INTERNATIONAL PACIFIC SALMON FISHERIES COMMISSION

PROGRESS REPORT
No. 29

ACUTE TOXICITY OF MUNICIPAL SEWAGE TO FINGERLING SOCKEYE SALMON

BY

D. W. MARTENS and J. A. SERVIZI

NEW WESTMINSTER, B. C.
CANADA
1974

INTERNATIONAL PACIFIC SALMON
FISHERIES COMMISSION

Appointed under a Convention
Between Canada and the United States for the
Protection, Preservation and Extension of
the Sockeye and Pink Salmon Fisheries
in the Fraser River System

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ABSTRACT

Simultaneous continuous flow bioassays were conducted using primary treated municipal sewage before and after chlorination at three nominal chlorine residual levels to determine if sewage could be adequately disinfected during a 1 hr contact period without increasing toxicity to sockeye salmon (Oncorhynchus nerka) fingerlings. The 96 hr median tolerance limit of primary sewage was between 10 and 25% v/v. Chlorination of primary sewage to an acceptable level of disinfection caused a substantial increase in toxicity of sewage to fish.

In view of the results, dechlorination before disposal is discussed as a means of eliminating chlorine induced toxicity to salmon.

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INTRODUCTION

Toxicity of sewage to various species of fish has been the subject of a number of recent investigations. The 96 hr median tolerance limit (TL_m) of primary treated sewage prior to chlorination is reported as 45% v/v for Golden Shiners (Notemignoses chrysoleucos) (Esvelt, Kaufman and Selleck 1973). Chlorinated secondary treated sewage was lethal to fathead minnows (Pimephales promelas) at concentrations of about 2.5 to 4% v/v where chlorine residuals were 0.07 mg/l and more (Zillich 1972). A study of water quality and fish populations downstream from sewage treatment plants indicated Brook trout (Salvelinus frontinalis) and Brown trout (Salmo trutta) were absent from receiving water where mean chlorine exceeded 0.02 mg/l (Tsai 1971). Bioassays in streams receiving chlorinated sewage indicated that lethal conditions existed for sockeye salmon (Oncorhynchus nerka) and pink salmon (O. gorbuscha) where chlorine was detectable by the amperometric method (0.02 mg/l or greater) (Servizi and Martens 1974).

Investigations reported herein were conducted at Lulu Island sewage treatment plant to determine whether a 1 hr chlorine contact period achieved adequate disinfection[1] without increasing toxicity of effluent to fish.

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[1] The term "adequate disinfection" has not been quantified by the Pollution Control Branch but it was believed that the range of chlorine residuals investigated would result in levels of disinfection adequate to meet any forthcoming standard. A median most probable number of coliform bacteria per 100 mls of sewage (MPN) below 10,000 was desired. (Greater Vancouver Sewerage and Drainage District (GVSDD), S. Vernon pers. comm.).

METHODS

Bioassay Site

Studies were conducted at Lulu Island sewage treatment plant. This primary treatment facility employs prechlorination to control odors, preaeration, settling and chlorination followed by discharge to the Fraser River. The chlorine contact tank was a rectangular channel with a theoretical average detention time of 60 minutes. Chlorine dose was controlled by an automatic amperometric chlorine residual analyzer positioned 5 minutes downstream of chlorine injection. The residual at 60 minutes was measured by a similar analyzer and recorded.

Mean sewage flow at Lulu Island was 2.5×10^6 Igpd, 20% of which was effluent from Brighouse activated sludge plant and the remainder raw municipal sewage. Sewage being treated at the Brighouse plant was approximately 20% industrial effluent from an electroplating plant. The electroplating plant was ordered to pretreat its effluent to reduce heavy metal concentrations in the discharge and facilities became operational as the study neared conclusion.

Bioassays

Simultaneous continuous flow bioassays were conducted using primary[2] and chlorinated sewage (effluent from contact chamber) to provide comparative toxicity data at three nominal total residual chlorine concentrations (0.02, 0.10 and 3.0 mg/l). Bioassays were conducted in 30 liter glass aquaria with flow and exchange rates conforming to recommended methods for measurement of acute toxicity (Sprague 1972).

Acclimation of test fish followed an irregular schedule (TABLE 1) since Fraser River water proved unsatisfactory owing to high turbidity which precluded feeding test fish during acclimation.

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[2] The terms "primary sewage" and "chlorinated sewage" are used to describe sewage before and after final chlorination.

TABLE 1 - Acclimation of fish.

Bioassay No.	Race	Acclimation to Fraser River water Days
1	Pitt Lake [a]	6
2	Pitt Lake	7
3	Pitt Lake	8
4	Pitt Lake	3
5	Pitt Lake	5
6	Cultus Lake [b]	1
7	Cultus Lake	2
8	Cultus Lake	3
9	Cultus Lake	0
10	Cultus Lake	0
11	Cultus Lake	0
12	Cultus Lake	0
13	Cultus Lake	0
14	Cultus Lake	0
15	Cultus Lake	0

[a] Pitt Lake sockeye reared at Sweltzer Creek Laboratory.

[b] Cultus Lake sockeye reared at Sweltzer Creek Laboratory.

Ten sockeye fry were exposed up to 96 hr in sewage, sewage-water mixtures and in control water. The wet weight of fish per unit volume of liquid in bioassays ranged from 0.11 to 0.27 gm/l. Natural receiving water trucked daily from the south arm of the Fraser River was used for control and sewage dilution water. Sewage and dilution water were supplied to each aquarium from head troughs by precalibrated metering pipettes. Flows from the pipettes were checked regularly and pipettes cleaned daily. Test temperatures in aquaria were maintained between 54 and 62°F throughout the study by immersing aquaria in cooling water baths. Dissolved oxygen (DO) was initially maintained with compressed air and a single air stone in each aquarium. However subsequent measurements revealed DO was too low in aquaria. Additional aeration was tried but compressed oxygen proved most satisfactory and was adopted (TABLE 2).

Aquaria were checked almost continually for mortalities or moribund fish during the initial 8 to 10 hr of fish exposure. Observation of fish was restricted by opaqueness of sewage, thus test fish were periodically herded near the surface with a small dip net.

Mean Survival Time (MST) of test fish was obtained from a graph on logarithmic probit paper of survival time in minutes versus accumulated per cent mortality.

Analyses of Sewage Characteristics

Dissolved oxygen was measured daily in each aquarium in bioassay 5 to 15 by the alkali-iodide-azide modification of the Winkler method (Standard Methods 1971). However DO measurements were not made in bioassays 1 to 4 owing to delays in receiving reagents and apparatus. Temperature (°F), pH, total residual chlorine and ammonia nitrogen were determined daily in each aquarium. Total residual chlorine was measured by the iodometric method, amperometric end-point, and the minimum detectable concentration was 0.02 mg/l (Standard Methods 1971). Ammonia nitrogen was measured by the method of Harwood and Kühn (1970).

TABLE 2 - Dissolved Oxygen (DO) in aquaria.

	DO mg/l													
	Effluent Concentration % by Volume													
	100		90		65		40		25		10		0	
Bioassay No.	a	b	a	b	a	b	a	b	a	b	a	b	a	b
1	≈2.0	≈3.0	≈2.5	≈4.0	≈5.0	≈5.0	≈6.0	≈7.0	≈8.0	≈8.0			≈10.0	≈10.0
2	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓			↓	↓
3	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓			↓	↓
4	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓			↓	↓
5	2.0	3.3	2.7	4.4	5.1 5.6	5.5	5.9 6.0	7.3	7.9 8.1	7.9			10.3	10.3
6	4.6	7.9 6.9	5.3	8.2 7.2	5.9	8.3 7.8	6.5	8.9 8.4			9.8	10.0 10.2	10.3	10.3
7	3.9	6.2	4.6 3.2	6.4	5.4 4.5	7.2	5.0 6.0	8.6			9.3	9.7	10.3	10.3
8	5.7		5.1		5.9		6.5				9.4		10.1	
9	6.4	7.4	5.5	8.2	7.0	8.4	7.6	8.9			9.8	10.0	10.3	10.3
10	6.4	7.4	6.1	8.3	6.5	8.6	7.6	9.1			9.6	10.2	10.3	10.3
11	10.2	12.5	10.7	10.8	9.7	10.4	9.9	11.2			11.4	10.2	10.3	11.9
12	6.7	8.2	5.1	8.5	8.6	8.0	8.7	10.4			8.9	10.4	10.3	10.3
13	8.2	9.5	10.5	10.7	8.5	9.0			8.9	9.2	9.5	9.6	10.3	10.3
14	6.8		7.2		8.2				11.6		9.2		9.7	
15	8.7		9.2		12.4				12.7		9.5		9.8	

a Primary sewage.

b Chlorinated sewage following 60 minutes theoretical average contact time.

≈ Approximation based on DO from bioassay 5.

Most probable numbers of coliform bacteria were measured Monday through Friday at the Greater Vancouver Regional District Laboratory (Standard Methods 1971).

Composite and grab samples of chlorinated sewage were collected daily and forwarded to Environment Canada West Vancouver Laboratory for measurements of copper, cadmium, chromium, iron, lead, manganese and zinc using atomic absorption spectrophotometry. Samples were acidified with nitric acid when collected to keep metals in solution. Analyses were made about 2 weeks to 2 months after collection and samples were not filtered. Anionic surfactants were measured by the Azure A method (Van Stevenick and Riemersma 1966).

RESULTS

Characteristics of Municipal Sewage

Toxicants characteristic of sewage, such as ammonia, surfactants and heavy metals were present in primary sewage at Lulu Island (TABLE 3). Ammonia concentrations were similar to those reported for other primary sewages (Esvelt, Kaufman and Selleck 1973). Surfactants were much lower in primary sewage at Lulu Island than was methylene blue active substance (MBAS) at four primary plants in the San Francisco, California area where MBAS averaged 5.0 to 10.9 mg/l (Esvelt, Kaufman and Selleck 1973). The reason for low surfactant is not clear.

Heavy metal content of primary sewage varied widely during the study (TABLE 3) and was believed caused by effluents from the electroplating plant. The minimum detectable cadmium concentration was 0.03 mg/l, however, experimental evidence indicated cadmium was lethal to fingerling sockeye at 0.01 mg/l (Servizi and Martens MS 1971). In 31 of 44 samples analyzed in the study, cadmium was reported less than 0.03 mg/l, but there was no way of knowing whether cadmium concentration was within the toxic range. In view of this, a meaningful average value could not be calculated.

TABLE 3 - Chemical characteristics of primary sewage from Lulu Island and San Francisco area.

Characteristic[a]	Lulu Island		San Francisco Area[c]	
	Average	Range	Average	Range
Hardness as $CaCO_3$	97	43 - 232	147	86 - 251
Alkalinity as $CaCO_3$	111	72 - 151	238	124 - 312
pH	7.20	6.90 - 7.44	7.4	7.2 - 7.6
Surfactants	0.67	0.31 - 1.30	9.5[d]	7 - 12
Ammonia Nitrogen	20.5	19.0 - 23.5	18.5	9.1 - 27.8
Un-ionized NH_3-N[b]	0.088	0.082 - 0.101	0.079	0.039 - 0.119
Temperature, °C	15	13.5 - 16.7	15	12 - 18
Total Cadmium		< 0.03 - 0.81	0.02	0.001 - 0.05
Total Copper	0.16	0.09 - 0.35	0.17	0.06 - 0.26
Total Chromium	0.17	0.05 - 0.34	No Data	
Total Lead	0.05	<0.02 - 0.16	<0.01	<0.01
Total Manganese	0.17	0.13 - 0.34	No Data	
Total Iron	3.4	2.0 - 6.3	4.5	1.0 - 9.8
Total Zinc	0.28	0.13 - 0.90	0.6	0.16 - 1.0

[a] Characteristics except ammonia nitrogen were measured by Department of the Environment, Fisheries Service. mg/l except pH and Temperature.

[b] Un-ionized ammonia nitrogen determined after Trussell 1972.

[c] Esvelt, Kaufman and Selleck 1971.

[d] MBAS.

Although raw sewage was prechlorinated to control odors, chlorine was not detected in primary sewage. In addition, chlorine was not detected in chlorinated sewage during bioassays 1 to 5 when the system was set to give a nominal residual of 0.02 mg/l (TABLE 4). During the period of chlorination to 0.1 mg/l nominal residual, chlorine was detected only during bioassay 7 when a chlorine surge was caused by malfunction of chlorination apparatus. Chlorine was detected at all sewage concentrations bioassayed during the period when a nominal residual of 3.0 mg/l was scheduled.

Chlorine concentrations varied widely with time. For example, in bioassay 11 at 10% v/v, chlorine was initially 0.23 mg/l but was 0.06 mg/l several hours later. Variations in chlorine residual during bioassays were not fully documented since a continuous recorder was not used.

The average MPN of primary sewage was reduced 87, 89 and 99.98% when chlorination apparatus was scheduled to maintain nominal residuals of 0.02, 0.1 and 3.0 mg/l, respectively (TABLE 5). Although actual residuals (TABLE 4) failed to equal nominal values, it is evident that only the highest nominal residual (3 mg/l) had sufficient disinfecting power to lower MPN into a range anticipated as standard.

Acute Toxicity of Primary Sewage

Undiluted primary sewage was lethal to fingerling sockeye within 109 to 260 minutes (TABLE 6). Mean survival times are not reported for 100 and 90% v/v primary sewage in bioassays 1 to 5 since low dissolved oxygen probably enhanced toxicity. Primary sewage was lethal at 25% v/v in 450 to 1,700 minutes in bioassays 3, 4, 5, 13, 14 and 15. Neither mortalities nor outward signs of distress were noted among fish exposed to 10% v/v primary sewage or in control aquaria for periods up to 5,760 minutes (96 hr). Thus the 96 hr median tolerance limit (TL_m) of primary sewage was between 10 and 25% v/v.

TABLE 4 - Total Residual Chlorine in aquaria[a].

Bioassay No.	Nominal Cl_2 - mg/l	Total Residual Chlorine mg/l Chlorinated Sewage % v/v						
		100	90	65	40	25	10	0
1	0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	–	< 0.02
2	↓	↓	↓	↓	↓	↓	–	↓
3	↓	↓	↓	↓	↓	↓	–	↓
4	↓	↓	↓	↓	↓	↓	–	↓
5	↓	↓	↓	↓	↓	↓	–	↓
6	0.10	< 0.02	< 0.02	< 0.02	< 0.02	–	< 0.02	↓
7	↓	.32	.25	–	–	–	–	↓
8	↓	< 0.02	< 0.02	< 0.02	< 0.02	–	–	↓
9	3.0	1.32	0.66	0.58	0.19	–	0.08	↓
10	↓	0.55	0.48	0.35	0.27	–	–	↓
11	↓	2.05	1.85	1.50	0.95	–	0.23	↓
↓	↓	1.90	1.70	–	0.91	–	0.18	↓
↓	↓					–	0.06	↓
12	↓	0.58	0.48	–	0.20	–	–	↓
↓	↓				0.43	–	–	↓
13	↓	1.43	1.61	1.07	–	0.35	0.08	↓
↓	↓	1.90	1.90	1.25	–	0.41	0.12	↓

[a] Chlorine was not detected (< 0.02 mg/l) in primary sewage.

TABLE 5 - Most Probable Numbers of coliform bacteria (MPN) in plant influent and chlorinated sewage.

Nominal Total Chlorine Residual mg/l	MPN[a]					
	Plant Influent[b]			Chlorinated[c]		
	Average	Range		Average	Range	
0.02	59×10^6	4.6×10^6	240×10^6	8.5×10^6	15×10^3	46×10^6
0.10	19.6×10^6	11×10^6	24×10^6	2.1×10^6	24×10^3	11×10^6
3.0	51×10^6[d]	24×10^6	110×10^6	9000	230	24×10^3

[a]MPN determined by Greater Vancouver Regional District staff.

[b]Samples collected up sewer of prechlorination.

[c]Effluent samples collected following 60 minutes theoretical average chlorine contact time.

[d]Only 4 samples collected owing to labor strike.

TABLE 6 - Mean Survival Time (MST) of sockeye exposed to primary and chlorinated sewage.

Bioassay No.	Nominal Chlorine[c] mg/l	MST minutes Sewage % v/v 100 a	100 b	90 a	90 b	65 a	65 b	40 a	40 b	25 a	25 b	10 a	10 b
1	0.02	-	-	-	-	288	-	-	-	-	-	-	-
2	↓	-	-	-	-	271	222	-	370	-	1527	-	-
3	↓	-	-	-	-	225	260	600	320	≈1700	-	-	-
4	↓	-	-	-	-	155	178	270	240	≈450	320	-	-
5	↓	-	-	-	-	208	225	243	≈350	≈750	≈650	-	-
6	0.10	245	203	280	218	340	320	455	453	-	-	>5760	>5760
7	↓	230	<72	280	<79	-	-	-	-	-	-	-	-
8	↓	260	<317	250	325	435	450	≈1300	-	-	-	-	-
9	3.0	165	11	180	16	230	24	350	62	-	-	>2880	≈100
10	↓	188	98	212	98	275	113	390	175	-	-	-	-
11	↓	138	11	≈152	14	260	17	480	28	-	-	>5760	290
12	↓	115	17	105	19	222	30	-	58	-	-	-	-
13	↓	109	9	132	11	148	14	-	-	610	62	>5760	215
14	↓	115	-	109	-	123	-	-	-	>336 <1350	-	>5760	-
15	↓	135	-	188	-	309	-	-	-	≈1600	-	-	-

[a] Primary sewage.

[b] Chlorinated sewage.

[c] Nominal values did not equal measured values.

Toxicity of primary sewage was not constant from one bioassay to the next. Such a result may reflect the influence of heavy metals on toxicity since these varied widely during the study.

Bioassays 14 and 15 were conducted at request of GVSDD to determine whether toxicity of primary sewage would be reduced by operation of pollution control facilities at the electroplating plant. Since MST's were unchanged from earlier bioassays, it was evident that toxicity was not reduced by pretreatment at the electroplating plant. Heavy metal content of the sewage was also similar to that in earlier bioassays.

Acute Toxicity of Chlorinated Primary Sewage

Toxicity remained virtually equal in primary and chlorinated sewage when nominal chlorine residual was scheduled to equal 0.02 mg/l (TABLE 6). The result is not unexpected, since chlorine residual was not detected by analyses (TABLE 4). A similar result was noted in bioassays 6 and 8. However, when chlorine residual was detectable (bioassays 7 and 9 through 13), chlorinated sewage was much more toxic than primary sewage. For example, undiluted chlorinated sewage was often lethal in 10 to 20 minutes, compared to 100 to 260 minutes for primary sewage. In addition, whereas no mortalities occurred at 10% v/v primary sewage in 4 days, MST's were between 100 and 300 minutes when chlorine was detected.

Chlorine residual was variable (TABLE 4) in spite of automatic control devices and as a consequence, MST's were not always correlated with spot measurements of chlorine residual. For example, MST's in 100% v/v chlorinated sewage were 98 and 17 minutes (Bioassays 10 and 12), even though chlorine residuals were 0.55 and 0.58 mg/l, respectively, during spot checks. These results suggest that brief surges of chlorine, undetected by spot checks, may have been partly responsible for variable MST's. In addition, the fact that toxicity of primary sewage varied in successive bioassays, bioassays 10 and 12 cited above being examples, probably added to variation in toxicity of chlorinated sewage.

DISCUSSION

The 96 hr TL_m of primary sewage at Lulu Island using sockeye salmon was between 10% and 25% v/v compared to 45% v/v for primary sewage in the San Francisco area, measured using golden shiners in continuous flow bioassays (Esvelt, Kaufman and Selleck 1973). Limited comparison indicated, with only one exception, that salmonids (rainbow trout, *Salmo gairdneri* and chinook salmon, *O. tshwytscha*), were slightly more sensitive to primary sewage than golden shiners (Esvelt, Kaufman and Selleck 1971). Although there is no assurance that rainbow trout, chinook salmon and sockeye are equally sensitive to sewage toxicity, the results tend to indicate that primary sewage at Lulu Island was more toxic than that in the San Francisco area.

Multiple correlation analysis of toxicity with chemical constituents of primary sewage indicated MBAS and ammonia accounted for about 67% of toxicity of San Francisco area sewage, while 33% was believed related to heavy metals and perhaps reduced substances (Esvelt, Kaufman and Selleck 1973). The MBAS content of sewage in the San Francisco area was 14 times the surfactant concentration at Lulu Island measured by the Azure A method. Assuming the test methods comparable, surfactants in Lulu Island primary sewage would have been less than the acutely toxic level, 2 to 6 mg/l (Esvelt, Kaufman and Selleck 1971).

The toxicity of ammonia is believed related to the amount of un-ionized ammonia (McKee and Wolf 1963), which is in turn dependent upon pH and temperature. Calculation of un-ionized ammonia content is dependent upon ionization constants. Unfortunately, accurate constants have not been used in every case (Trussel 1972). Furthermore, Esvelt, Kaufman and Selleck (1971) apparently overlooked the effect of temperature in calculating the per cent of un-ionized ammonia, thus these values were recalculated in TABLE 3. According to recalculated values, un-ionized ammonia concentrations in both studies were less than levels currently believed lethal (0.2 to 0.9 mg/l, Esvelt, Kaufman and Selleck 1971).

However, toxicity was correlated with ammonia nitrogen concentration in the San Francisco study which suggests that factors in addition to un-ionized ammonia may be associated with toxicity of ammonia. Thus, in view of the similarity in ammonia and pH values for the two studies, it is assumed that ammonia contributed to toxicity of primary sewage at Lulu Island.

Cadmium and copper concentrations in Lulu Island primary sewage were often well in excess of those found lethal to fingerling sockeye, whereas zinc was present at less than lethal levels (Servizi and Martens 1971). Little information concerning toxicity of iron is available but there is a possibility that levels were high enough to be toxic to salmon (McKee and Wolf 1963). The remaining metals measured were present at concentrations less than those reported acutely toxic (McKee and Wolf 1963).

The role which effluent from the electroplating plant played in toxicity was not well defined since primary sewage toxicity was unaffected by pretreatment at the plating plant. A somewhat similar experience was noted in the San Francisco area where primary sewages had a significant toxicity, regardless of whether they were principally domestic or included substantial industrial contributions (Esvelt, Kaufman and Selleck 1973).

The objective of the study was to determine whether 1 hr chlorine contact would reduce MPN's to acceptable levels without increasing toxicity. Although an allowable MPN for Lulu Island sewage had not been specified, it was believed that values obtained when the residual was a nominal 3 mg/l were acceptable, whereas MPN's associated with nominal residuals of 0.02 and 0.1 mg/l were not acceptable. It is emphasized that chlorine residuals were measurable in only one case when the two lower nominal residuals were tested. Furthermore, chlorine residual varied considerably, indicating that refinements were required in the system in order to maintain a consistent residual. In this regard, obtaining thorough mixing of chlorine and sewage at the chlorine contact chamber inlet is considered a key factor. It was also evident that toxicity of primary sewage to sockeye salmon was increased several fold whenever chlorine residuals were detected in the effluent. Thus chlorination was only effective from an MPN standpoint when a chlorine residual was measurable, but under such circumstances toxicity to fish was increased. Such a result is not unexpected since appreciable increases in toxicity of primary sewage were noted elsewhere following chlorination (Esvelt, Kaufman and Selleck 1973).

Chlorinated effluent at Lulu Island was toxic in 100 to 300 minutes at 10% v/v. Supplies of dilution water were insufficient to permit bioassays at greater dilutions of sewage. However, bioassay of chlorinated activated sludge effluents indicate acute toxicity to fathead minnows may persist down to about 2 to 3% v/v of effluent, where chlorine residuals were 0.07 mg/l and greater. Sublethal stress was noted at 0.04 mg/l (Zillich 1972). In-stream bioassays of rainbow trout and sockeye salmon indicated toxic conditions were likely when chlorine exceeded 0.02 mg/l (Basch, not dated; Servizi and Martens MS 1972). Similarly, it was concluded that combined chlorine is toxic to fish as long as there remains a measurable residual as determined by the amperometric method (Esvelt, Kaufman and Selleck 1973).

In view of the foregoing discussion it is evident that primary sewage is toxic to fish, especially when chlorinated. On the other hand public health considerations make chlorination for the purpose of disinfection a necessity in many areas. However, this study has demonstrated that when disinfection is acceptable, a chlorine residual highly toxic to fish remains, thus dechlorination is necessary to eliminate chlorine induced toxicity.

Dechlorination has been demonstrated on a laboratory scale using sodium thiosulfate (Zillich 1972) or sodium bisulfite (Esvelt, Kaufman and Selleck 1973). Full-scale dechlorination is practiced at Sacramento and Burlingame, California, using SO_2, while sewage treatment plants at

Palo Alto, San Jose and Hayward were awaiting installation of dechlorination equipment (H. F. Collins pers. comm.). Thus experience elsewhere indicates dechlorination using SO_2 is worthy of testing at Lulu Island.

The authors would be remiss if they failed to mention that although dechlorination is expected to eliminate chlorine induced toxicity, only a minor reduction in toxicity of primary effluent would be anticipated (Esvelt, Kaufman and Selleck 1973). On the other hand, evidence indicated that secondary treatment by activated sludge detoxified sewage (Esvelt, Kaufman and Selleck 1973; Zillich 1972). This factor should not be overlooked when planning sewage disposal to waters inhabited by fish.

CONCLUSIONS

1. Primary treated municipal sewage at Lulu Island sewage treatment plant was lethal to fingerling sockeye salmon, with the TL_m96 between 10 and 25% v/v.

2. Chlorination of primary sewage to an acceptable level of disinfection caused a substantial increase in toxicity of sewage to fish.

RECOMMENDATIONS

In order to maintain a consistent chlorine residual, refinements in the chlorination system appear warranted with emphasis on thorough mixing of sewage and chlorine at the contact chamber inlet.

Since experience elsewhere has demonstrated that chlorine induced toxicity can be eliminated by chemical dechlorination, testing of this process appears warranted. However, reports indicate dechlorinated primary treated sewage would be toxic to fish, but toxicity could be substantially reduced by biological treatment and should be examined further.

ACKNOWLEDGEMENTS

The assistance and cooperation of the Department of Environment, Fisheries Service and Environmental Protection Service, and the Greater Vancouver Sewerage and Drainage District in conducting this study are gratefully acknowledged.