APPENDICES

APPENDIX A: MDOT DEICING SUR VEY QUESTIONS AND RESPONSES

1. ***Are you a licensed driver?*** Nearly all, 99.8 percent, of respondents answered yes.

What is your gender?

SAMPLE DISTRIBUTION BY SEX AND STATE AREA CODE				
SEX	UP-906	DET-313	517-616	TOTAL
Male	159 14.3%	178 16.0%	139 12.5%	476 43.0%
Female	209 18.7%	198 17.8%	232 20.8%	639 57.0%
TOTAL	368 33.0%	376 33.7%	371 33.3%	N=1115

2. *Into what age group do you fall?*

AGE GROUP DISTRIBUTION BY STATE AREA CODES				
AGE GROUP	UP-906	DET-313	517-616	TOTAL
18-25	41 11.2%	48 12.7%	49 13.2%	138 12.4%
26-40	112 30.5%	169 44.8%	99 26.8%	380 34.1%
41-55	92 25.1%	82 21.8%	92 24.9%	266 23.9%
Over 55	122 33.2%	78 20.7%	130 35.1%	330 29.6%

3a. ***Do you think that current use of road salt by Michigan Department of Transportation** results **in environmental problems?***

ROAD SALT CAUSES ENVIRONMENTAL PROBLEMS				
N=1116	**UP-906**	**DET-313**	**517-616**	**TOTAL**
YES	**185 50.3%**	**219 58.6%**	**167 45.0%**	**571 51.2%**
NO	**117 31.8%**	**81 21.7%**	**102 27.5%**	**303 27.2%**
DON'T KNOW	**66 17.9%**	**74 19.8%**	**102 27.5%**	**242 21.7%**

3b. *If yes, what do you think is the worst impact?*

WORST IMPACT OF ROAD SALT				
N=603	**UP-906**	**DET-313**	**517-616**	**TOTAL**
AUTO RUSTING	63 32.8%	86 36.0%	59 35.1%	208 34.5%
WATER POLLUTION	36 18.8%	71 29.7%	44 26.2%	151 25.0%
PLANT DAMAGE	14 7.3%	18 7.5%	15 8.9%	47 7.8%
ANIMAL HAZARD	3 1.6%	6 2.5%	5 3.0%	14 2.3%
DON'T KNOW	11 5.7%	14 5.9%	15 8.9%	40 7.3%
OTHER	65 33.9%	44 18.4%	30 17.9%	139 23.1%

4. *Should the department's use **of** road salt be:*

INCREASE OR DECREASE ROAD SALT USE				
N=1116	UP-906	DET-313	517-616	TOTAL
INCREASED	21 5.7%	25 6.6%	29 7.9%	75 6.7%
DECREASED	137 37.2%	152 40.3%	127 34.4%	416 37.3%
STAY THE SAME	152 41.3%	150 39.8%	118 32.0%	420 37.6%
DON'T KNOW	58 15.8%	50 13.3%	95 25.7%	203 18.4%

5a. *Should the **department** replace road salt with another material that is less harmful to the environment even **if** it costs more?*

REPLACE ROAD SALT WITH ANOTHER MATERIAL				
N=1115	UP-906	DET-313	517-616	TOTAL
YES	271 73.8%	246 65.3%	282 76.0%	799 71.7%
NO	51 1369	89 23.6%	49 13.2%	189 17.0%
DON'T KNOW	43 12.3%	42 11.1%	40 10.8%	127 11.4%

5b. *If yes, would you be willing to pay an additional ten cents per gallon of gas to pay for a higher costing alternative?*

WILLING TO PAY ADDITIONAL GAS TAX				
N=939	UP-906	DET-313	517-616	TOTAL
YES	134 48.0%	192 50.9%	131 46.3%	457 48.8%
NO	99 35.5%	152 40.3%	116 41.0%	367 39.2%
DON'T KNOW	46 16.5%	33 8.8%	36 12.7%	115 12.3%

6. *If the department stopped or reduced the use of road salt, would you accept the resulting icy or snow covered roads?*

ACCEPT ICY ROADS TO REDUCE USE OF ROAD SALT				
N=616	UP-906	DET-313	517-616	TOTAL
YES	59 29.9%	107 43.5%	74 42.8%	240 39.0%
NO	117 59.4%	124 50.4%	87 50.3%	328 53.2%
DON'T KNOW	21 10.7%	15 6.1%	12 6.9%	48 7.8%

7a. ***Do you own a car?***

DO YOU OWN A CAR				
N=1116	UP-906	DET-313	517-616	TOTAL
YES	356 96.7%	367 97.3%	359 95.6%	1082 97.0%
NO	12 3.3%	10 2.7%	12 4.4%	34 3.0%

7b. ***If yes, does rust damage cause you to trade in your car sooner than you would otherwise?***

DOES RUST DAMAGE FORCE YOU TO TRADE IN YOUR CAR				
N=1091	UP-906	DET-313	517-616	TOTAL
YES	142 39.3%	108 28.7%	117 32.6%	367 33.5%
NO	190 52.6%	249 66.2%	233 64.9%	672 61.3%
DON'T KNOW	29 8.0%	19 5.1%	9 2.5%	57 5.2%

8. ***Do you cut down the amount of driving you do when roads are snow covered or icy?***

REDUCE AMOUNT OF DRIVING WHEN ROADS ARE ICY				
N=1115	UP-906	DET-313	517-616	TOTAL
YES	247 66.0%	227 60.2%	255 68.5%	729 65.4%
NO	118 31.6%	145 38.5%	114 30.6%	377 33.8%
NO RESPONSE	9 2.4%	5 1.3%	3 0.8%	17 0.8%

9. ***Do you wait for the roads to be plowed and salted before you drive on them?***

DO YOU WAIT FOR ROADS TO BE PLOWED BEFORE DRIVING				
N=1116	UP-906	DET-313	517-616	TOTAL
YES	212 57.6%	184 48.8%	217 58.5%	613 54.9%
NO	139 37.8%	188 49.9%	151 40.7%	478 42.8%
NO RESPONSE	17 4.6%	5 1.3%	3 0.8%	25 2.2%

10. *For your usual work trip do you leave earlier when roads are snow covered or icy?*

LEAVE HOME EARLIER WHEN ROADS ARE SNOW COVERED				
N=1116	UP-906	DET-313	517-616	TOTAL
YES	223 60.6%	264 70.0%	226 60.9%	713 63.9%
NO	37 10.1%	82 21.8%	41 11.1%	160 3.7%
NO RESPONSE	108 29.3%	31 8.0%	104 28.0%	243 21.8%

11. *Have you ever had an accident that you believe to have been caused by snow or ice on the roadway?*

EVER HAVE AN ACCIDENT THAT WAS CAUSED BY SNOW OR ICE				
N=770	UP-906	DET-313	517-616	TOTAL
YES	73 26.1%	110 29.2%	79 41.1%	262 34.0%
NO	205 73.2%	265 70.3%	34 17.7%	504 65.5%
NO RESPONSE	2 0.7%	2 0.5%	79 41.1%	a3 10.8%

12. ***How many miles (approximately) do you drive during a winter week?***

HOW MANY MILES DO YOU DRIVE IN A WINTER WEEK				
N=1115	UP-906	DET-313	517-616	TOTAL
UNDER 50	123 33.5%	76 20.2%	115 31.0%	314 28.2%
50 - 100	109 29.7%	126 33.4%	124 33.4%	359 32.2%
101 - 300	89 24.3%	133 35.3%	97 26.1%	319 28.6%
301 - 500	22 6.0%	32 8.5%	19 5.1%	73 6.5%
OVER 500	24 6.5%	10 2.7%	16 4.3%	50 4.5%

APPENDIX B: SALT TOLERANCE OF SELECTED WOODY PLANTS

Common Name	Scientific Name	Tolerance Level and Reference*
	Deciduous Plants	
Alder, European Black	*Alnus glutinosa*	I(K)
Alder, Speckled	*Alnus rogosa*	I(K)
Alder, White	*Alnus incana*	I(K)
Ash, Blue	*Fraxinus quadrangulata*	*(K)
Ash, European	*Fraxinus excelsior*	T(K)
Ash, Green	*Fraxinus pennsylvanica*	T(K); I(H)
Ash, White	*Fraxinus americana*	T(K)
Baldcypress	*Taxodiwn distichum*	T(K)
Beech, American	*Fagus gmndifolia*	I(K)
Beech, European	*Fagussylvatica*	I(K)
Birch, European White	*Betula pendula*	*(K)
Birch, Gray	*Betulapopulifolia*	T(K)
Birch, Japanese Whitespire	*Betulaplatyphylla 'Whitespire'*	[illegible]
Birch, Paper	*Betula papyrifera*	T(K)
Birch, River	*Betula nigra*	*(K)
Birch, Yellow	*Betula alleghaniensis*	*(K)
Buckeye, Ohio	*Aesculus glabra*	[illegible]
Buckeye, Yellow	*Aesculus octandm*	*(K)
Buckthom, Common	*Rhamnus cathartica*	T(K)
Burningbush	*Euonymus alata*	*(L)
Butternut	*Juglans cinerea*	T(K)
Catalpa. Northern	Catalpa *speciosa*	*(K)
Catalpa. southern	*Catalpabignonioides*	*(K)
Cherry, Black	*Prunus serotina*	I(K)
Cherry, Pin	*Prunuspennsylvanica*	*(K)
Cherry, Choke	*Prunus virginiana*	*(K)
Chestnut American	*Castanea dentata*	*(K)
Chesmut Horse	*Aesculus hippocastanum*	*(L)
Coffeetree, Kentucky	*Gymnocladus dioicus*	*(K)
Corktree. Amur	*Phellodendron amurense*	*(K)
Crabapple	*Malus*	*(L)
Dogwood, Comeliancherty	*Cornus mas*	I(K)
Dogwood, Flowering	*Cornus florida*	*(K)
Dogwood Pagoda	*Cornus alternifolia*	*(K)
Elm, American	*Ulmus americana*	*(K)
Elm. Chinese	*Ulmus parvifolia*	*(K)
Elm, Red	*Ulmus rubra*	*(K)
Elm, Siberian	*Ulmus pumila*	T(K)
Filbert. European	*Corylus avellana*	I(K)
Filbert. Turkish	*Corylus colurna*	I(K)
Forsythia	*Forsythia X intermedia*	[illegible]

[1] T = Tolerant of salt; I = Intolerant of salt; . = Intermediate in tolerance or intolerance to either aerosol or soil-provided salt.
(H) = Hanes, 1976.
(K) = Kelsey, Hootman, 1992.
(L) = Lumis, et al., 1971.

Common Name	Scientific Name	Tolerance Level and Reference[1]
Ginkgo	*Ginkgo biloba*	*(K)
Hackberry, Common	*Celtis occidentalis*	I(K)
Hackbeny, Sugar	*Celtis laevigata*	I(K)
Hawthorn, Cockspur	*Cmtaegus crus-galli*	I(K)
Hawthorn, English	*Crataegus lacvigata*	I(K)
Hawthorn, Downy	*Crataegus X lavallei*	I(K)
Hawthorn. Dotted	*Crataegus punctata*	I(K)
Hawthorn, Lavalle	*Crataegus mollis*	I(K)
Hawthorn, Vaughn	*Cmtaegus Vaughn'*	I(K)
Hawthorn, Washington	*Cmtaegus phaenopyrum*	I(K)
Hawthorn. Winter King	*Cmtaegus viridis Winter King'*	I(K)
Hickory, Bittemut	*Carya cordiformis*	*(K)
Hickory, Shagbark	*Carya ovata*	*(K)
Honeylocust, Thornless	*Gleditsia triacanthos var.inermis*	T(K)
Honeysuckle	*Lonicera*	T(J)
Hornbeam, American	*Carpinus caroliniana*	I(K)
Hornbeam. European	*Carpinus betulus*	I(K)
Horsechestnut, Common	*Aesculus hippocastanum*	T(K)
Ironwood	*Ostrya virginiana*	*(K)
Katsuratree	*Cercidiphyllum japonicum*	*(K)
Larch, American	*Larix laricina*	I(K)
Larch. European	*Larix decidua*	T(K)
Lilac, Peking	*Syringa pekinensis*	T(K)
Linden, American	*Tilia americana*	I(K)
Linden. Littleleaf	*Tilia cordata*	I(K)
Locust, Black	*Robinia pseudoacacia*	T(K)
Magnolia, Cucumbertree	*Magnolia acuminata*	*(K)
Maple, Amur	*Acer ginnala*	*(K)
Maple, Black	*Acer nigrum*	I(K)
Maple. Boxelder	*Acer negundo*	*(K)
Maple, Freeman	*Acer X freemanii*	*(K)
Maple, Hedge	*Acer campestre*	T(K)
Maple, Japanese	*Acer palmatum*	*(K)
Maple, Miyabe	*Acer miyabei*	*(K)
Maple. Norway	*Acer platanoides*	T(K)
Maple. Paperbark	*Acer griseum*	*(K)
Maple, Purple-blow	*Acer truncatum*	*(K)
Maple. Red	*Acer rubrum*	I(K); *(L)
Maple, Silver	*Acer saccharinum*	T(K)
Maple. Sugar	*Acer saccharum*	I(K); T(L); *(H)
Mountainash, American	*Sorbus americana*	*(K)
Mountainash. European	*Sorbus aucuparia*	*(K)
Mountainash. Showy	*Sorbus decora*	T(K)
Mulberry, Red	*Morus rubra*	T(K)
Mulberry, White	*Morus alba*	T(K); I(L)

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(L) = Lumis, et 1.1971.

Common Name	**Scientific** Name	Tolerance Level **and Reference**[1]
Oak, Black	*Quercus velutina*	*(K)
Oak, Bur	*Quercus macrocarpa*	*(K)
Oak, Chinkapin	*Quercus muhlenbergii*	*(K)
Oak, English	*Quercus robur*	T(K)
Oak, Hill's	*Quercus ellipsoidalis*	*(K)
Oak, Pin	*Quercus palustris*	I(K)
oak, Post	*Quercus stellata*	*(K)
Oak, Red	*Quercus rubra*	I(K); T(L)
oak. Scarlet	*Quercus coccinea*	I(K)
Oak, Shingle	*Quercus imbricaria*	*(K)
Oak, Swamp White	*Quercus bicolor*	I(K)
Oak, White	*Quercus alba*	T(K)
Osage-orange	*Maclura pomifera*	*(K)
Pawpaw	*Asimina triloba*	*(K)
Pear, Callery	*Pyrus calleryana*	*(K)
Pecan	*Carya illinoensis*	*(K)
Persimmon, Common	*Diospyrus virginiana*	*(K)
Plum, Wild	*Prunus americana*	*(K)
Poplar, Bigtooth Aspen	*Populus grandidentata*	T(K)
Poplar, Cottonwood	*Populus deltoides*	T(K)
Poplar, Lombardy	*Populus nigra 'Italica'*	T(K)
Poplar, Quaking Aspen	*Populus tremuloides*	T(K)
Poplar, White or Silver	*Populus alba*	T(K)
Quince	*Cydonia oblonga*	*(L)
Redbud	*Cercis canadensis*	I(K); *(H)
Redwood, Dawn	*Metasequoia glyptostroboides*	I(K)
Russian-olive	*Elaegnus angustifolia*	T(K)
Sassafras, Common	*Sassafras albidum*	*(K)
Serviceberry, Apple	*Amelanchier X grandiflora*	*(K)
Serviceberry, Shadblow	*Amelanchier arborea*	*(K)
Serviceberry. Allegheny	*Amelanchier laevis*	*(K): I(L)
Sourgum	*Nyssa sylvatica*	*(K)
Staghom Sumac	*Rhus typhina*	T(L)
Sweetgum	*Liquidambar styraciflua*	*(K)
sycamore	*Platanus occidentalis*	*(K)
Tree of Heaven	*Ailanthus altissima*	T(K)
Tuliptree	*Liriodendron tulipifera*	I(K)
Viburnum. Blackhaw	*Viburnum prunifolium*	*(K)
Viburnum, Siebold	*Viburnum sieboldii*	*(K)
Walnut, Black	*Juglans nigra*	T(K)
Willow, Black	*Salix nigra*	T(K)
Willow, Corkscrew	*Salix matsudana 'Tortuosa'*	T(K)
Willow, Weeping	*Salix alba 'Tristis'*	T(K); *(L)
Willow, Pussy	*Salk discolor*	T(K)
Yellowwood	*Cladrastis lutea*	*(K)

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(H) = Hanes, 1976.
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(L) = Lumis, et al., 1971.

Common Name	Scientific Name	Tolerance Level and Reference[1]
	Evergreen Plants	
Arborvitae. White Cedar	*Thuja occidentalis*	I(K)
Douglasfir	*Pseudotsuga menziesii*	*(K)
Fir, White	*Abies concolor*	*(K)
Hemlock, Canadian	*Tsuga canadensis*	I(K)
Juniper. Eastern Redcedar	*Juniperus virginiana*	T(K)
Juniper, Rocky Mountain	*Juniperus scopulorum*	T(K)
Pine, Austrian	*Pinus nigra*	T(K)
Pine, Eastern White	*Pinus strobus*	I(K); *(H)
Pine, Jack	*Pinus banksiana*	T(K)
Pine, Ponderosa	*Pinus ponderosa*	*(K)
Pine, Red	*Pinus resinosa*	I(K)
Pine Scotch	*Pinus sylvestris*	I(K)
spruce, Colorado	*Picea pungens*	T(K)
Spruce, Blue Colorado	*Picea pungens var. glauca*	T(K)
Spruce. Norway	*Picea abies*	I(K): *(H)(L)
Spruce, White	*Picea glauca*	*(K)
Tamarack	*Larix laricina*	*(L)
Yew	*Taxus*	I(L)

SOURCES: R.E. Hanes, *Effects of De-icing Salts on Water Quality and Biota* (Washington. D.C.: Transportation Research Board National Research Council, 1976). P.D. Kelsey and R.G. Hootman, "Deicing Salt Dispersion and Effects on Vegetation Along Highways," in *Deicing Chemicals and the Environment*, ed. F.M. DItri (Chelsea, Mich: Lewis Press, 1992). G.P. Lumis et al., "Salt Damage to Roadside Plants," 1971, in P.H. Jones and B.A. Jeffrey, *Environmental Impact of Road Salting* (Toronto, Ont: Research and Development Branch, Ministry of Transportation. 1986).

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APPENDIX C: CHLORIDE IN THE GREAT LAKES

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Introduction

The purpose of this paper is to examine the potential impact of using road salt (halite, NaCl) to deice Michigan roads on chloride levels in the Great Lakes. This is of concern because the State of Michigan has the longest coast line of the Great Lakes states, most of the surface drainage from Michigan directly enters the Great Lakes and Michigan uses a significant amount of road salt. This problem was investigated examining historical trends (historical analysis) (e.g. Moll et al., 1992), projections of chloride levels in the lakes from the work of Sonzogni et al., (1983) (projection analysis), the effects on chloride levels in the Great Lakes if there is an increase in the use of road salts (sensitivity analysis), and the impact on chloride levels in the Great Lakes by directly adding to each lake the amount of road salt used by the MDOT and the entire state in one year (impacts analysis).

Historical Analysis

Chloride enters the Great Lakes from a variety of sources which includes industrial discharges, municipal discharges, natural weathering, atmospheric deposition, and runoff from road deicing (PLUAG, 1977). In addition, there is recent evidence that chloride might be added to Lake Ontario, possibly Saginaw Bay and Lake Huron by the direct discharge of saline formation water (Drimmie, 1992; Long et al., 1992). There is general agreement that the chloride levels have increased in the Great Lakes, but that each lake shows a different trend. Figure 1 shows the historical trends of chloride in the Great Lakes up to 1970 from the often cited work of Pringle et al., (1981).

Lake Superior - Chloride values in Lake Superior are the lowest of the Great Lakes. Concentrations are approximately 1 mg/L, appear to have remained relatively constant at this amount (Figure 1), and have been at this value for at least the past two hundred years (Moll et al., 1992).

Lake Michigan - Chloride values in Lake Michigan appear to have increased from concentrations around 3 mg/L in the 1870s to around 8 mg/L by 1980 (Figure 1). Figure 2 shows data for chloride levels in Lake Michigan from 1962 to 1986 (Moll et al., 1992). Moll et al. (1992) interpret these data to indicate an increase in chloride levels in Lake Michigan during this time period. Using least-squares regression they calculated a 0.11 mg/L/yr increase in chloride in the lake. When the data were analyzed as a function of season they found regression coefficients of 0.09 mg/L/yr and 0.07 mg/L/yr for spring and late summer, respectively. However, in all three calculations the R-squared values were less than 0.12. Thus, these recent trends which indicate a possible increase in chloride in Lake Michigan are statistically insignificant. Recent chloride levels are around 9 mg/L (Moll et al., 1992).

Lake Huron - Similar to Lake Superior, chloride concentrations in Lake Huron have been relatively constant. Concentrations have averaged 5.9 mg/L from 1956 to 1980. Current concentrations are considered to be around 5.5 mg/L (Sonzogni et al., 1983).

Lake Erie. Chloride levels in Lake Erie were around 10 mg/L prior to 1910 and rose to greater than 20 mg/L around 1950 (Figure 1). Recently, chloride levels have decreased in Lake Erie to around 20 mg/L (Whyte et al., 1990).

Lake Ontario - Similar to Lake Erie, chloride levels in Lake Ontario have increased significantly during the period 1890 to 1970 (Figure 1). Present values (1983) are around 25 mg/L (Sonzogni et al., 1983).

Projection Analysis

Sonzogni et al., (1983) examined chloride loads to the Great Lakes and concluded that road salt contributes an important proportion of anthropogenic chloride to the Great Lakes. But, they also concluded that even if all chloride applied to the Great Lakes watershed from road salt reached the lakes, the road salt would generally account for less than 35% of the total load for the lakes.

Based on the data available, Sonzogni et al. (1983) also concluded that the chloride input and output to the Great Lakes is not in steady state. Steady state is defined as the condition when input of a chemical component equals the output of the component for a particular system. Accordingly, they developed a chloride model for the Great Lakes to predict chloride concentrations in the Great Lakes when steady state is obtained. The model is a mass balance calculation based on the equation:

$$V\frac{dc}{dt} = \sum W - QC$$

where

C = in-lake average chloride concentration,
V = lake volume
ΣW = sum of all chloride loads, including those from upstream lakes,
Q = flow out of the lake, and
t = time

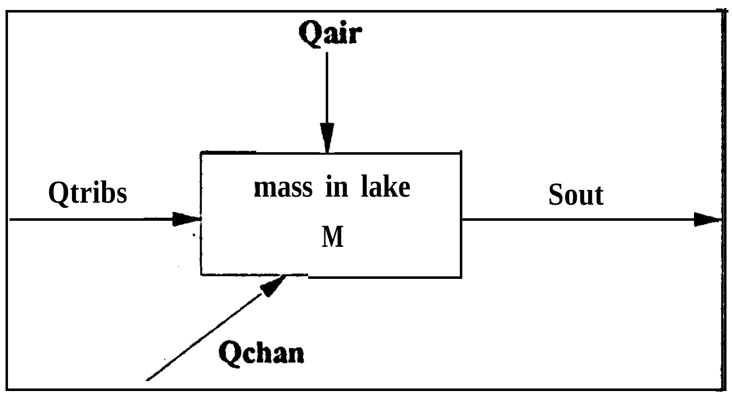
Details on this type of modeling are discussed in the next section. However, the results of their model are shown on Figure 3. The model begins in 1975 and steady state is approached around 2275. Concentrations at the steady state conditions are 4 mg/L (Lake Superior), 20 mg/L (Lake Michigan), 10 mg/L (Lake Huron), 25 mg/L (Lake Erie), and 30 mg/L (Lake Ontario).

Sensitivity Analysis

To estimate the effect of increasing the use of road salt on chloride levels in the Great Lakes, a mass balance for chloride in the Great Lakes system must be calculated first. The mass balance must consider the Great Lakes as an integrated system for the best results in the sensitivity analysis. QUATRO PRO for Windows was used for the analysis.

The mass balance is calculated on the assumption that chloride in the Great Lakes is a conservative chemical. A conservative chemical is one whose concentration is not affected by precipitation-dissolution reactions, oxidation-reduction reactions, adsorption-desorption reactions or biologic activities. For the Great Lakes ecosystems, this assumption is warranted for chloride.

The parameters needed in the mass balance calculations are shown on the illustration below.



These parameters need to be estimated with the best available data, because exact knowledge of the magnitude of the fluxes (Q and S) and the mass of chloride in the lakes (M) is not known. Since chloride is conservative, changes in its Q, S, and M values will follow that of changes in similar parameters of water. Therefore, the rates of exchange of chloride and mass of chloride in the lake are estimated from a mass balance of water in the Great Lakes. This mass balance is shown on Figure 4 and is taken from the data of Strachan and Eisenreich (1989). The mass of chloride (M) in the lakes will be a function of the volume of water and the concentration of chloride in the lake. Concentrations of chloride in the lakes were taken from the projected estimates of Sonzogni et al. (1983) at steady-state as listed above. At steady state $\Sigma Q = S$ and $dM/dt = 0$. That is, the inputs equal the outputs and there is no change in the mass of chloride in the lake. Therefore, the concentration of chloride in the lakes defines the concentration of chloride in water leaving the lake. Thus, the flux of chloride out of the lakes (Sout) can be calculated from the volume of water leaving the lake. Sout is then the basis for estimating the amount of chloride entering the lakes from connecting channels (Qchan).

Chloride added to the lake from air (Qair) is estimated from the amount of rain (Figure 4) and the concentrationof chloride in the rain for each lake. Concentrations of chloride in the rain were taken from the data of Bemer and Bemer (1988) and reflect regional variations. Relative to other sources for chloride to the lakes, Qair is small and errors in this estimate do not significantly affect the sensitivity calculations. The amount of chloride added to the lakes from tributaries (Qtribs.) is then calculated on the basis of steady state as Qtrib = Sout - Qair - Qchan.

The mass balance model for chloride in the Great Lakes is shown on Figure 5. From these data the turn-over time (τ) or the time it takes for a lake to adjust to changes in the input of a chemical can be calculated. Turn-over time is calculated from the equation $\tau = M/\Sigma Q$. Turn-over times for chloride in the Great Lakes are shown on the table below. Chloride and water. turn-over times are the same. Lake Erie has the fastest turn-over time and Lake Superior has the slowest. The combined turn-over time reflects the maximum time it takes for the whole Great Lakes system to respond to perturbations of the water or chloride cycles.

The rate constant (k) by which a lake will respond to a perturbation of the water or chloride cycle is defined as $1/\tau$. If Q is changed, the adjustment process of chloride in the lake is defined by:

$$\frac{dM}{dt} = Q_{new} - S = Q_{new} - kM$$

Turn-over times and rate constant for the Great Lakes				
Lake	τCl	τH_2O	k	$\tau Comb$
	. years	years	10^{-3}	years
Superior	**172**	172	5.81	172
Michigan	100	100	10	loo
Huron	20	20	50	192
Erie	2.3	2.3	435	194.3
Ontario	6.5	6.5	154	200.8

The solution to this equation with the initial condition M(t =0) = M o is:

$$M(t) = M_{new} - (M_{new} - Mo)\exp(-kt)$$

Thus, a lake approaches the new concentration of chloride (M_{new} . Q_{new}/k) at a rate k^{-1} or τ. The values of k from the table above and the equation for M-were used to calculate the new chloride concentrations in the lakes after various increases in Q.

The response of the lakes to increased inputs of chloride was examined by increasing Qtrib for each lake by **1%, 10%,** SO%, lOO%, and 200%. Therefore, the effect on chloride concentrations in each lake from increasing road salt use is estimated by increasing Qtrib for each lake by the above percentages. This is a worst case scenario in that chloride inputs from "road salt" may be greatly over estimated for the following reasons:

- The estimates for Qtribs for each lake considers all sources for chloride to a lake including additions from road salt. The exact proportion of chloride from road salt for each lake is unknown **(Sonzogni** et al., **1983),** but is generally believed to be less than 35% as discussed earlier. Thus, increasing road salt use by 50% would not increase Qtrib by the same amount. For example, increasing Qtrib by 100% simply because of increases in road salt use means that road salt use would need to be increased 5.7 times (based on the 35% estimate of the contribution of road salt to chloride in the Great Lakes) and not 1.5 times.

- Increases in Qtrib are calculated for all the lakes. In reality, Qtrib for Lake Ontario would not be affected by increasing road salt use in Michigan, only Qchan would be. Similarly, Qchan would change greater than Qtrib for Lake Erie because of changes in road salt use in Michigan. Little road salt is used in the Upper Peninsula of Michigan bordering Lake Superior. Increasing the use of road salt would probably have little effect on dissolved chloride in Lake Superior.

The results of the sensitivity analysis are shown on Figure 6. Chloride concentrations in the lakes follow the order Ontario > Erie > Michigan > Huron > Superior. Increasing Qtrib by 200% (9 fold increase in road salt used), for example, increases chloride levels in the lakes to 12 mg/L in Lake Superior to 90 mg/L in Lake Ontario.

Direct Addition Analysis

In this analysis, the effect on dissolved chloride concentrations in each lake is calculated by adding to each lake the amount of road salt used by the State of Michigan in one year. This simulation assumes that 100% of the road salt added to Michigan roads in one year goes directly into each lake in one year. Similar to the above calculations, it is a worst case scenario. The calculations overestimate the effect of road salt additions on the lakes because they do not take into account the relative amounts of the total salt that each lake receives. Rather, each lake receives total chloride from one year's use of road salt. Information on road salt usage for nine years is from the Michigan Department of Transportation. There are two types of data: one consists of salt usage on state trunklines within counties for the nine districts (Figure 7) and the second consists of the use of road salt on state trunklines within city limits (Figure 8). These data represent all road salt used by MDOT on state trunklines but does not capture salt used on county or city roads not on the state trunkline. For example, there are close to 120,000 miles of highway in the State of Michigan, and only approximately 8% or 10,000 of those miles fall under MDOT jurisdiction. The information on Figures 7 and 8 relates to that 8%. Therefore an estimate for the “state wide” use of road salt in a year was made by extrapolating the MDOT data to the 120,000 miles of highway. This estimate for state-wide use is probably an over estimate for the amount of salt used. (QUATRO PRO for Windows was again used for the calculations.) No data were available for municipal salt usage for 1983 and 1984. These values were taken as the average salt usage for the seven years that the data were available.

A simple regression analysis was performed on the MDOT data (Figure 9). There are no trends in the amount of municipal applications as a function of year. County applications shows an increasing trend. However, with an R-Squared value of 13.22% and a correlation coefficient of 0.36 this trend can be considered statistically insignificant. Total applications show a positive trend which is dictated by the county application rates. This trend (R-squared = 11.27% and correlation coefficient of 0.35) also can be considered statistically insignificant. Because of the lack of a discernible trend, the average total application rate for a nine year period was used in the calculations.

Figure 10 shows the results of the calculations for changes in chloride concentrations by the addition to the lakes of one year’s worth of road salt used by MDOT not accounting for the linkage effects from adjoining lakes. Also on the figure are the results of adding to the lakes the estimated total salt used by the State of Michigan in one year. Finally, for purposes of illustration, the results of calculations are shown for the addition to each lake of the total salt tonnage used in a nine year period (1983-1991).

The results show that except for the case of adding an estimated total of salt used by the state for nine years directly to each lake, chloride concentrations in the lakes are not significantly affected.

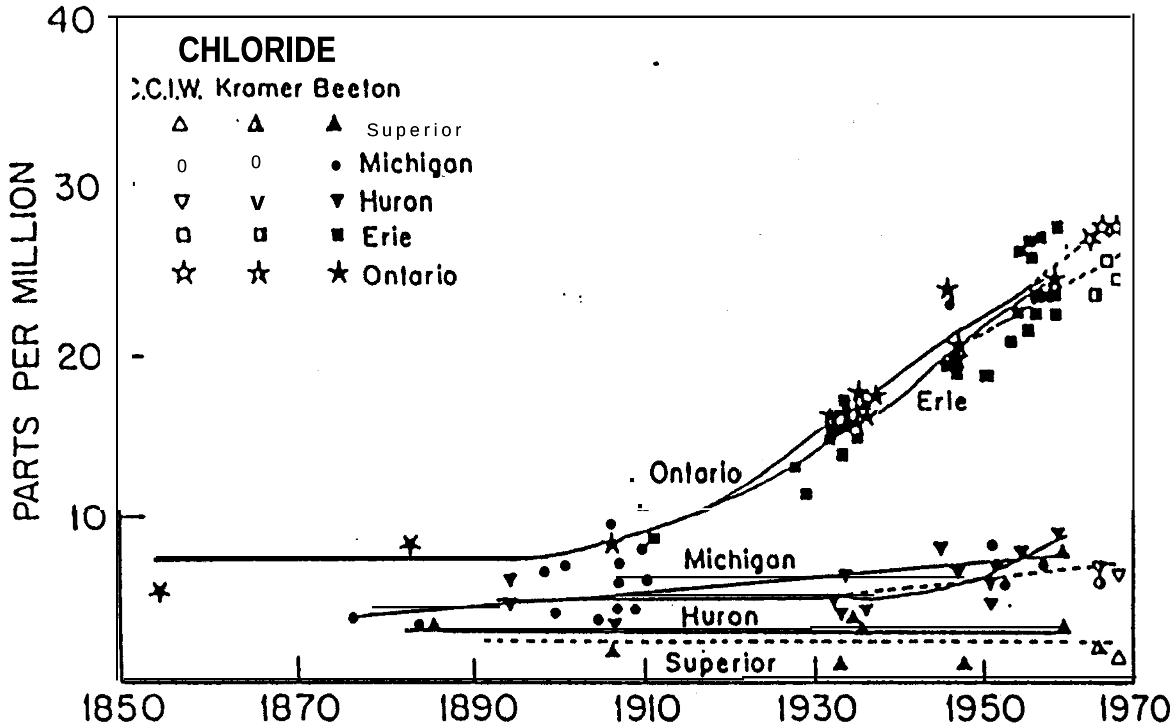


Figure 1. Historical trends in chloride concentrations in the Great Lakes. Graph is from Pringle et al. (1981).

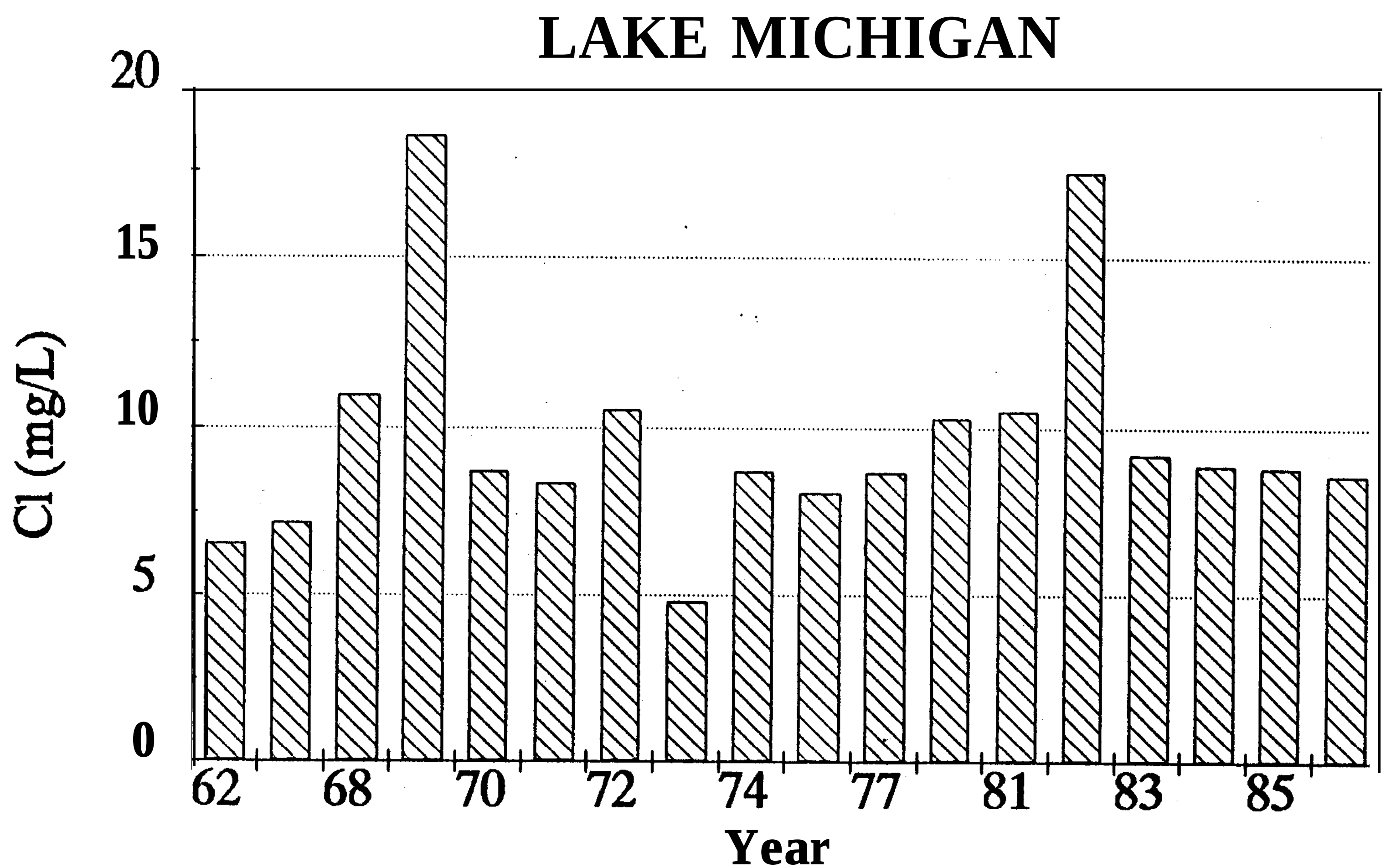


Figure 2. Changes in dissolved chloride concentrations in Lake Michigan. Data from Moll et al. (1992).

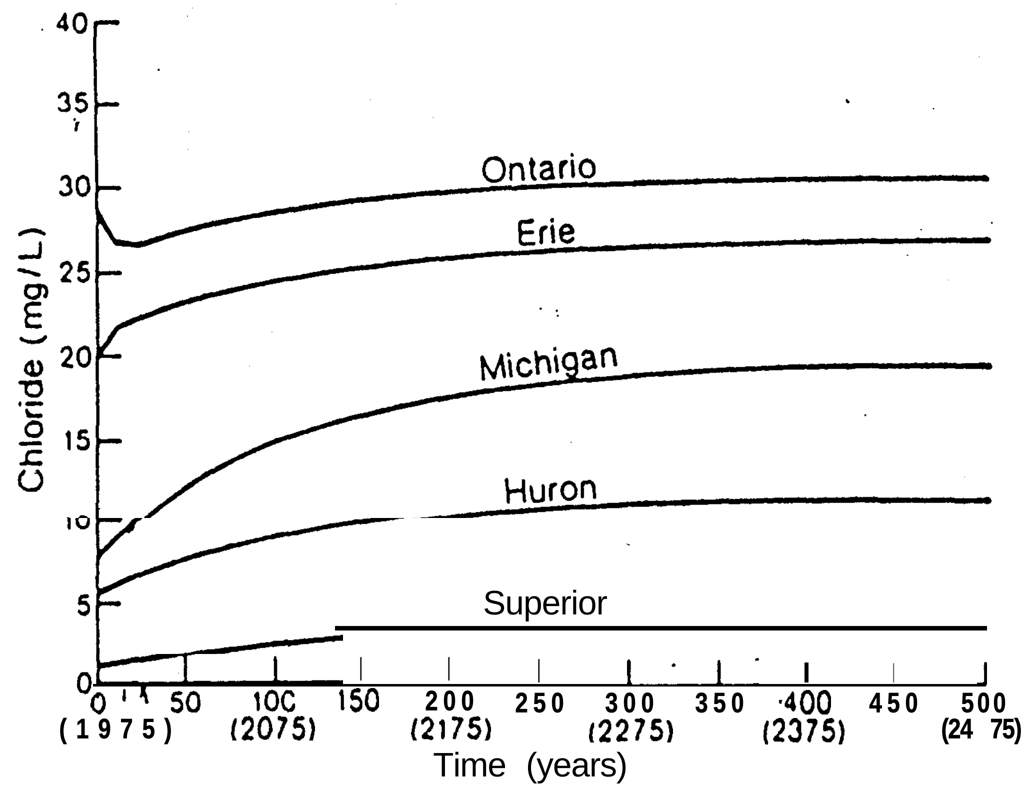


Figure 3. Projections of chloride concentrations over time in response to current external loads. From Sonzogni et al. (1983).

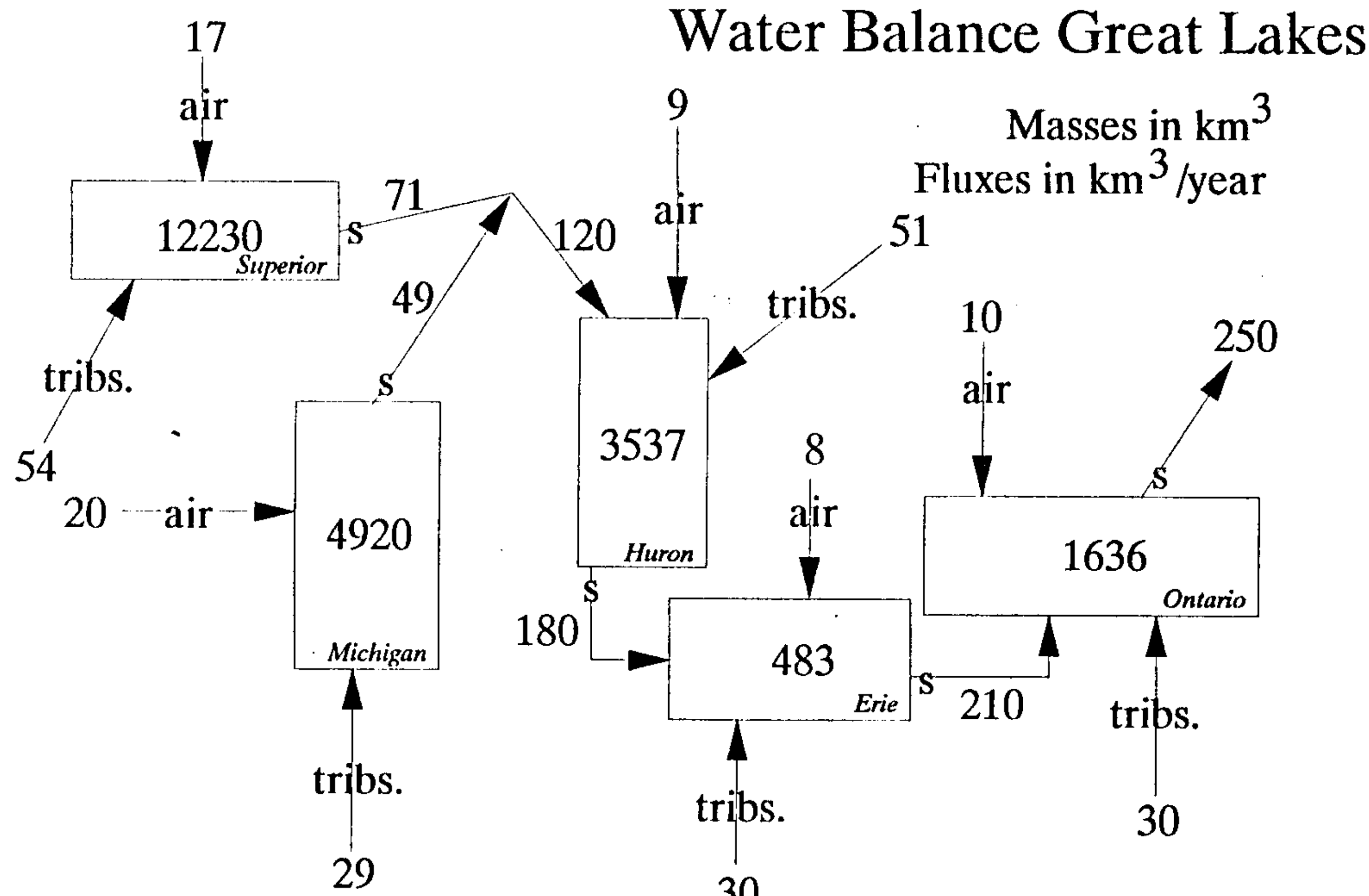


Figure 4. Mass balance of water in the Great Lakes.
Data from Strachan and Eisenreich (1989).

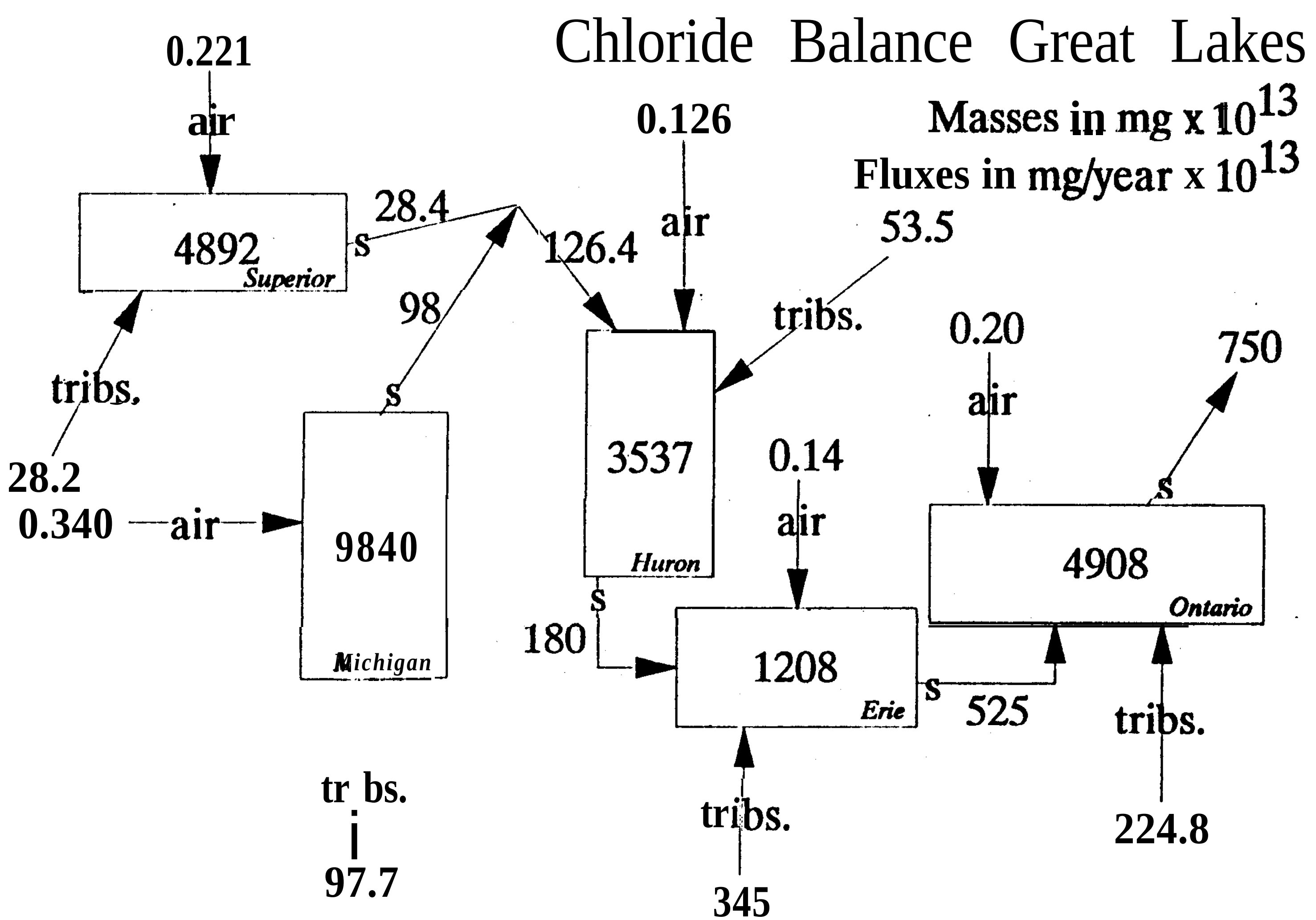


Figure 5. Chloride mass balance in the Great Lakes.

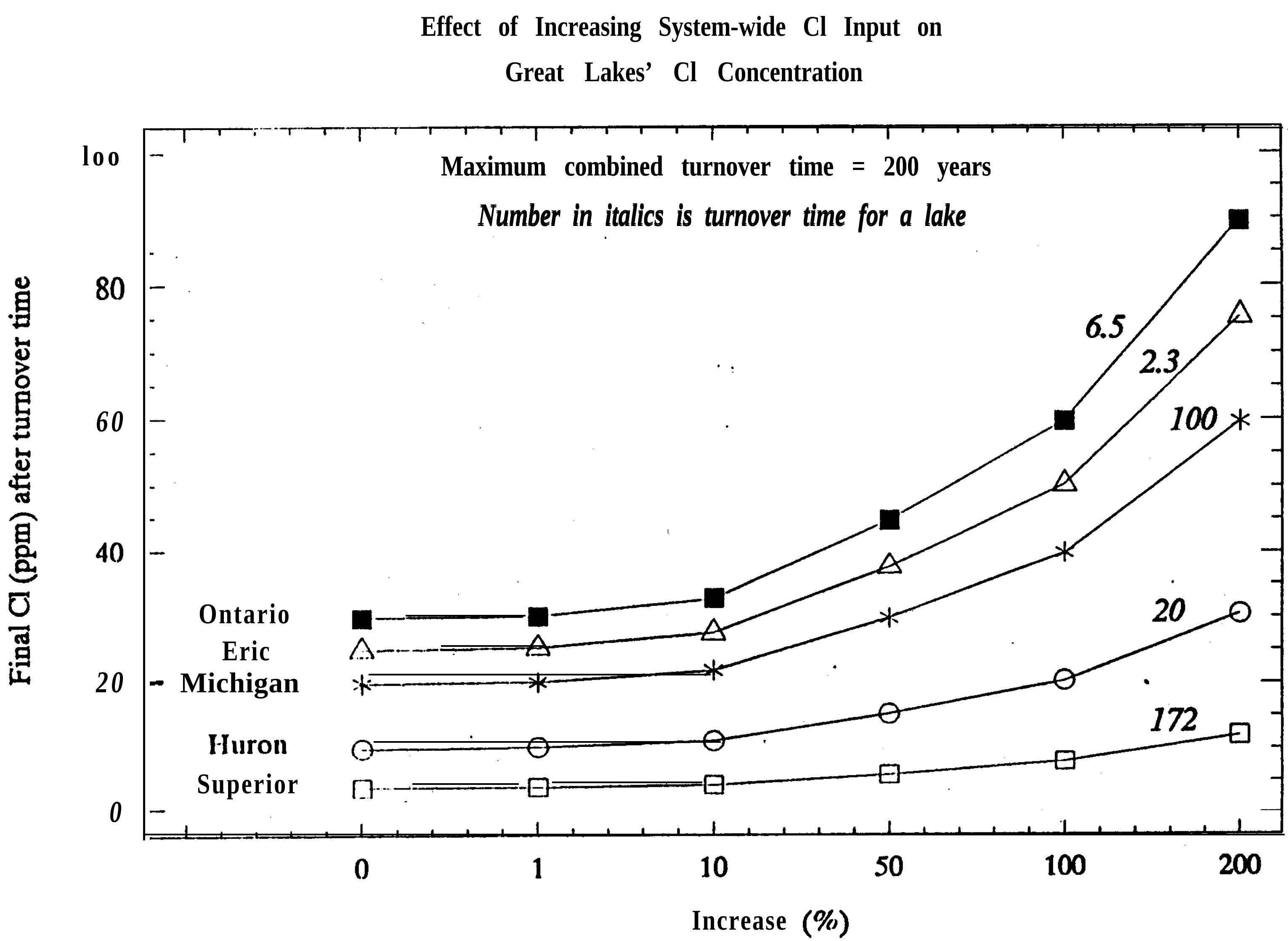


Figure 6. Results of sensitivity analysis.

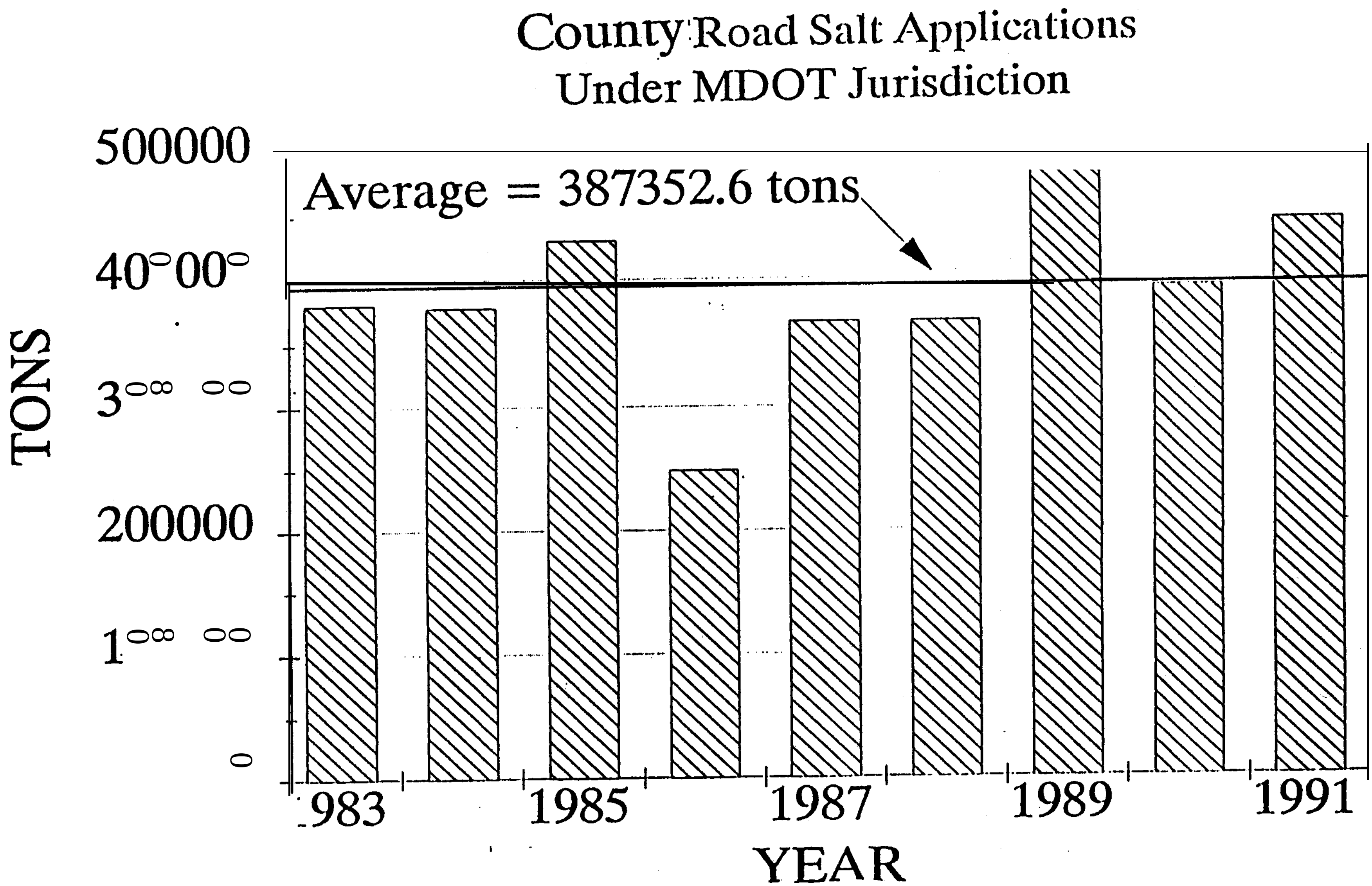


Figure 7. Amount of road salt used on state trunklines within counties

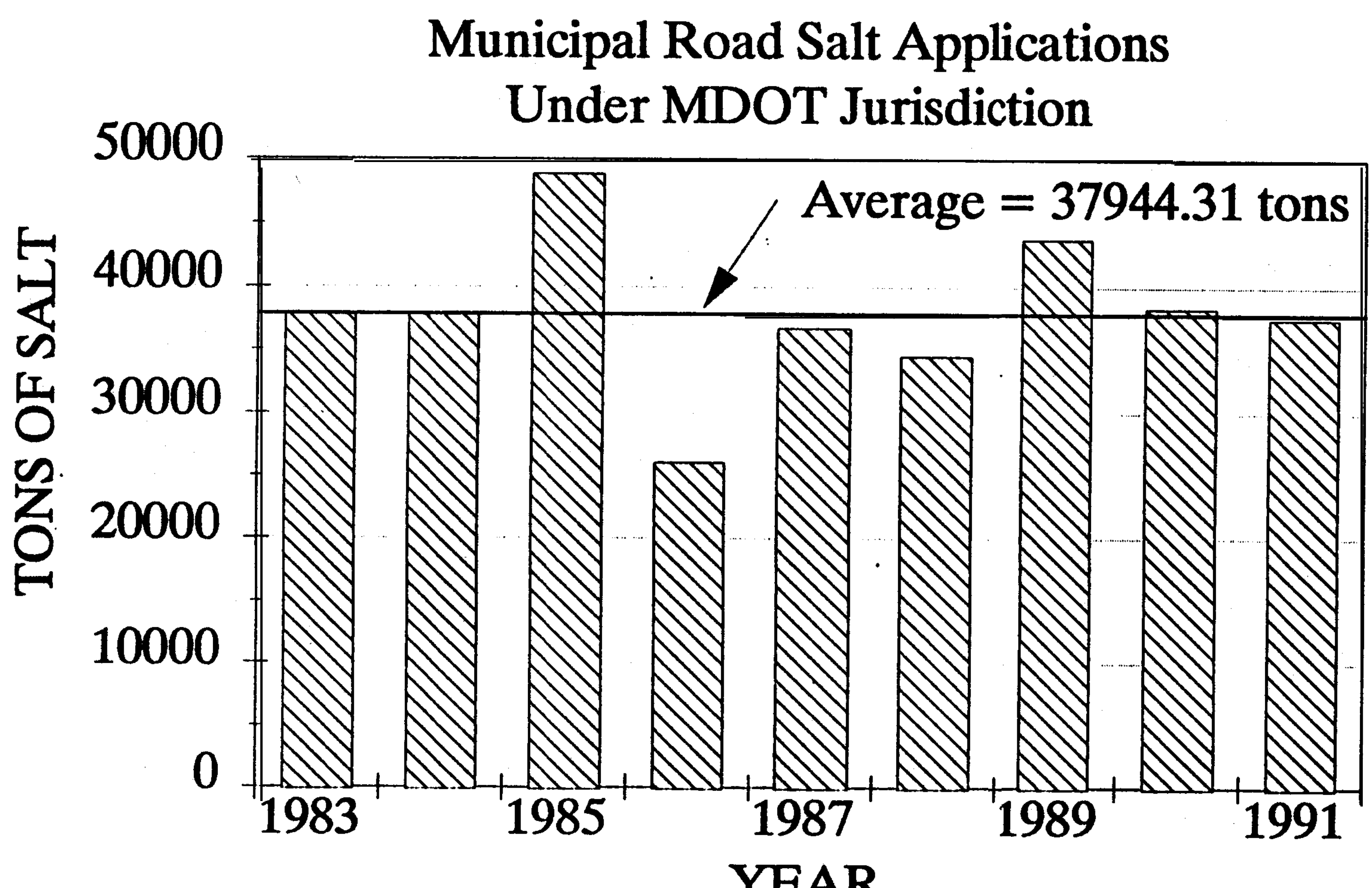
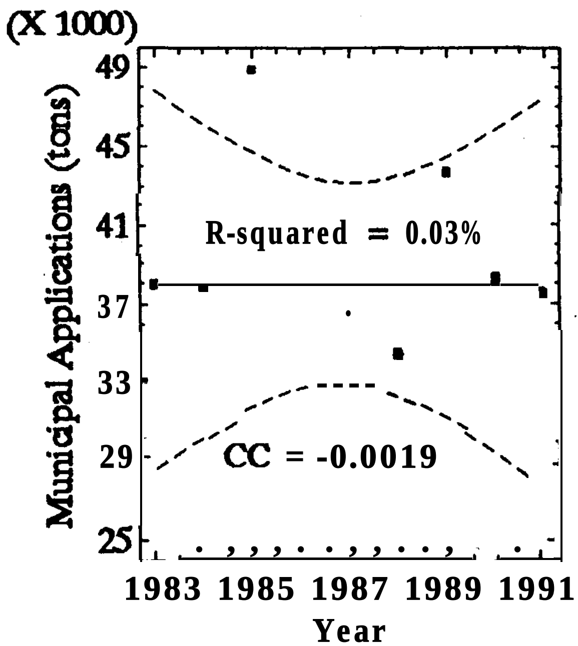
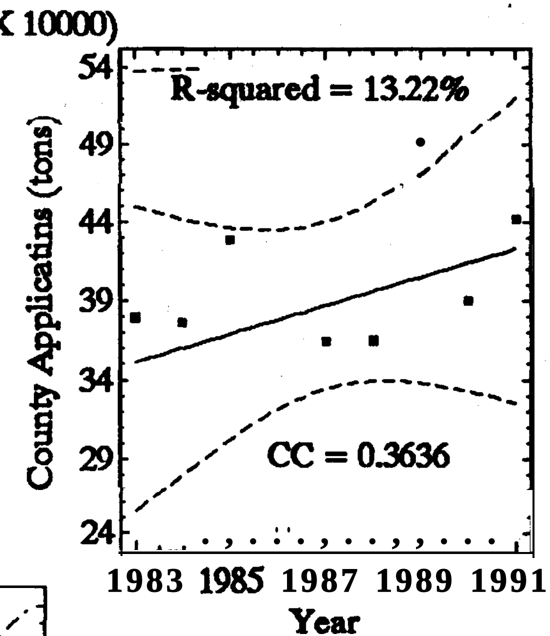


Figure 8. Amount of road salt used on state trunklines within municipalities.



CC= correlation coefficient



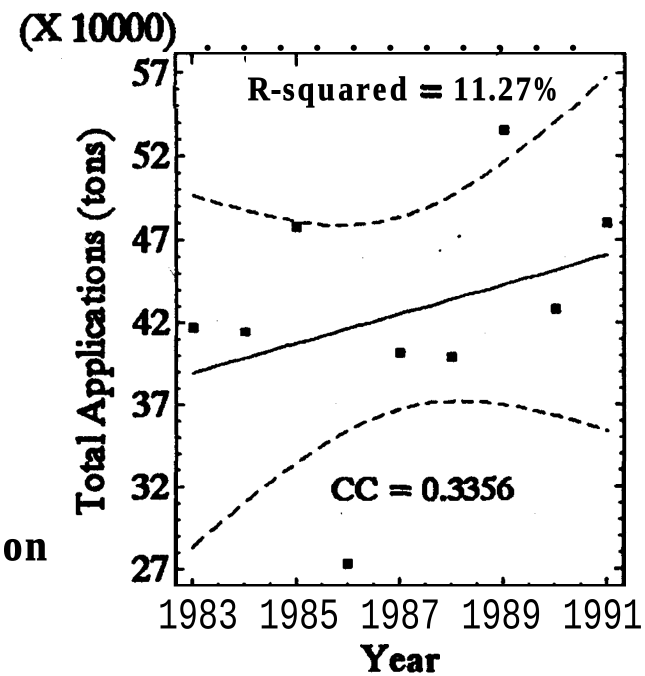


Figure 9. Regression analysis on yearly road salt applications by MDOT.

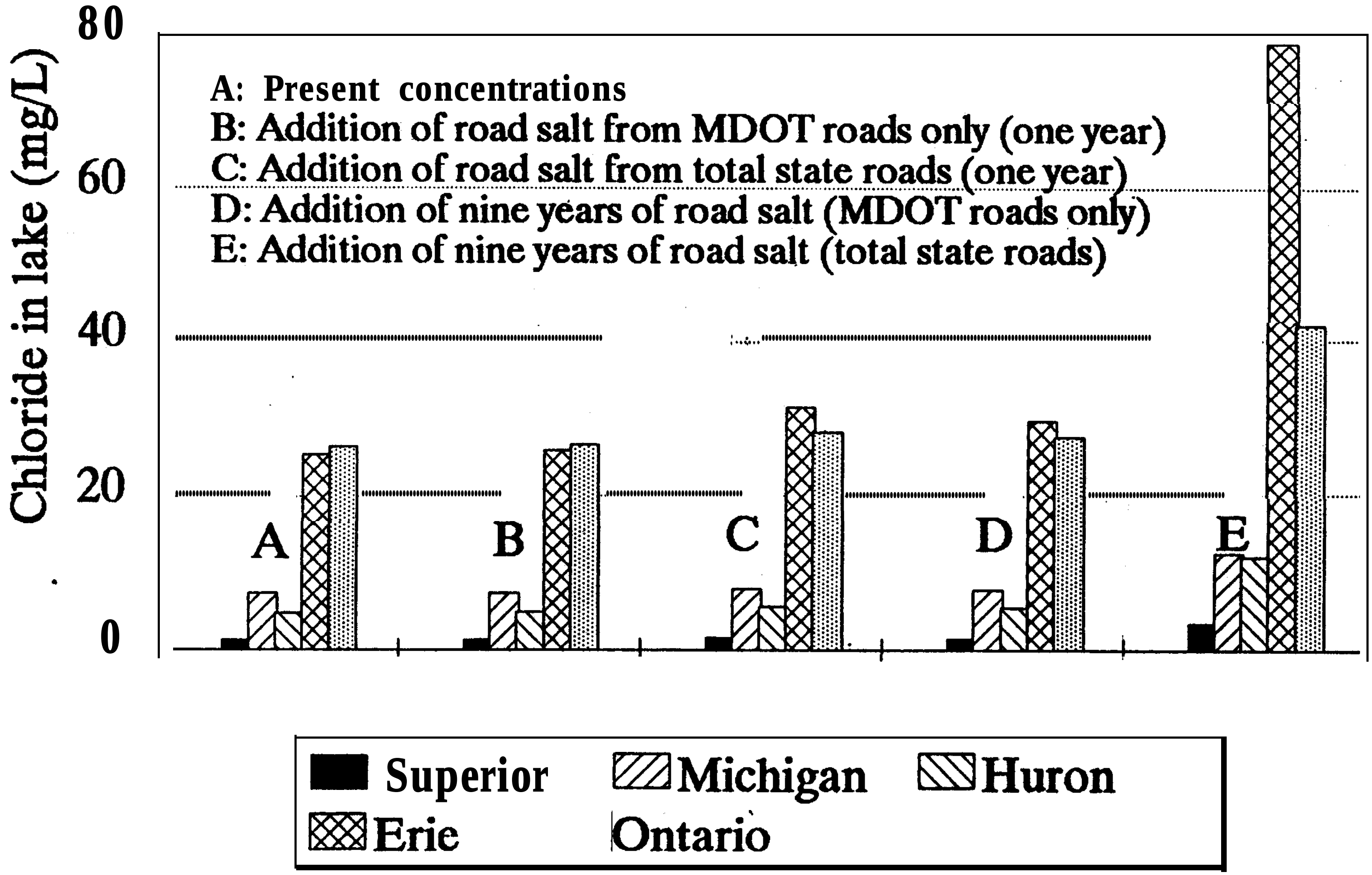


Figure 10. Impact of single direct addition of one year or nine years total amount of road salt used on Michigan roads on Cl levels in Great Lakes.

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