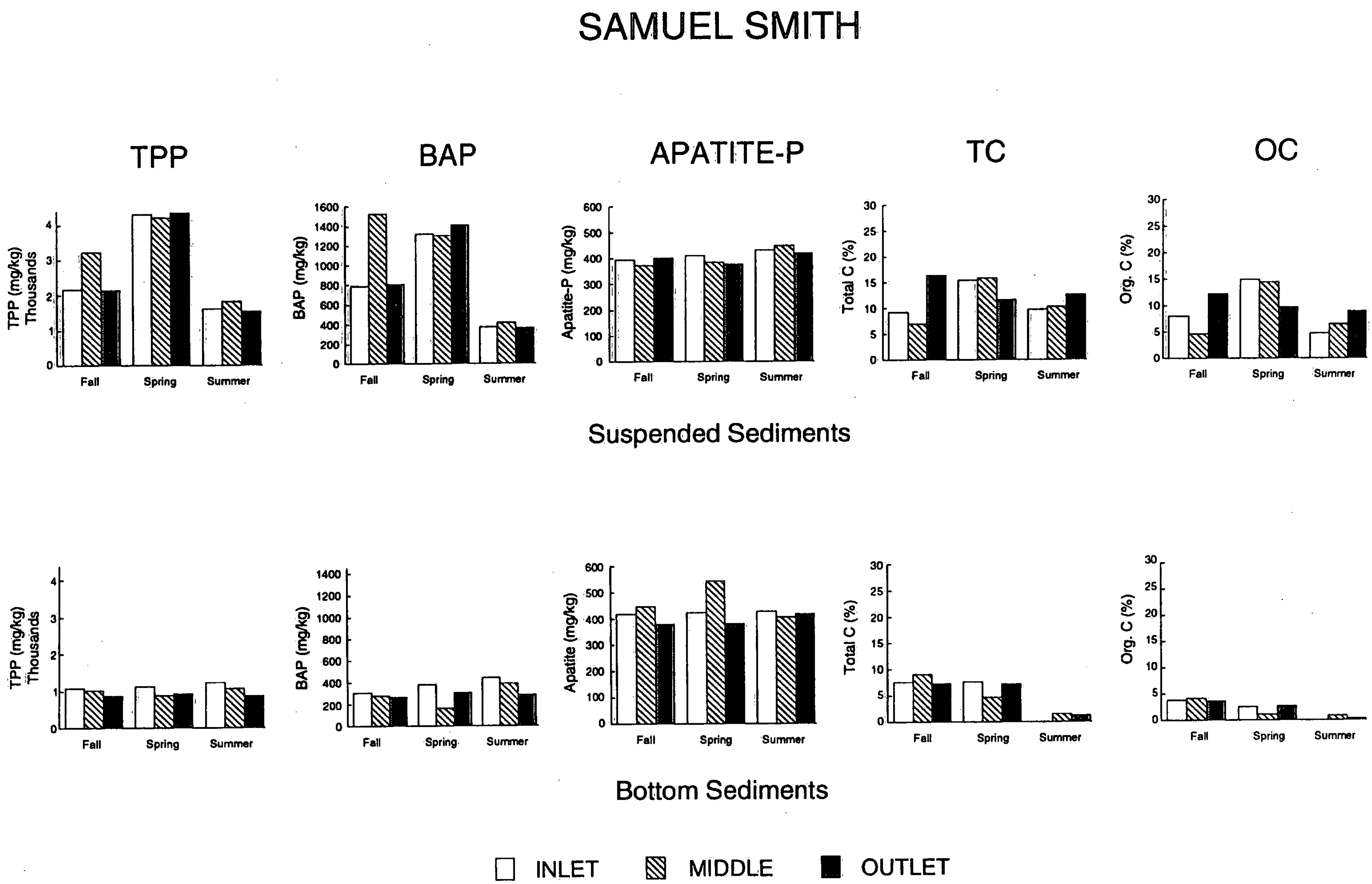

SAMUEL SMITH
TPP
BAP
APATITE-P
TC
OC
TPP (mg/kg) Thousands
BAP (mg/kg)
Apatite-P (mg/kg)
Total C (%)
Org. C (%)
Fall
Spring
Summer
Suspended Sediments
TPP (mg/kg) Thousands
BAP (mg/kg)
Apatite (mg/kg)
Total C (%)
Org. C (%)
Fall
Spring
Summer
Bottom Sediments
INLET
MIDDLE
OUTLET

Fig. 7

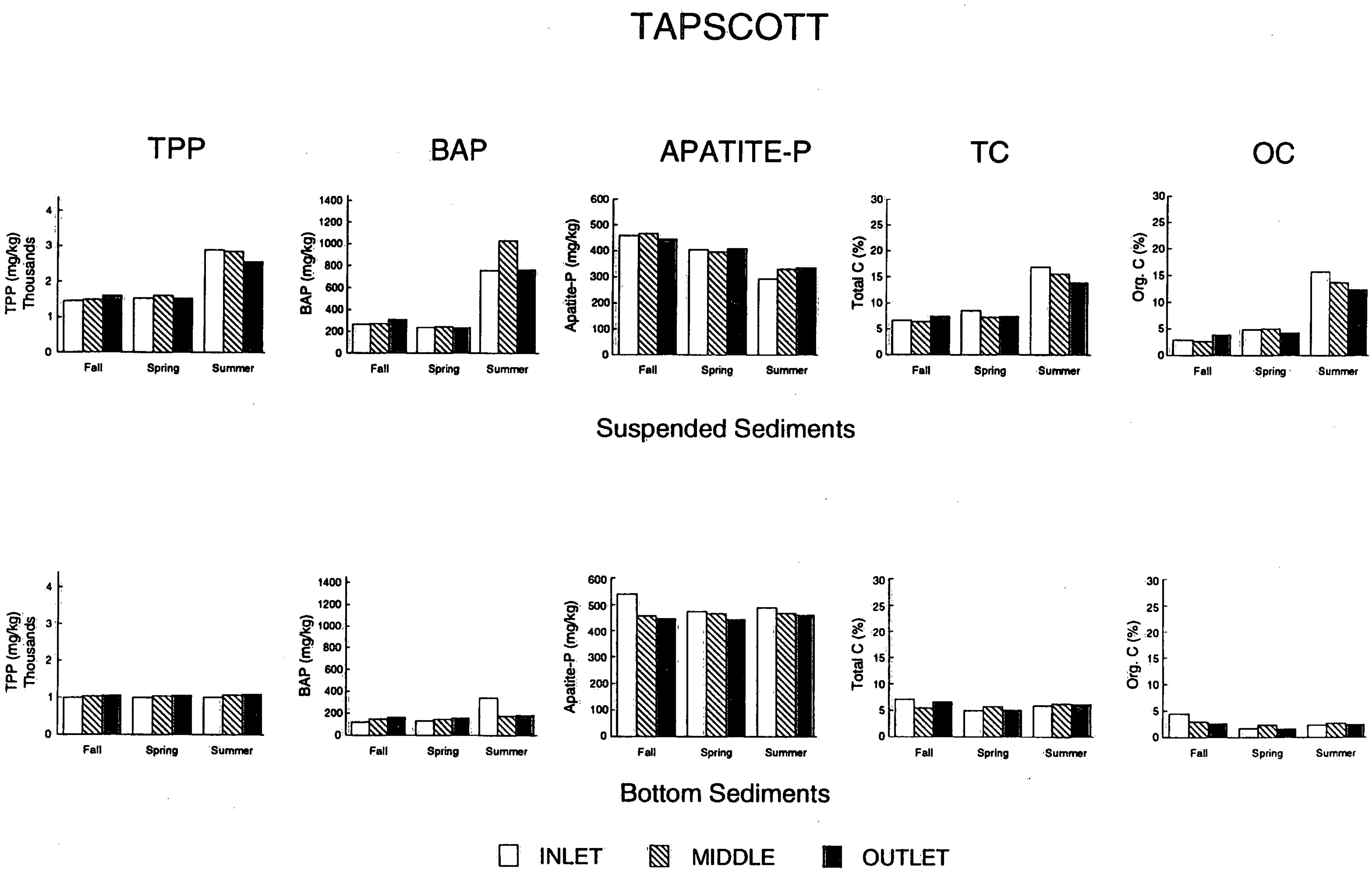

TAPSCOTT
TPP
BAP
APATITE-P
TC
OC
TPP (mg/kg) Thousands
BAP (mg/kg)
Apatite-P (mg/kg)
Total C (%)
Org. C (%)
Fall
Spring
Summer
Suspended Sediments
Bottom Sediments
INLET
MIDDLE
OUTLET

Fig. 8

UNIONVILLE

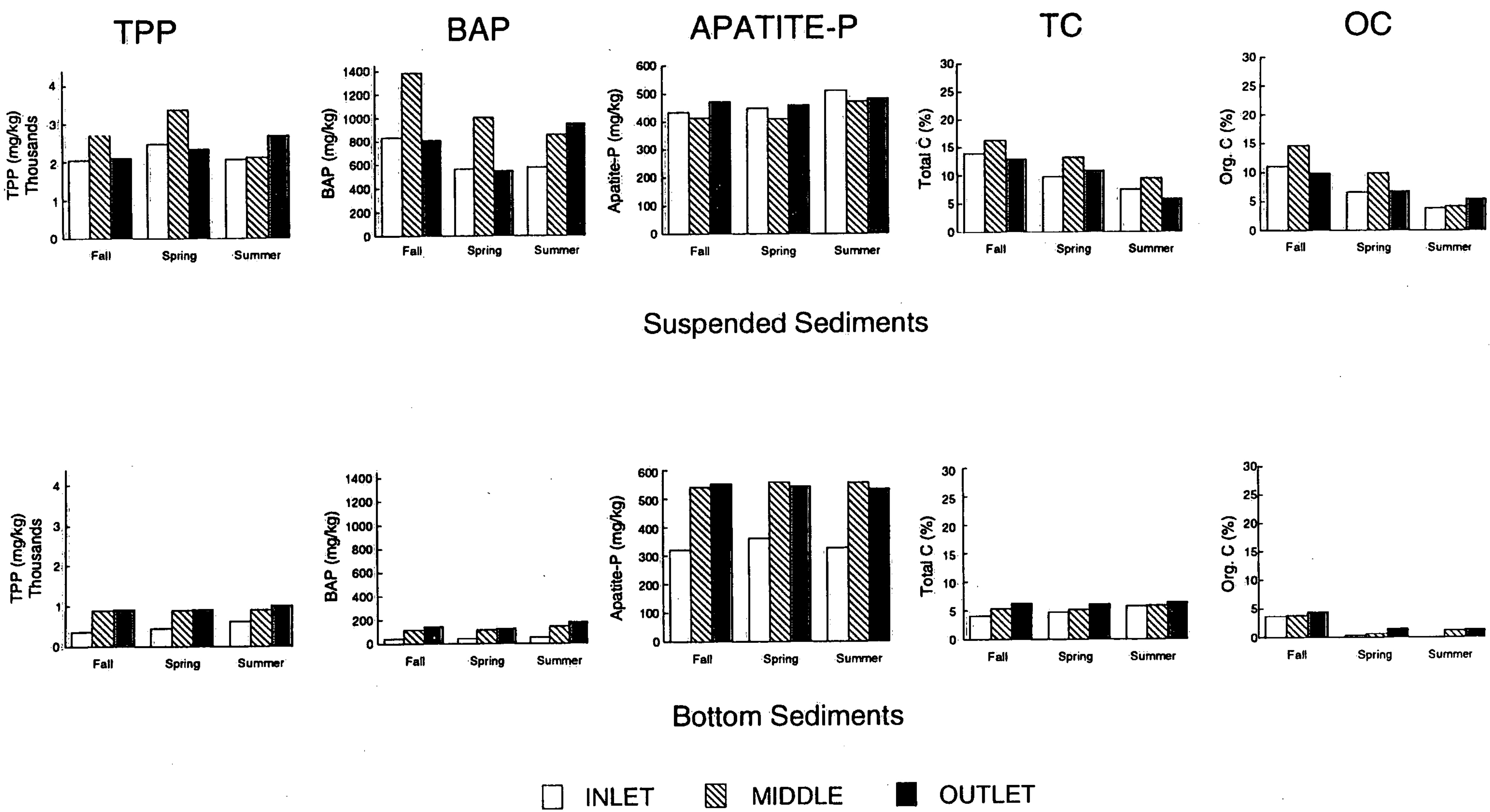


Fig. 9

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