

Ionic Inputs To Onondaga Lake: Origins, Character, and Changes¹

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ABSTRACT

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The origins and loadings of Cl⁻, Na⁺, and Ca²⁺ to ionically polluted Onondaga Lake, NY, are determined based on monitoring data collected for surface inflows over the 1973-1993 interval. The analysis delineates for lake managers the central role a chemical company has played in the loading of these constituents to the lake and the resulting ionic enrichment of the lake. The recurring, but disparate, ratios of Cl⁻, Na⁺, and Ca²⁺ concentrations maintained in the two largest tributaries to the lake depict contrasting industrial and geologic origins of these constituents. Concentrations of the three ionic species are inversely related to flow in these tributaries. The average annual combined loading of Cl⁻, Na⁺, and Ca²⁺ to the lake over the last 12 y of operation of the chemical plant was 1.2 million metric tons. The plant closed in 1986, and by 1989 the annual loads of Cl⁻, Na⁺, and Ca²⁺ had decreased by about 79, 67, and 70% respectively. The residual annual input of the ionic waste in 1989, from the area of the most recently abandoned waste beds, was about 12% of the pre-closure load.

Key Words: ionic pollution, chloride, sodium, calcium, industry, loads, tributary.

Onondaga Lake (e.g., Dean and Eggleston 1984, Driscoll et al. 1994, Effler 1987, Effler and Owens 1996, Madsen et al. 1996, Rowell 1996, Siegfried et al. 1996) and adjoining portions of the Seneca river, (e.g., Canale et al. 1995, Effler 1987, Effler et al. 1984) that receives the lake's outflow (Fig. 1), have been profoundly impacted by enrichment with Cl⁻, Na⁺, and Ca²⁺. These impacts are consistent with the fundamental role major ion chemistry is known to play in regulating thermodynamic properties such as density (Chen and Millero 1977), and the precipitation of certain minerals (e.g., Jones and Bowser 1978), the occurrence of various biochemical processes (e.g., Westrich and Berner 1984), and the composition of biological communities (e.g., Remane and Schieper 1971). From a lake management perspective, it is essential to resolve the contributions of anthropogenic inputs to this ionic enrichment to assign responsibility and guide related remediation efforts.

This study used surface inflow data for the 1973-

1993 interval to quantify the inputs of Cl⁻, Na⁺, and Ca²⁺ from lake tributaries and a chemical plant. Loading calculations and distinctive ionic signatures of geologic and anthropogenic sources allowed us to unequivocally assign inputs of these ions to their sources. Relationships between stream concentrations and flow were delineated as part of the development of loads. Changes in these relationships and loads brought about by the closure of the chemical plant are documented. An accompanying manuscript (Effler and Owens 1996) documents the differences in density between the major inflows and the lake and related impacts on the lake's stratification regime.

Study System

Sodium chloride brines were found around the southeastern shore of Onondaga Lake (Fig. 1) in colonial times, and were largely responsible for the early growth of Syracuse (Effler and Hennigan 1996).

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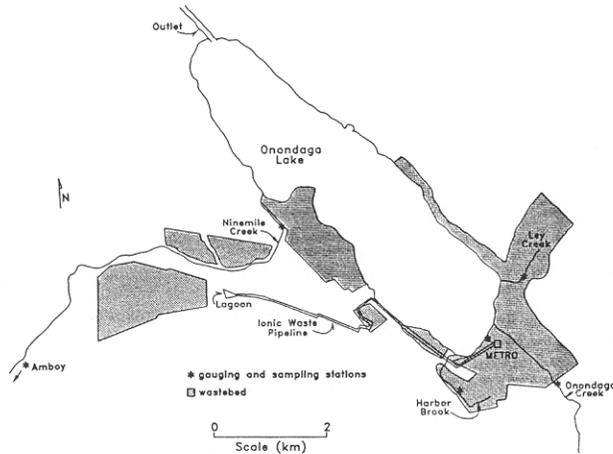


Figure 1.—Onondaga Lake, selected tributaries, and location of Solvay waste beds.

The brines originated from dissolution of NaCl deposits located in the upper portion of Onondaga Creek's watershed (Fig. 1). The use of NaCl brine from the natural salt springs adjoining the lake by a soda ash manufacturer (Solvay process) commenced in 1884. In the late 1880s the salt springs were traced 36 km southward to the Tully Valley, where salt beds were found at depths ranging from 335 to 427 m below the valley floor and in layers up to 31 m thick (Tully 1985). Brines continue to be found adjoining Onondaga Lake (Higgins 1955, Perkins and Romanowicz 1996). Salt brine from the Syracuse Formation was continuously solution mined (at variable rates) from the Tully Valley from 1889 to 1988. Geologic evidence indicates that natural sources of brine in the Ninemile Creek watershed (Fig. 1) are limited to reaches north of Amboy (Perkins and Romanowicz 1996), and it is unlikely that significant natural Cl loading to the stream occurs south of Amboy. Ninemile Creek becomes a "gaining" stream (i.e., receives groundwater inputs) near the waste beds (Blasland & Bouck 1989; Fig. 1).

The setting, tributary hydrology and salient features of the history of pollution of Onondaga Lake, including a description of the operation and waste production of

the adjoining soda ash/chlor-alkali facility, were described by Effler and Hennigan (1996) in this issue. Over the 1944 to mid-May 1981 interval, ionic waste from soda ash production, composed mostly of Cl⁻, Na⁺, and Ca²⁺, entered Ninemile Creek (and subsequently the lake) from Solvay wastebeds (Fig. 1). Starting in May 1981, a portion of this waste was diverted to the Metropolitan Sewage Treatment Plant (METRO), 4.6 km to the southeast (Fig. 1), to affect precipitation of phosphorus (tertiary treatment). The volume of ionic waste diverted from the soda ash/chlor-alkali facility's waste lagoon (Fig. 1) to METRO over the 1981-1990 period was highly dynamic (Fig. 2). The diversion was not temporally uniform before closure of the facility in early 1986 (Fig. 2; particularly during the first 2.5 y), largely as a result of operating problems at METRO caused by the reception of the ionic waste. METRO has continued to receive the ionic waste, albeit in smaller quantities, following closure of the industry (Fig. 2), because the lagoon (Fig. 1) continues to fill.

Chemical analyses of the ionic waste leaving the wastebeds reported in three different studies indicate that ratios of the three principal ions were constant (Table 1), thereby providing a signature of this source. The variability of the signature implied by these limited observations is small; e.g., coefficient of variation (cv)

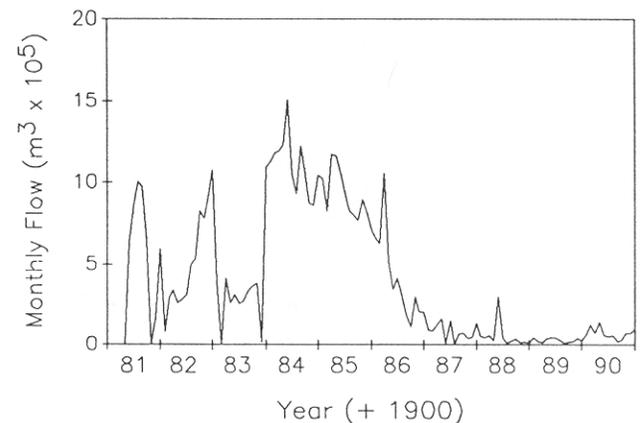


Figure 2.—Value of monthly discharge of ionic waste from the soda ash/chlor-alkali facility lagoon to METRO, 1981-1990.

Table 1.—Ion ratios (weight basis) for Solvay process waste bed overflow from published studies.

Ion Ratio	Ratio Values			x	cv
	(1)	(2)	(3)		
Na ⁺ /Ca ²⁺	0.45	0.55	0.61	0.54	0.15
Cl ⁻ /Na ⁺	5.34	4.88	4.35	4.86	0.10
Cl ⁻ /Ca ²⁺	2.43	2.69	2.67	2.60	0.06

(1) O'Brien & Gere 1969.

(2) USEPA 1974.

(3) Blasland & Bouck 1989.

Table 2—Average concentrations in the upper waters of Onondaga Lake in 1980 and 1989.

Constituent	Concentration	
	1980	1989
Cl ⁻ (mg/L)	1691	431
Na ⁺ (mg/L)	566	195
Ca ²⁺ (mg/L)	564	154
S (‰)	3.4	1.2

* data sources included Onondaga County (1981, 1990) and Effler (1995), for spring to fall interval.

values range from 0.06 to 0.15 for the three ratios (Table 1). Note that the Cl⁻/Na⁺ ratio of the Solvay Process waste (Table 1) differs greatly from that of a strictly NaCl brine (Cl⁻/Na⁺ (by weight) = 1.54).

Major decreases in lake concentrations of Cl⁻, Na⁺, and Ca²⁺ and salinity (S, ‰) occurred following the closure of the soda ash/chlor-alkali facility. Concentrations of Cl⁻, Na⁺, and Ca²⁺ were 75, 66, and 73% lower, respectively, in 1989, following closure; S was 65% lower (Table 2). These reductions establish that certain earlier analyses (O'Brien & Gere Engineers 1973, Rooney 1973) substantially underestimated the contribution of waste loadings from the soda ash/chlor-alkali facility to the lake's salinity during its operation (Doerr et al. 1994). Despite major decreases, Onondaga Lake remains ionically enriched compared to most other lakes (e.g., Hutchinson 1957, Wetzel 1983).

Methods

This analysis draws upon long-term (since 1973) monitoring data for tributary and waste discharge flow and ion (Cl⁻, Na⁺, and Ca²⁺) concentrations (Onondaga

County 1974-1990, United States Geological Survey 1974-1990), and several shorter term programs conducted by the authors (Fig. 1, Table 3). Inputs monitored include Onondaga Creek, Ninemile Creek, METRO, Ley Creek, and Harbor Brook (Fig. 1). All samples have been grab-type, except those from METRO, which have been 24 h flow-weighted composites since 1985.

Sodium and Ca²⁺ analyses were conducted by atomic absorption spectrophotometry. Chloride measurements by Onondaga County through 1980 were done by the AgNO₃ titration (APHA 1975) method. Thereafter, Cl⁻ measurements from the County program were made according to the automated ferricyanide (APHA 1980) method. All other Cl⁻ analyses (Table 3) were conducted by the Hg(NO₃)₂ titration (APHA 1980) method. Tributary temperature (T) was measured with a thermistor.

Analysis of ion ratios for the three primary inflows, Ninemile Creek, Onondaga Creek, and METRO, which together represent about 80% of total annual inflow to the lake (Effler and Hennigan 1996) was based on paired measurements of Cl⁻, Na⁺, and Ca²⁺ performed by Onondaga County (1974-1990). These data were screened before inclusion in the ratio analysis. Only paired data which met the criterion of charge balance within 10% (including all major ions) were included in the analysis. This rather stringent requirement significantly reduced the size of the data sets for these inflows; e.g., 41% of the Ninemile Creek, and 26% of the Onondaga Creek, paired observations did not meet the requirement.

Annual loading estimates for Cl⁻ (presented previously by Doerr et al. (1994)), Na⁺ and Ca²⁺, are based on daily estimates developed for each of the routinely monitored inputs (see Table 3) using FLUX (version 4.4, 1990), a loading analysis software package developed by Walker (1987). Ninemile Creek loads for the 1974-1980 interval were corrected for cooling water

Table 3.—Features of data bases utilized in this work.

Description	Tributary/Input	Sampling Frequency	Period of Record	Source
Cl ⁻ , Na ⁺ , Ca ²⁺	*O, N, M, L, H	biweekly	Cl ⁻ , since 1973; Na ⁺ and Ca ²⁺ , since 1981	Onondaga County (1974-1990)
Cl ⁻	N	4/hr	April-Nov. 1980; April-June 1981	this work
Cl ⁻	N ⁺	1/d, 5d/wk	April 1989- Oct.	Effler et al. 1991
Cl ⁻	M	1/d	June/Oct. 1990	this work

* O, N, M, L, H - Onondaga Creek, Ninemile Creek, METRO, Ley Creek, Harbor Brook.

+ includes paired measurements for regular station and Amboy (upstream, Figure 1).

recycle inputs (note this input was located downstream of the waste bed discharge, Fig. 1), to reflect "net" loading to the lake from this tributary. Flow-concentration relationships, for tributary/year combinations in which the relationships were strong, were used to support loading estimates, according to features available in FLUX. In other cases, the time interpolation option of FLUX was used to estimate loads. Annual loading estimates for Na^+ and Ca^{2+}

reported by Onondaga County (1974-1980) for the 1974-1979 interval have been used to fill gaps in the original data. Onondaga County calculated the annual loads for each input as the simple mean of the daily loads (product of concentration from grab sample and daily flow); the most rudimentary procedure supported by FLUX. However, results presented subsequently support the use of the County's estimates to fill gaps.

Estimates of the continuing contribution of ionic

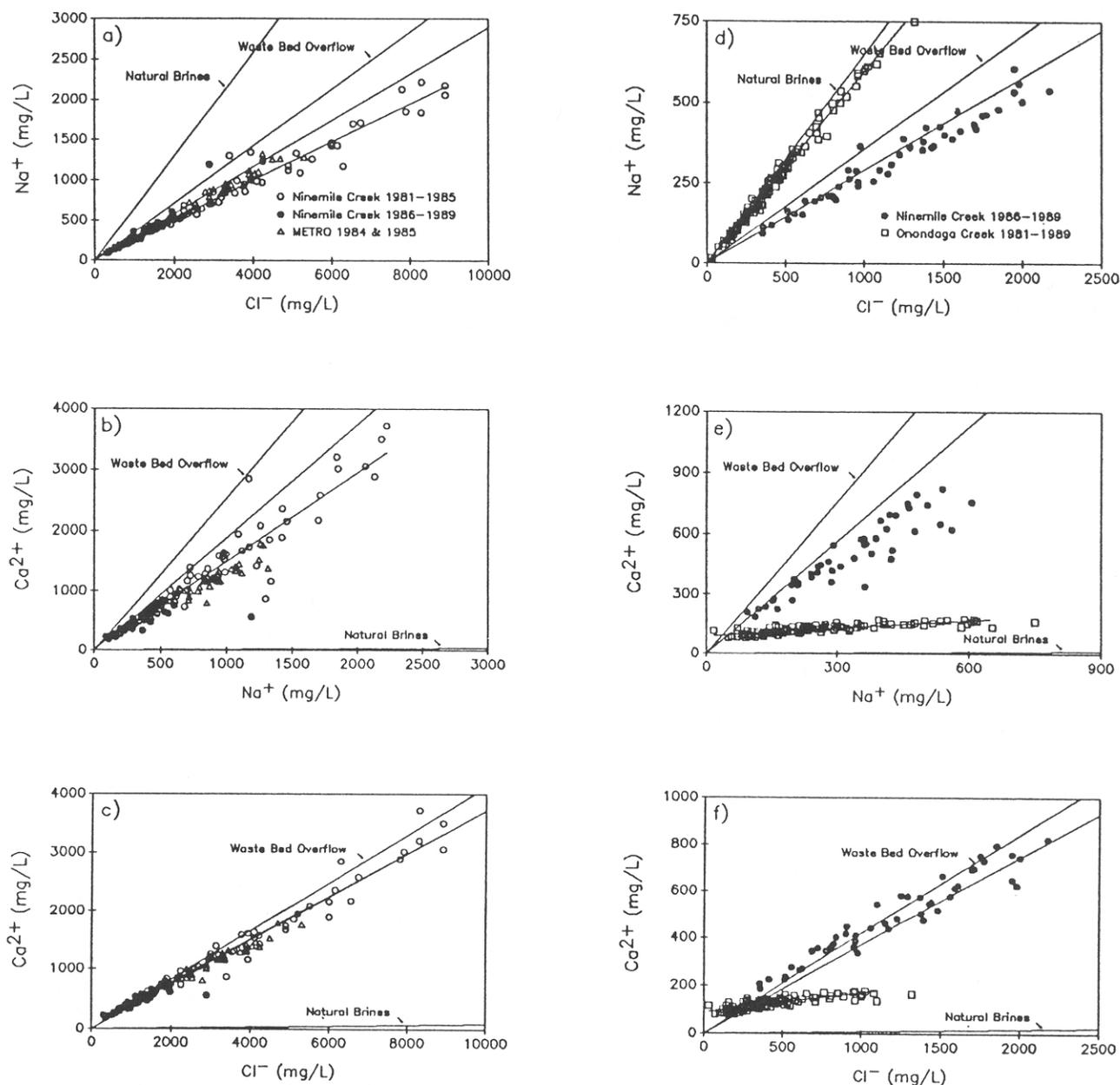


Figure 3.—Relationships between concentrations of major ions in selected inflows to Onondaga Lake: (a) Na^+ versus Cl^- , Ninemile Creek and METRO, (b) Ca^{2+} versus Na^+ , Ninemile Creek and METRO, (c) Ca^{2+} versus Cl^- , Ninemile Creek and METRO, (d) Na^+ versus Cl^- , Ninemile Creek and Onondaga Creek, (e) Ca^{2+} versus Na^+ , Ninemile Creek and Onondaga Creek, and (f) Ca^{2+} versus Cl^- , Ninemile Creek and Onondaga Creek. With ratios (lines) corresponding to NaCl and waste bed overflow, for reference.

waste from soda ash production to ionic loading for the post-closure period were developed from data bases described and findings presented herein, and from concentrations reported for the Amboysite (upstream, Fig. 1) on Ninemile Creek. The ionic waste contribution from Ninemile Creek is calculated as the difference between the downstream and upstream loads. The upstream, or background, load is calculated as the product of the average (relatively invariant) concentrations (values of 54 mg/L for Cl^- ($n = 155$; Effler et al. 1991), 20 mg/L for Na^+ ($n = 13$; unpublished data from New York State Department of Environmental Conservation (NYSDEC)), and 151 mg/L for Ca^{2+} ($n = 12$; unpublished data from NYSDEC)) and daily flow. Daily flow at Amboy was estimated from the downstream gauge values according to the protocol described by Effler et al. (1991). Calculations are based on the temporally intensive data set of 1989/1990. Contributions of ionic waste to the METRO loads were based on daily observations of Cl^- concentration over a 5-month period reported here. The background, or non-ionic waste, component of the Cl^- load from METRO was estimated as the product of the average Cl^- concentration for days on which no input from the waste lagoon (Fig. 1) was received (167 mg/L) and daily flow. The ionic waste (i.e., from soda ash production) contribution was calculated as the residual of the total and background loads. The ionic waste contributions to the METRO Na^+ and Ca^{2+} loads were calculated according to the established waste bed ion ratios (Table 1).

Ion Ratio Signatures

Concentrations of Cl^- , Na^+ , and Ca^{2+} in Ninemile Creek (downstream of the waste beds), Onondaga Creek (near its mouth), and the METRO effluent have been strongly inter-related (Fig. 3a-f). Conditions in Ninemile Creek before closure of the industry are represented by data collected over the 1981-1985 interval (Fig. 3). Post-closure conditions are reflected by observations for the 1986-1989 period (Fig. 3). Effluent characteristics of METRO during the interval of ionic waste diversion before closure are represented by data from 1984 and 1985 (Fig. 3a-c). Strong linear relationships (i.e., ion ratios) emerge for Ninemile Creek, Onondaga Creek and METRO (during period of ionic waste diversion) that represent reliable signatures of the origins of these constituents (Fig. 3).

The ion ratios in Ninemile Creek and METRO's effluent during ionic waste diversion have tracked closely the ratio values reported for the waste bed overflow (Fig. 3, Table 1). This establishes the dominant

role this waste has played in the loadings from these inflows. The maintenance of these ratios in Ninemile Creek following the closure of the facility, despite the reductions in concentrations (Fig. 3), establishes the continuing ionic-waste origins of these constituents in this stream. Apparently the ionic waste has continued to enter the stream following closure as leachate from the waste beds and/or as polluted ground water (e.g., Doerr et al. 1994). In sharp contrast, the relationship between Na^+ and Cl^- in Onondaga Creek (Fig. 3d) reflects NaCl brine origins for these constituents within the tributary's watershed. This is consistent with the hydrogeologic setting of this stream (Perkins and Romanowicz 1996). The Ca^{2+} relationships for Onondaga Creek are more variable (Fig. 3e and f), because of uncoupled (e.g., geographically separated) inputs from limestone and gypsum deposits. Note that higher concentrations of Cl^- and Ca^{2+} continued to occur in Ninemile Creek compared to Onondaga Creek following closure of the facility (Fig. 3d-f).

Tributary Cl^- Concentrations: Flow and Time Relationships

Ninemile Creek

Wide variations in Cl^- concentrations have been observed in Ninemile Creek downstream of the wastebeds, mostly in response to the dynamics of stream flow. Concentrations are generally higher at lower stream flows. Various concentration-flow relationships (e.g., Walker 1987) were evaluated. The strongest relationships, for both before diversion of the ionic waste to METRO (i.e., before closure) and following closure, are in the form of plots of concentration versus

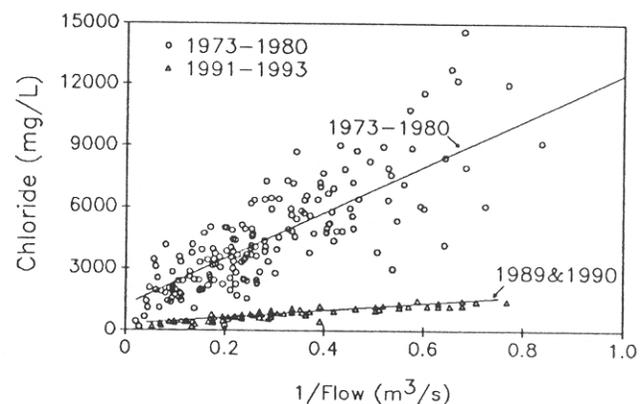


Figure 4.—Relationship between Cl^- concentration and flow in Ninemile Creek for differing periods; 1973-1980 (observations and best fit line), 1989/1990 (best fit line), and 1991-1993 (observations).

inverse flow (Fig. 4). The linearity of the relationships (Fig. 4) is consistent with a "dilution model", that is generally applicable for systems that receive localized continuous inputs such as wastewater discharges and enriched groundwater seeps (Manczak and Florczyk 1974). The relationship between Cl⁻ concentration and flow for the 1973-1980 interval is

$$[\text{Cl}^-] = 11234 Q^{-1} + 1241, R^2 = 0.64 \quad (1)$$

in which [Cl⁻] = the concentration of Cl⁻ (mg/L), and Q = stream flow (m³/s). The relationship for the 11 month period of 1989/1990 is

$$[\text{Cl}^-] = 1756 Q^{-1} + 288, R^2 = 0.81 \quad (2)$$

The pre-closure analysis (Fig. 4) is based on 176 bi-weekly observations over the 1973-1980 interval. The post-closure relationship for 1989/1990 is based on 156 observations. Originally, the 1989/1990 data were reported in a log-log format by Effler et al. (1991). More recent observations from bi-weekly monitoring over the 1991-1993 interval have been added for comparison (Fig. 4).

In-stream concentrations in Ninemile Creek decreased abruptly in May of 1981 with the diversion of a portion of the ionic waste to METRO (Fig. 1; Effler and Whitehead 1996). However, the relationship between Cl⁻ concentration and stream flow was much

more erratic over the 1981-1985 period because of irregular variations in volume of ionic waste diverted (e.g., Fig. 2). The major decreases in Cl⁻ concentration that occurred in Ninemile Creek in response to the closure of the soda ash/chlor-alkali facility are clearly depicted by the shift in the dilution model relationships (Fig. 4; e.g., from Equation (1) to Equation(2)). This form of comparison for pre- and post closure conditions is superior to comparing yearly average concentrations, because it normalizes the concentrations for stream flow, which demonstrates strong year-to-year variability in this region (Effler and Whitehead 1996).

The dilution model is markedly stronger for Cl⁻ in the creek following closure of the facility, implying the residual industrial input is more constant in character than discharges before closure. This is probably attributable to temporal variations in both the operation of the waste beds and production of waste during the period of production of soda ash. Interruptions in the discharge of ionic waste are apparent as abrupt changes in Cl⁻ concentration in the absence of changes in stream flow (e.g., observations from intense 1980 data set (Table 3)). The dilution model for 1989/1990 continues to accurately represent the "loading potential" for Ninemile Creek for the post-closure period, as the most recent stream observations (1991-1993) support the same relationship (Fig. 4). Thus there are no indications that the residual ionic waste loading to Ninemile Creek will decrease in the near (e.g., several years) future.

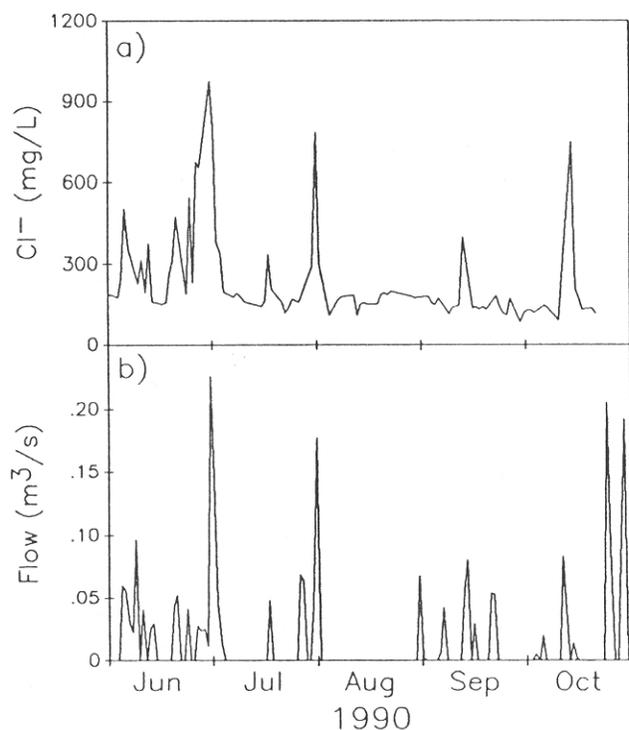


Figure 5.—Temporal distributions for METRO during the June-October period of 1990: (a) Cl⁻ concentration in the METRO effluent, and (b) flow of ionic waste from lagoon of soda ash/chlor-alkali facility to METRO.

Onondaga Creek and METRO

The dilution model is also a good representation of the relationship between Cl⁻ concentration and flow in Onondaga Creek. The best fit linear least squares regression fit for the 1973-1989 data base is

$$[\text{Cl}^-] = 696 Q^{-1} + 130, R^2 = 0.54 \quad (3)$$

in which [Cl⁻] = concentration of Cl⁻ (mg/L), and Q = stream flow (m³/s). This Cl⁻ (and Na⁺; Fig. 3) has mostly groundwater origins (e.g., Doerr et al. 1994, Perkins and Romanowicz 1996), and is received mostly in the lower portions of the watershed (Effler and Whitehead 1996).

Chloride concentrations in METRO's effluent have been highly variable since diversion of ionic waste to the municipal treatment facility. However, these variations largely reflect fluctuations in the quantity of ionic waste received from the soda ash/chlor-alkali facility (e.g., Fig. 2), rather than variations in the flow rate of METRO discharge. Reliable data are not available for METRO before diversion of the ionic waste; presumably concentrations were more uniform and

often lower in that period. Concentrations in the METRO effluent have decreased dramatically since the closure of the soda ash/chlor-alkali facility because of the major reduction in ionic waste received. The median concentrations for the 1981 to 1985 and 1986 to 1990 intervals were 2900 and 185 mg/L, respectively. Striking short-term variations in the Cl⁻ concentration in the METRO effluent occurred in a 5 mo period of 1990 (Table 3; Fig. 5a). The abrupt increases reflect the continuing irregular input of ionic waste from soda ash production (Fig. 5b; here as daily flow of ionic waste to METRO).

Annual Loading Rates

Recent History

Major decreases in total annual loading of Cl⁻, Na⁺, and Ca²⁺ to the lake resulted from closure of the soda ash/chlor-alkali facility in 1986 (Fig. 6a-c). Pronounced

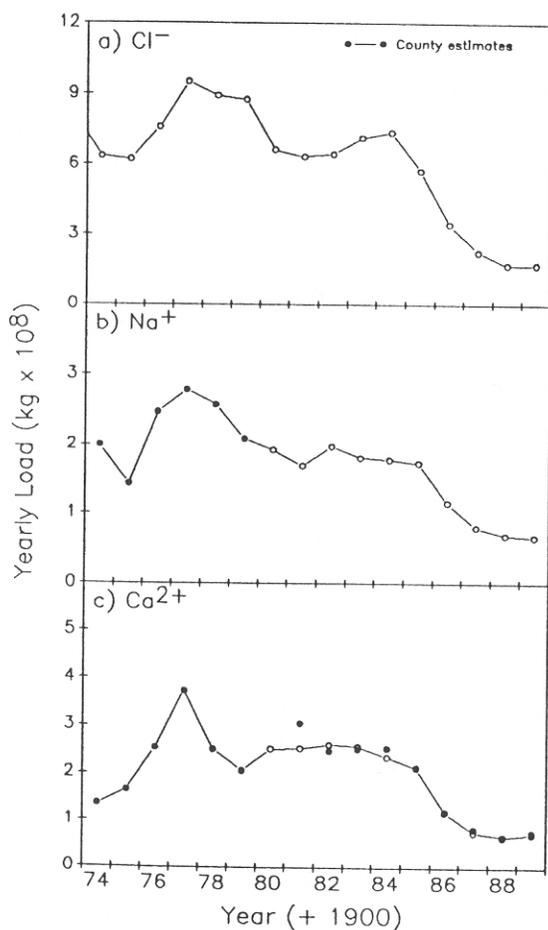


Figure 6.—Annual total loads of ionic species to Onondaga Lake, for the period 1974-1989: (a) Cl⁻, (b) Na⁺, and (c) Ca²⁺.

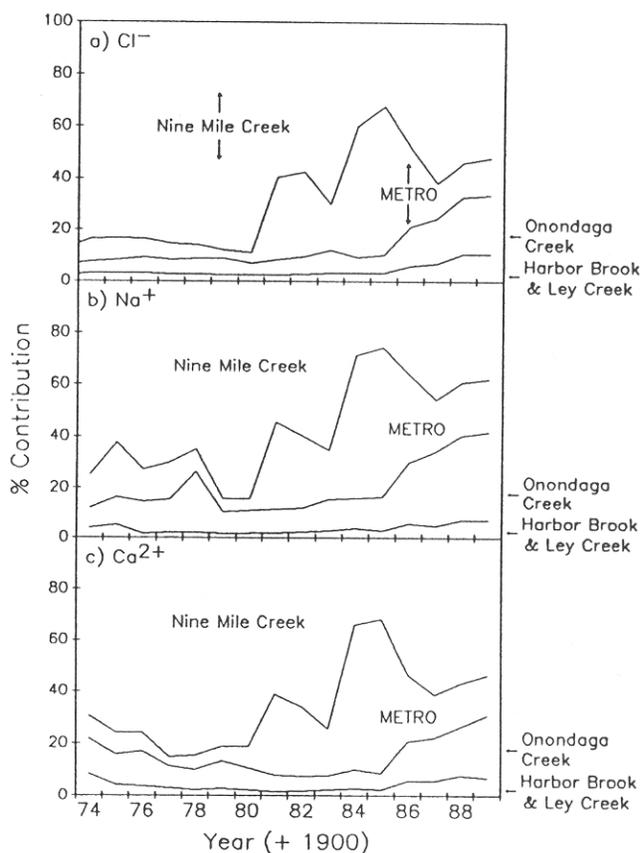


Figure 7.—Contributions (%) to the annual external load by various sources for 1974-1989: (a) Cl⁻, (b) Na⁺, and (c) Ca²⁺.

shifts in the contributions of the various sources to the total loading of Cl⁻, Na⁺, and Ca²⁺ resulted from diversion of ionic waste to METRO (starting in 1981) and the closure of the soda ash/chlor-alkali facility (Fig. 7a-c). These dynamics reflect the dominant role that discharge from the most recently formed Solvay waste beds (along Ninemile Creek) has played in the loading of these materials to the lake. Variations in the loading of these three constituents have tracked each other over the period of record. This is consistent with the dominant role of soda ash waste in this loading and the observed ion ratios (Fig. 3a-c). The variations in loading before closure were probably mostly due to variations in the production of the industrial waste.

The range of the combined annual loading of Cl⁻, Na⁺ and Ca²⁺ over the interval 1974-1985 was 9.5 - 16.4 x 10⁸ kg. The average over this 12 y period was 12 x 10⁸ kg, or 1.2 million metric tons. Over the 1974-1980 period, approximately 86, 71 and 78% of the annual loads of Cl⁻, Na⁺ and Ca²⁺ (respectively) that entered the lake came from Ninemile Creek. The diversion of the discharge (1981-1986) from the waste beds to METRO represented a major shift in the point of entry (Fig. 1), but did not result in a significant reduction in the

overall loading of these constituents to the lake (Fig. 6). Interannual differences in the relative contribution of Ninemile Creek and METRO during the period of diversion reflect variations in the quantity of ionic waste diverted to METRO (Fig. 2). For example, 90% of the variation in annual Cl⁻ load calculated for the period of diversion can be accounted for by interannual differences in the volume of ionic waste pumped to METRO.

The closure of the soda ash/chlor-alkali facility also altered the relative contributions of inputs to overall loading. Onondaga Creek's relative contribution increased with the closure of this facility (Fig. 7). Ninemile Creek remains the largest source of Cl⁻ and Ca²⁺ to the lake, while Ninemile Creek and Onondaga Creek make nearly equal contributions to the Na⁺ load. By 1989, the annual loading of Cl⁻, Na⁺, and Ca²⁺ to the lake had decreased by about 79, 67, and 70%, respectively, from the average documented for the 1974-1985 period. The decreases in lake concentrations since closure (Table 2) approximately match these reductions. This result is expected for the conservative ions, Cl⁻ and Na⁺, for this rapidly flushed (Effler and Hennigan 1996) lake, if all important sources have been accurately accommodated in the loading calculations. Doerr et al. (1994) have demonstrated, through their validation of a dynamic mass balance Cl⁻ model for the lake for the 1973-1991 period, that the lake Cl⁻ concentrations have been consistent with external loads. The near match in the relative reductions in external Ca²⁺ loading and lake Ca²⁺ concentration implies that the loss of this species to the lake sediments through CaCO₃ precipitation (Driscoll et al. 1994, Effler and Driscoll 1985) has been modest compared to the magnitude of the change in external loading.

Continuing Anthropogenic Contributions

The vast majority of the Cl⁻ and Na⁺ loads from Ninemile Creek are attributable to soda ash waste; this waste represents about 46% of that tributary's Ca²⁺ load (Table 4). The soda ash waste that continues to be received irregularly by METRO (Fig. 5b) represents about one-third of the load of each of these constituents discharged by METRO. The contribution of the continuing ionic waste inputs from soda ash production to the total loads is estimated to be 55, 42, and 30%, for Cl⁻, Na⁺, and Ca²⁺, respectively (Table 4). The residual annual loading rate of ionic waste from soda ash production in 1989 was about 0.14 million metric tons, or about 12% of the pre-closure (average for 1974-1985 interval) load. This is probably a conservative estimate of the continuing input of this ionic waste, as potential direct inputs from the other, older waste beds, bordering

Table 4—Contribution (%) of ionic waste from soda ash production to continuing (post-closure) loadings.

Ion	Ninemile Creek	METRO	Total Lake Load
Cl ⁻	94	33	55
Na ⁺	91	35	42
Ca ²⁺	46	33	30

the lake (Fig. 1, Effler and Hennigan 1996) have not been quantified. This continuing waste input is manifested in elevated levels of CaCO₃ precipitation (Driscoll et al. 1994), the degradation of the oxygen resources of the Seneca River (Canale et al. 1995), and lingering impacts on the lake's stratification/mixing regime (Effler and Owens 1996).

Other anthropogenic inputs of these ions, particularly Cl⁻ and Na⁺, enter Onondaga Lake. The contribution of NaCl de-icing operations from the City of Syracuse is minor with respect to the total loads (Fig. 6). The portion of the METRO input that is not waste from soda ash production (the remaining two-thirds of the load) is also largely anthropogenic. There is considerable debate with regards to the extent to which the Onondaga Creek loads are anthropogenic, and the well-established history of NaCl springs and the salt industry in the lowermost portions of this watershed proximate to the lake (see Doerr et al. 1994) adds to the confusion. Much of the Cl⁻ and Na⁺ loads carried by Onondaga Creek may be related to NaCl solution-mining by the soda ash/chlor-alkali facility in the upper portions of the watershed. However, additional hydrogeologic studies are necessary to establish this connection and partition quantitatively the relative contributions.

Management Perspectives

The vast majority of the loading of Cl⁻, Na⁺, and Ca²⁺ relieved by Onondaga Lake before 1986 was ionic waste from soda ash production. Thus this source was largely responsible for the impacts of ionic enrichment on the lake and the Seneca River during its operation. Residual inputs from soda ash production are a substantial fraction of the prevailing loadings of these constituents, thus making this industry responsible for continuing impacts on the lake and river. Remedial action should be considered to abate the residual load of this industry, as its magnitude has not diminished significantly in the interval since closure of the soda ash/chlor-alkali facility. Remediation should focus on the most recent waste beds along Ninemile Creek.

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