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TRACE METAL POLLUTION OF THE LOWER
NORTH CANADIAN RIVER BASIN

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TRACE METAL POLLUTION OF THE LOWER
NORTH CANADIAN RIVER BASIN

CHAPTER I

INTRODUCTION

Water is a natural resource for which man has prayed, danced, fought and died, dug, seeded, diverted, transported, impounded, then used, polluted and damned. Assessment of the water resources on Planet Earth has revealed a total of 1,360,000,000 cubic kilometers of water, over 97 percent of which is contained in the world's oceans (1). The remaining 3 percent is located in and on the land areas and totals 37,000,000 cubic kilometers, 75 percent of which is contained in ice caps and glaciers. Thus only 0.7 percent of the total global water remains as a usable fresh water asset available to man (1).

The portion of the world water supply allocated to the United States by total annual precipitation is about 30 inches, which amounts to about 4,300 billion gallons per day, of which 3,000 billion gallons per day is lost due to evaporation and transpiration (2). Of the remainder, about half is lost as flood waters which run rapidly into the sea, thus leaving a dependable minimum amount in our lakes, rivers and man-made impoundments of 600 billion gallons per day (2). Assuming that half of this is required for navigation, fish and wildlife, our developed supply

in this country is just over 300 billion gallons per day.

Water use and population studies projected to the year 2000 reveal a frightening situation when viewed in the light of our water resources (1). The predicted 1980 population of 232 to 274 million Americans will require, for municipal, industrial and agricultural uses, an estimated 598 billion gallons per day, an amount that very closely approximates the total potential fresh water resources of the nation (2). Projections for the year 2000 include a predicted population of 295 to 420 million people and an estimated water requirement of 888 billion gallons per day, an amount which surpasses the current potentially available supply by almost 50 percent.

Obviously, action is necessary. Concepts of conservation currently reserved for minerals, soils, wildlife, and forests must be expanded and applied to our water resources. The management of the quantity and quality of water must be accelerated if the growth and prosperity of this or any nation is to be maintained (3).

To be effective such management programs must be comprehensive not only with respect to the levels of government involved and with respect to the consuming populations involved (i.e. municipalities, industry, agriculture, recreation, etc.), but also with respect to the management team which must represent skills varying from systems analysts to geologists.

Historically, the progress of nations can be related to the availability and management of their water resources; this dependence will become more critical in the future. If the population explosion and the marked trend toward urbanization continues, as has been predicted for

this, as well as other countries, it is foreseeable that our population centers will develop adjacent to available water resources rather than mineral resources or transportation facilities as they have in the past.

Water use means water pollution, a "people problem" which, like water itself, is not a respecter of national, state or political boundaries. The realization that water is a global problem is reflected by the programs of Water for Peace and the International Hydrological Decade which are attempts by more than 100 nations to work cooperatively toward a better understanding and utilization of the limited water resources of the world (1). At the national level, several states in the past have entered interstate agreements concerning a mutual river basin and for many years the federal government has provided enormous sums of tax monies to assist state, municipal and rural areas in the development of adequate water and waste water plant construction. However, the inadequacies and shortsightedness of these approaches was soon recognized; but it was not until the advent of the Water Quality Act of 1965 and the Clean Water Restoration Act of 1966 that authority capable of overcoming local interest was established (3, 4, 5). The Water Resources Planning Act enabled the Department of the Interior to establish River Basin Commissions and an overall Water Resources Council to establish policy relative to water resources and river basin development on a regional or interbasin basis (5, 6). Approximately 22 of these basin commissions are expected to be formed by 1970. The model or pilot program is the Delaware River Basin Commission which has existed since 1961 with members including the states of Delaware, New Jersey, New York, Pennsylvania and the U. S. Federal Government, and is one of seven River Basin

Commissions currently in operation.

Industry which in the past has, justly or unjustly, borne the major responsibility for water pollution, is currently shedding its "lassaiz faire" role and assuming a major role in pollution control. This is exemplified by the National Technical Task Committee on Industrial Wastes and National Association of Manufacturers in which industries work together and with the federal government on specific problems of waste treatment (5).

Along with an increasing demand and a static supply has come water re-use, not only the "unintentional" re-use commonly observable where numerous cities and industries located along a water course use the stream as both a source of water and as a channel for conveying wastes, but also the planned deliberate re-use exemplified at Santee, California (7), Lancaster, California (8), Lubbock, Texas (9) and Grand Canyon, Arizona (10). The re-use of water intensifies the concern over water quality particularly with respect to residual pollutants which are materials such as pesticides, nitrates, phosphates and trace metals (2, 11). Some of these pollutants reach a water course via surface drainage and consequently are not subjected to waste treatment operations; others are generated by the waste treatment processes in the normal course of operation; and others result from common commercial and industrial operations and can pass unaltered through conventional waste treatment. This latter class of pollutants is only currently becoming recognized and is causing an increased concern among all classes of water users.

One area, which experiences all phases of the water problem from limited supply to re-use and residual pollution, lies in the arid to

semi-arid southwestern United States. This area, typified by the North Canadian River Basin, encompasses not only extensive agricultural operations, but also large population centers and varied industrial processes.

The North Canadian River (NCR) heads in the foothills of the Rocky Mountains in Northeastern New Mexico, flows easterly through the high plains of the Oklahoma Panhandle, then swings southeastward into Central Oklahoma to a point near Oklahoma City. There its waters, which are the principal water source in the basin, are impounded in Lake Overholser and Lake Hefner, both of which are located several miles upstream from the municipal and industrial waste effluents from Central Oklahoma's largest metropolitan and associated industrial complex. It then continues on an eastward course to its terminus in Lake Eufaula.

The importance of this water source and the extent to which it is used and re-used is indicated by the fact that the average daily volume of water withdrawn for municipal and industrial uses and the average daily volume of waste water returned to the stream exceeds the average daily flow of the stream by an estimated factor of three. In fact, the flow of the NCR available for domestic, industrial and recreational uses between Oklahoma City and Lake Eufaula, Oklahoma's largest reservoir, is frequently nearly 100 percent waste waters, some adequately treated, some inadequately treated and some receiving no treatment.

Judicious development and protection of this resource is vital to the continued growth of the basin's urban and industrial interests, to its agricultural and recreational industries, as well as to the health and prosperity of its people.

Pollution and its effects on water quality in this basin are of

utmost concern and foremost in this concern is the degradation of this limited resource with residual pollutants, particularly trace metals, some of which can be toxic to man, animals, vegetation and fish life, at levels as low as 0.01 mg/l. Some of the more toxic members of this group can, even at lower concentrations, affect the aquatic ecology and thus alter the utility of the water (2, 12). The release of these materials to the waters of the basin is known to occur as is their persistence in the environment in an active form. It is these materials which could markedly limit the utility of this water resource and it is these materials which must be very thoroughly studied if their effects and subsequently their control are to be realized.

CHAPTER II

LITERATURE REVIEW

A toxic condition is said to exist in an organism when a substance interferes with the normal functioning of that organism (13). Such a condition can be mild, chronic, acute or even lethal for the organism. Some of the most toxic substances known are among our "metallic" elements and when these occur in the mg/l range they may be referred to as "trace metals".

The most important metals from the standpoint of human toxicology are arsenic, lead, mercury, antimony, cadmium and thallium (14). Other elements which have been found in the human body, but play no clearly defined beneficial biochemical role are aluminum, barium, bromine, chromium, nickel, rubidium, strontium, silver, bismuth, tin, titanium and gold (15). The presence of these "metals" in the body indicates probable exposure to environmental pollution either by inhalation or ingestion of contaminated food or water. Each metal has its own environmental and industrial hazards and each has certain pathological effects (14, 15).

Antimony, arsenic, lead, mercury and thallium affect certain enzyme systems in the body with antimony, arsenic and mercury particularly antagonistic to the sulfhydryl groups. Mercuric ions, even in fairly dilute solutions, denature proteins and cause protein precipitation (14).

Mercury is highly toxic to man and is cumulative in body

tissues (16). It is absorbed from the gastrointestinal tract into the blood and produces a loss of activity of certain enzyme systems. In 1957 over 4,000,000 pounds of mercury were used in the United States for medical and scientific research, mercury vapor lamps, amalgams with copper, tin, silver and gold in solders, photoengraving, bronzing, paint colors and antifouling agents for the hulls of ships (14). Mercuric chloride which is soluble up to 61,000 mg/l in water at 20° C is used in embalming, disinfecting, preserving, manufacturing of ink and may occur in wastes from lead mining and chemical industries (17).

Lead is a cumulative poison in man. It is stored in bone and retained within the body in bone marrow, blood, liver and the kidneys (14). Drinking water contaminated with lead becomes available to the gastrointestinal tract and has caused a high incidence of chronic nephrosis associated with increased skeletal lead and an increase of lead in the urine (18). Lead is consumed by industrial sources at over 2,200,000 pounds per year, part of which returns to the environment principally through the use of tetraethyl lead in gasoline and lead base paints and sealers (14).

Cadmium is also a cumulative poison with accumulation occurring in both the soft and hard tissues of the body (19). It is known to be a renal poison and Schroeder (20) has associated cadmium with common hypertension in the United States. Acid foods and beverages stored in cadmium-lined containers produce violent gastrointestinal symptoms within 20 minutes after ingestion (14). The main source of environmental contamination from cadmium is from the metal plating and industrial chemical industries. It is associated with metallic zinc sulfides and is used in

making alloys, cadmium plating, vapor lamps, colors, glass works, storage batteries, welding, zinc smelting and refining, and in the grinding and polishing of alloys (18). Operations of this type are common and millions of gallons of cadmium-bearing wastes are being discharged into environmental waters daily.

Silver is highly toxic to mammals (16), and has become well known for the permanent bluish skin discoloration called argyria. Ingestion of silver in low concentrations is followed by deposits of the metal in the skin tissues where subsequent reaction to light produces the discoloration (19). Intravenous injections of 1 g of silver has been reported to cause this effect (17).

Chromium dust is known as a potential lung carcinogen in man (21). Hexavalent chromium is slightly cumulative in rat body tissues at ingestion levels greater than 5 mg/l (22). It is also an active skin sensitizer and can cause skin cancer (21). According to Underwood (23), Tipton has shown chromium to be the only "abnormal" element in which body tissue concentrations actually decrease with the age of the individual. Chromium is widely used in industry as a metal cleaner, coloring agent and in electro-plating of metals, and in the waters of industrial cooling towers (24).

Nickel is known to be a skin sensitizer when in the form of its soluble salts and it acts as a neurotoxin to the cardiac and respiratory nerves (19).

Copper ingested in amounts exceeding normal human diets by a factor of ten has been indicated as being potentially toxic to man (25). High copper concentrations in man have been associated with Mediterranean

anemia, hemochromatosis, cirrhosis of the liver, yellow atrophy of the liver, tuberculosis, carcinoma, severe chronic diseases and anemia, but these observations do not necessarily implicate copper as being the causative agent (18).

Arsenic is a cumulative poison to man, entering the environment primarily from pesticides and insecticides (14). The minimum lethal dose of As_2O_3 is between 60 to 180 mg (14). It is stored in the body tissues in the hair and nails (16), and can cause skin and liver cancer when ingested in the drinking water (26).

A partial list of other trace metals of importance and their toxicities to man include: antimony, used in therapy for leishmaniasis, can produce oliguric renal failure; thallium commonly used in rat poisons produces tachycardia, albuminuria and neurologic symptoms; bismuth is an industrial poison whose action on man is associated with acute renal failure; gold whose administration to rheumatoid arthritis patients is often followed by gold poisoning in the form of dermatitis; and uranium, whose toxic action on man is similar to mercury poisoning (18). Loeb (18) reports that chronic nephrotoxins such as Hg, Ag, Bi, Cu, Cd, U, Pb, Au, As, Fe, Sb, and Tl, when ingested over a period of months or years, can produce toxic nephropathy. Schreiner (18) states that World Health Organization studies have recently revealed 25,000 cases of interstitial nephritis variously termed Yugoslavian, Bulgarian and Balkan nephritis having a geographical distribution conforming to specific altitudes and specific river valleys. Cotzias (27) reports that chronic manganese poisoning is a crippling disease of the nervous system.

Trace metals in drinking water have been of growing concern in

the field of Public Health (19, 28, 29, 30, 31). In 1961 the World Health Organization published limits for five metals ranging from 0.05 mg/l for hexavalent chromium, cadmium and silver to 0.2 mg/l for arsenic. Today not only the World Health Organization but the U. S. Public Health Service Drinking Water Standards (as shown in Table 1) currently encompass seven metals having rejection values less than or equal to 1.0 mg/l and three more metals having suggested limits of 5 mg/l or less (12).

TABLE 1

U.S. PUBLIC HEALTH SERVICE DRINKING WATER STANDARDS OF 1962

Chemical Characteristics	Suggested Limit (mg/l)	Rejection Value (mg/l)
Arsenic	0.01	0.05
Barium		1.0
Cadmium		0.01
Chromium (Cr ⁺⁶)		0.05
Copper	1.0	
Iron	0.3	
Lead		0.05
Manganese	0.05	
Selenium		0.01
Silver		0.05
Zinc	5.0	

Even though the environmental concentrations of certain trace metals may be below the levels expressed above, they still pose a potential threat to the health of man since there are numerous points in the environment where they may be concentrated to significant levels and returned to the human through the food chain (32, 33).

The biogeochemical interrelationships involved in the process of trace element extraction from soils and water, utilization and concentration by organisms and their eventual release back to the environment in

a form available for re-use describes a cycle of trace metal concentration in its simplest form. The physical law of gravitation essentially requires that the mineral remains of terrestrial organisms be carried down the rivulets and streams into the realm of the aquatic ecosystem (34, 35, 36).

Many minerals selected and concentrated by previous life forms are readily consumed by organisms in the aquatic system. The diversity of aquatic species relates to the variability in demand for the specific kind and amounts of materials essential for cell growth. Selectivity and concentrating ability for trace metals reaches a zenith in the aquatic ecosystem in the members of the fish food chain (17).

Generally, selection and concentration of trace elements depends upon the requirements of the organism and cutoff mechanisms are activated to limit further concentration (20). Exception is noted to this generalization especially in the fish food chain organisms. Trace metals in excess of required amounts continue to be taken up from the medium and can become toxic to the organism (17) or to the next higher organism in the food chain (37).

Much evidence has recently been obtained from radionuclide uptake studies in the concentrating ability of aquatic organisms (17, 33, 38, 39). It matters not to an organism which selectively concentrates copper that the copper be tagged "64" as opposed to "stable" copper.

Typical examples of several concentrator organisms and their ability to concentrate trace elements from the aqueous medium are indicated as follows (17):

ORGANISM	CONCENTRATION FACTOR		
COPPER			
The algae <u>Ochromonas</u>	1,800	to	3,000
Freshwater fish		50	
Marine invertebrates and bacteria	1,000	to	5,000
<u>Sphaerotilis</u>		4,000	
COBALT			
<u>Ochromonas</u>	1,000	to	1,500
Marine plankton		10,000	
Diatoms (<u>Navicula</u>)		250	
Copepods		50	
CHROMIUM			
Brown algae	100	to	500
IRON			
Algae (six species)	1,000	to	7,000
Freshwater fish		10,000	
Marine organisms (grouped)	1,000	to	100,000
The flagellate, <u>Platymonas</u>		1,000	
<u>Ochromonas</u>	1,500	to	4,500
The diatom <u>Navicula conf.</u>		4,200	
The flagellate <u>Chlamydomonas</u>		6,000	
Fish		10,000	
Noncalcareous algae		20,000	
Filamentous algae		100,000	
Phytoplankton		200,000	
PHOSPHORUS			
Algae	5,000	to	13,500
Protozoa		200,000	
Insect larvae		200,000	
Freshwater fish	30,000	to	100,000
Marine invertebrates		40,000	

Additional studies reveal many well-known trace metal concentration plants and animals which pose potential health hazards to man. The

plant Astragalus racemosus is known to concentrate selenium from the soil into its leaves to a concentration of more than 14,000 ppm (37), a level sufficient to kill a cow. The lowly mushroom concentrates silver into its cell tissues to more than 100 mg/kg of tissue weight (17), and the oyster concentrates zinc from sea water into its tissues to a concentration factor (C.F.) of 5,000 (17). Copper concentrated by the oyster makes it unfit to eat at a C.F. of 3,000 (17).

Aside from the ability of certain organisms to concentrate metals from non-toxic levels in the aqueous phase of the aquatic environment to toxic levels in the food chain, trace metal pollution has an additional effect on the aquatic ecosystem which may alter the utility of the water - that being the effect of trace metals on certain aquatic organisms.

The aquatic organism is a captive of the aquatic medium. Escape from the influx of undesirable or toxic substances poured down upon such an organism is impossible - it must endure or die. During this process some of the trace metals are adsorbed upon exposed surfaces, absorbed into the cells of the organism, or ingested and assimilated into the tissues (17, 33, 39).

Some of the toxic aspects of trace metals to aquatic organisms have been recognized; however, the evidence has been limited until recently due to the lack of techniques having the sensitivities required to measure those minute quantities where toxic trace metal activity occurs.

Although aquatic organisms require certain trace metals at given concentrations for normal cell growth, a higher concentration may become toxic and even lethal to the organism (40). Synergistic effects of trace

metals on organisms in the aqueous medium is a dynamic phenomenon related to the multitude of chemical and physical factors present within the medium at a given time (17).

Controlled laboratory studies on cause and effect relationships of toxic agents introduced to organisms at individual species levels in laboratory waters fail at the very outset to reproduce results obtained in an environmental aquatic medium. The laboratory medium does not contain those compounded variables and interrelationships in which the study of organismic responses to toxic materials should occur. This environment is extremely difficult to reproduce in the laboratory and researchers have been primarily limited to quasi-environmental toxicity studies on aquatic organisms. Results of such studies are seen to differ greatly (41). Consequently, studies of the response of aquatic organisms to toxic materials introduced into the medium are best undertaken with environmental waters (41).

Arsenic (17) introduced into the aquatic system has not been shown to be a highly poisonous substance; its toxicity to fish food chain organisms varies in magnitude from 1.0 to 40 mg/l as As_2O_3 .

Aluminum (17) has been found toxic to stickleback fish in a concentration of 0.1 mg/l as $\text{Al}(\text{NO}_3)_3$ during a one-week exposure.

Barium (17) has been found to be toxic to the alga Scenedesmus at a concentration level of 34 mg/l as $\text{BaCl}_2 \cdot 2\text{H}_2\text{O}$ in a 96-hour TLM and to goldfish at 200 mg/l.

Cadmium (17) has been found toxic to Scenedesmus at a concentration of 0.1 mg/l as CdCl_2 and to Daphnia magna at 0.0026 mg/l. Cadmium acts synergistically with zinc and copper to increase toxicities of all

three metals to aquatic organisms. Calcium and magnesium ion concentrations in hard water act antagonistically towards cadmium toxicity. Calcium also decreases the toxicity of lead, zinc and aluminum to aquatic biota.

Copper (17) is toxic to plankton at 0.015 to 3.0 mg/l and toxicity has been shown to be greater in hard water. The sulfates of copper and zinc, and copper and cadmium exhibit a synergistic effect on their toxicity to fish. Zinc at 8 mg/l is toxic to fish and copper at 0.2 mg/l is toxic, but together zinc and copper act synergistically to kill fish at 1.0 mg/l Zn and 0.025 mg/l Cu. Copper toxicity varies widely among the species of aquatic organisms in the system.

Chromium (17) toxicity to aquatic life varies widely with species, temperature, pH, valence and antagonism or synergism. Some fish have been found to be relatively tolerant to chromium salts but the Diatom navicula is killed at 0.2 mg/l as $K_2Cr_2O_7$. Hexavalent chromium salts have been found to be highly toxic to certain species of aquatic organisms but to other species the trivalent form is more toxic. Schiffman, et al. (42) showed that rainbow trout exposed to low level concentrations of chromium exhibited physiological response by increased blood hematocrit level. Interestingly, this response level was at a concentration greatly below the 24-hr TLm of 100 mg/l as chromium.

Iron (17) immobilized Daphnia magna in Lake Erie water at a concentration level of 18 mg/l as ferric chloride and was toxic to Cyclops vernalis at 116 mg/l. The toxicity of iron to aquatic organisms is increased at pH levels of 5.5 and lower, at increased temperatures, in soft water and decreased dissolved oxygen content, but certain salts have an

antagonistic effect by precipitation of the iron from the water as an insoluble form, thereby making it unavailable directly and relatively non-toxic to the aquatic organisms.

Lead (17) in River Havel water at an alkaline pH and at 24° C was toxic to Scenedesmus at 2.5 mg/l, to E. coli at 1.3 mg/l and to Daphnia magna at 5 mg/l. A 96-hr TLM for fathead minnows has been described at 2.4 mg/l in soft water and 75 mg/l in hard water. Minute quantities of lead and other metallic salts in water have been found to cause a coat of mucous to form over the body of fish and the surface of the gills, resulting in death by suffocation. The toxicity of lead to rainbow trout is increased with a decreased dissolved oxygen (DO) concentration in the water, and calcium at a concentration of 50 mg/l in water containing 1 mg/l of lead acts antagonistically, thus rendering the lead non-toxic to fish.

Mercury as the chloride is highly soluble in water and is extremely toxic to fish (17). Concentrations of 0.01 mg/l are toxic to minnows on exposure from 80 to 92 days and 0.02 mg/l has been observed to be toxic to stickleback fish in 7 days. Copper acts synergistically with mercury to increase the toxicity of mercury towards aquatic organisms.

Nickel (17) is lethal to stickleback fish at 1 mg/l as nickel nitrate. It is more toxic than iron or manganese; however, some fish are reported to live in water at a concentration of 18 mg/l as nickel. Nickel chloride varies widely in toxicity to fish, depending on synergism, pH and species. The 96-hr TLM for fathead minnows in soft water was found to be 4 mg/l and in hard water 24 mg/l expressed as $\text{NiCl}_2 \cdot 6\text{H}_2\text{O}$. Nickel ammonium sulfate is toxic to Scenedesmus at 0.09 mg/l. Synergism

was shown to exist between nickel and zinc which increased the toxicity of each metal to aquatic organisms.

Silver (17) was found to be lethal to stickleback fish at 0.03 mg/l when administered as silver nitrate, and the toxic threshold for sticklebacks was 0.0048 mg/l. The TLm for Scenedesmus occurred at 0.05 mg/l and for Daphnia and Microregma at 0.03 mg/l of silver. Silver nitrate is highly soluble in water, but the sulfate is less soluble. The insoluble salts of silver in water include the chloride, sulfide, phosphate and arsenate.

Zinc (17) has been reported lethal to the stickleback at a concentration of 0.13 mg/l. Jones (17) reported that calcium is antagonistic to zinc toxicity to fish and that a concentration of 0.3 mg/l of zinc is lethal in soft water but 2 mg/l is not toxic in water containing 50 mg/l calcium. Zinc expresses its greatest toxicity towards aquatic organisms. Copper with zinc has a synergistic toxic effect on aquatic organisms in soft water, and zinc with cyanide is more toxic to fish than is cyanide alone (17).

Strain (43) has stated:

It is evident that trace metals in environmental health is an enormous field, both practically and theoretically. The health of man is strongly influenced by the elements. Some are essential to life, others are subtle poisons, and even beneficial elements become toxic as the level increases. Thus, the kinds, amount and interrelationships of these trace substances must be considered in balancing our ecology.

Unknown concentrations of residual trace metal pollutants are being dumped daily into local stream systems as untreated waste by-products from industrial processes. The potential hazards to the health of man; the effects of toxic concentrations of trace metals in his foods;

the effects on birds, fish and wildlife; the effects on livestock; and the effects on that limited natural resource - water - are as yet only partially understood. Immediate steps must be taken to evaluate the extent and magnitude of the trace metal pollution of our natural waters.

CHAPTER III

PURPOSE AND SCOPE

The literature indicates that extensive work has been done in the field of water pollution in the areas of municipal and industrial waste effluents and their effects on human health and the water quality of the receiving stream. It also reveals an increased interest in water as a limited natural resource whose use and re-use is limited by its chemical and physical quality, and that interest in eutrophication has increased due to the problems generated by increased nitrate and phosphate concentrations added to natural waters from waste effluents. However, trace metals as waste products from man's industrial and municipal progress have been almost completely overlooked as low-level residual pollutants particularly with respect to the potential hazards to human health and to the ultimate effects on aquatic ecology.

On the basis of laboratory toxicity studies and bioassays, it is well established that many trace metals are toxic to aquatic organisms in the fish food chain and to the fish themselves. It is also well established that sensitivities to trace metals vary both at the individual species level and according to synergistic and antagonistic effects due to other chemical and physical parameters present within the medium.

The literature abounds with individual studies in the laboratory setting which deal with a single variable under carefully controlled

conditions. Thus it has been seen that even with identical concentrations of certain metals, different levels of toxicity to identical organisms have been published; the difference being most likely due to variations in those chemical and physical variables contained within the medium.

Unfortunately, experimental conditions developed in the laboratory under completely controlled conditions appear to be incompatible with conditions prevailing in the field. Such laboratory results may be valid for indicating general trends or for comparison purposes, but they can be grossly misleading when projected to large-scale environmental conditions. Thus trace metal pollution of natural waters is seen to be a multi-faceted problem whose impact ultimately compounds the effects of those physical, chemical and biological conditions normally associated in the natural environment upon the water quality of the stream and its biota.

The purpose of this investigation was to study the type, extent and effects of trace metal pollution on a natural stream under the full range of environmental conditions and to bring into sharper focus the impact of trace metals as residual pollutants.

To achieve this goal, the lower portion of the NCR, representing water varying from relatively high quality to highly polluted, was studied over a complete cycle of climatic and hydrologic conditions. Specifically, water studies involving the analyses of water and suspended solids for chromium, copper, cadmium, silver, nickel, iron and zinc were conducted on samples from locations covering the 280 river miles and principal tributaries from Oklahoma City through the influent arm of Lake Eufaula. In addition, similar analyses were conducted on samples of fish life and bottom sediment from the lake.

CHAPTER IV

METHODS AND PROCEDURES

A comprehensive river basin survey of the 850-mi length and 15,000 sq mi watershed of the North Canadian River (NCR) Basin was conducted in order to determine more objectively the water use and waste waters generated within the basin and to select the actual sites for the trace metal study. The basin survey entailed a broad sweep of people and their associated activities in an environment physically contained within the drainage basin. An attempt was made to assess those natural resources available to man and to compare his utilization of those resources.

Current basic resource data were gathered, analyzed and oriented in their proper perspective in relation to the entire physical scope of the basin. Comparative studies of the meteorology, geography, hydrology and geology of the entire basin revealed distinct differences in precipitation, temperature, evaporation, elevation, stream gradient, runoff, stream discharge, drainage area, rate of precipitation, minerals, aquifers, and surface and ground water uses. Precipitation averages ranged from 15 in/yr in the upper basin to 40 in/yr in the lower basin. The rate of precipitation in the upper basin was seen to be extremely variable, with many of the annual values reported resulting from a few violent seasonal thunderstorms, causing rapid runoff and short term flood conditions on the river, yet leaving only a trickle of water in the stream a few days

later. Soil evaporation and plant transpiration account for high water losses which at times greatly exceed the amount shown for annual precipitation. Each of these differences were sufficient to warrant division of the overall basin into three separate sub-basins which are described in more detail in Table 11, Appendix A.

Further studies of the basin survey with regard to the people and where they are located resulted in another distinct set of differences within the basin. Again, these differences presented a logical division of the basin into three sub-basins. Populations and political divisions involving about 800,000 people and parts of four states and 26 counties are compared in Table 12, Appendix A.

When compared to adjacent basins, the North and South Canadian River Basins maintain a unique feature with respect to natural water quality. Their watershed drainage is across geological formations which are relatively free from natural salt deposits; whereas, basins to the north and south drain areas of geological outcrops consisting of the highly soluble Permian Age salt beds from which low-quality surface waters are obtained (44). Thus, it is this relatively high quality which greatly enhances the value of waters of the NCR Basin. Geological formations which are exposed by the river are shown in Appendix A, Table 11, and potential groundwater aquifers within the basin are described in Table 15.

Additional analyses of the basin survey data resulted in distinct differences in the economy of the region based on industry and agriculture. Agriculture is the backbone of the economy in the upper basin consisting mostly of dry farming of wheat and sorghums and beef cattle ranching on the larger grasslands; however, the trend to irrigation farming has

increased due to the tremendous ground water resource available in the Ogallala aquifer (45, 46, 47 and 48).

Income from petroleum production was found to be unexpectedly high in an area usually regarded as primarily agricultural. This result was regarded with some question even by the Oklahoma State Corporation Commission. Comparative data describing industry and agriculture for the three divisions of the NCR basin are presented in Table 13, Appendix A. Agricultural acreage is compared for irrigated lands against non-irrigated lands and industry is compared as to types of industry and minerals produced. Thus, a third area of interest having pronounced differences within three sections of the basin provided sound reason for division of the basin into separate sub-basins.

Review of the river basin survey in regard to water uses and waste waters generated within the basin denoted radical differences among upper, middle and lower regions as compared in Table 14, Appendix A. Domestic and industrial waters in the more densely populated and industrialized areas are obtained from lakes and reservoirs, whereas upstream populations rely on groundwater as their source of supply. The waste water survey reveals that some municipalities have been forced to retreat from river alluvium as a source of domestic supply due to gross pollution by upstream cities. This is understandable when streamflow data are compared to sewage discharge data which reveal a ratio of 35 gal of sewage per gal of natural water flowing in the stream. The data are presented for more detailed comparison in Table 18, Appendix A. The waste inventory estimate of 60 MGD from 84 sources does not include wastes produced by the new commercial beef cattle feed lot operations in the upper

portions of the basin or other recent industries, nor does it include federal or military installations located within the basin.

Agricultural water uses showed distinct areal differences for ground water aquifers and surface sources of supply. Data regarding these situations are located in Table 14, Appendix A.

The river basin survey revealed water resource developments in all regions, including the Optima Reservoir currently under construction in the high plains area, and Lake Eufaula - Oklahoma's largest reservoir (area-wise) at the terminus of the NCR basin. The surface and ground water development efforts within the basin (tabulated in Table 16, Appendix A), show exceptional differences for ground water development in numbers of irrigation wells currently in operation between the upper and lower regions.

Water resource development planning programs for the NCR basin are tabulated in Table 17, Appendix A, and reveal an irrigation plan for utilizing over 700,000,000 gallons of treated sewage per month on lands adjacent to the NCR near Oklahoma City. Inspection of Table 18, will show that there would be no water in the NCR at Wetumka at times if this sewage flow were stopped! Planning for development of water resources must necessarily include waste waters, and projected population studies have caused concern that not only will there be inadequate water available in the future, but adjudication over "wastewater rights" will be in evidence.

Administration of water resources within the basin is legally designated by the State Legislature to five separate agencies consisting of the Oklahoma State Health Department, Oklahoma Water Resources Board, Oklahoma State Department of Fish and Wildlife, Oklahoma State Department of Agriculture, and the Oklahoma State Corporation Commission. The North

Canadian River Basin is subject to federal legislation involving interstate waters, and water quality standards have been legally assigned by the State and accepted by the federal government. In spite of, and at least partially due to the multiplicity of agencies involved, there is still an apparent need for total water resource management at the state level, unfettered and undiluted by individualized interests.

Individual surveys consisting of meteorology; geography, hydrology, geology; political divisions; populations; industrial and agricultural economy; municipal, industrial and agricultural water uses; waste waters generated; surface and ground water resource developments; and water resource planning were analyzed. The results of these analyses, both individually and collectively, tended to delineate the NCR basin into three distinct sub-basins. The proposed sub-basins are designated by a map shown in Figure 1, and are described as: the Upper NCR Basin from N. E. New Mexico to Woodward, Oklahoma; the Middle NCR Basin from below Woodward to El Reno, Oklahoma; and the Lower NCR Basin from above Oklahoma City down to and including the NCR arm of Lake Eufaula.

A more intensive review of the three sub-basins revealed the Lower NCR Basin as most appropriately fitting the design criteria for the trace metal water pollution study.

Above Oklahoma City the stream waters are of relatively high quality and are impounded for domestic use in Oklahoma City. Downstream, the river receives storm runoff and local drainage from lower Oklahoma City, treated municipal waste effluents from the major populations and industries of Oklahoma City, the wastes from the large industrial Air Materiel Center at Tinker Air Force Base, and wastes from Shawnee and

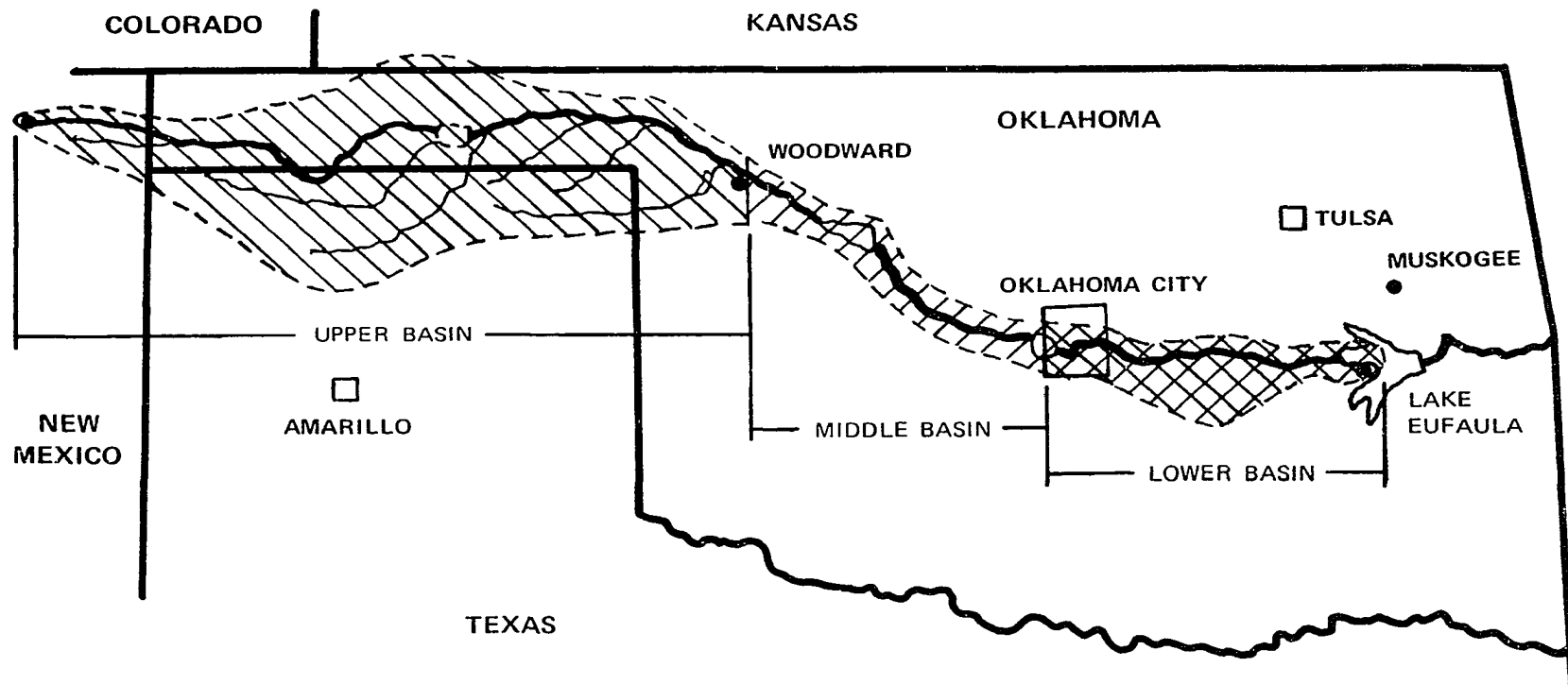


Figure 1--North Canadian River Basin

other municipalities. The river continues for 280 mi from Oklahoma City to Lake Eufaula, a new reservoir which had not reached normal lake level at the outset of the trace metal study.

It was desired to sample multiple ranges of waters from highest to lowest quality and at relatively equal distances between downstream sampling stations on the mainstream and into the NCR arm of Lake Eufaula. Accordingly, a topographic map survey was conducted and extensive ground work was accomplished in the selection of representative station locations for the study of river and lake waters, fish food chain organisms, lake bottom sediments and fish samples for trace metal analyses. The choice of station locations was further based relative to the United States Geological Survey (USGS), Water Resources Division streamflow gaging station at the upper extreme of the basin as a known reference point above Oklahoma City; a second stream gaging station operated by the United States Army Corps of Engineers (USCE), Tulsa District, as a known reference point on the NCR near Wetumka in the middle of the basin; and a third stream gaging station as a known reference point on the Wewoka Creek tributary to the Lower NCR. Unfortunately the latter station was discontinued midway through the trace metal study.

Additionally, upstream station locations were selected relative to the on-going research by the Oklahoma City Water Pollution Control Laboratory, and liaison was established with that laboratory to insure that stations for all upstream samples in this study coincided with their routine sampling locations. Finally, liaison was established with the Oklahoma State Department of Health, Environmental Health Services, Water Quality Control Division for additional suggestions concerning station

locations. Consideration of the above factors led to the selection of the eight most representative mainstream and lake sampling station locations.

In addition to the eight mainstream stations, 13 additional stations were selected in order to include specific tributary streams as well as stations within the lake. Of these, several tributary streams were suspected of containing large concentrations of metals from electroplating wastes. Permission to conduct a tributary stream flow study from wastes generated within the grounds of Tinker Air Force Base was granted, and under the auspices of Dr. Charles H. Lawrence, as Consulting Engineer, eight V-Notch weirs were constructed, emplaced and monitored for data on streamflow leaving the military reservation for a period of several months prior to commencement of the trace metal study. Figure 2 reveals the location of water sampling stations in the Lower NCR Basin and delineates the watershed within the drainage basin.

The following location descriptions include the NCR mainstream, tributary and Lake Eufaula sampling stations as located on the schematic map in Figure 2.

- | | |
|---------------|--|
| Station I | NCR at N.W. 10th Street bridge, 0.5 mi below Lake Overholser outfall, upstream from Oklahoma City proper, at river mile 280. |
| Station II | NCR at N.E. 4th Street bridge, Oklahoma City. |
| Station III-A | NCR at N.E. 23rd Street Bridge (below the Southside Sewage Treatment Plant), Oklahoma City. |
| Station III-B | Soldier Creek tributary to NCR (drains the N.E. corner of Tinker Air Force Base) at Interstate Highway No. 40. |

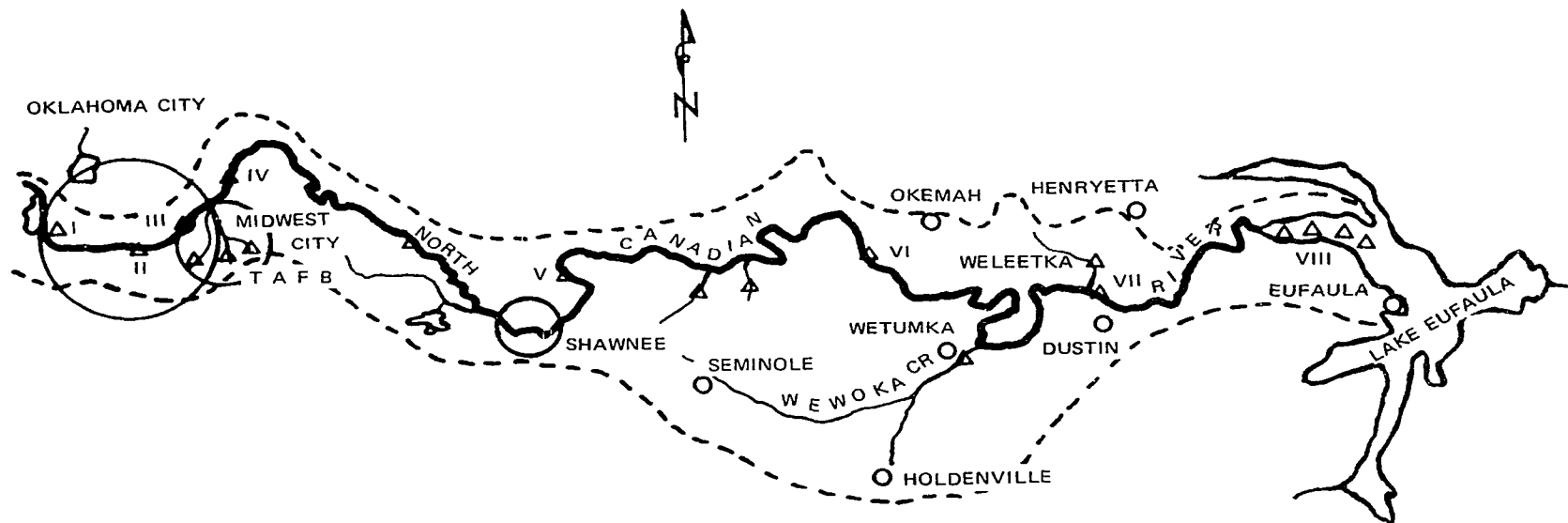


Figure 2--Schematic representation of the Lower North Canadian River Basin water sampling stations and locations.

- Station III-C Crutcho Creek tributary to the NCR (drains the western portion of Tinker Air Force Base) at Interstate Highway No. 40.
- Station III-D Industrial Boulevard Drainage Ditch tributary to Soldier Creek (drains the north-central portion of Tinker Air Force Base) at Interstate Highway No. 40.
- Station IV-A NCR at N.E. 63rd Street bridge, below Spencer, Del City, Midwest City and Tinker Air Force Base waste water treatment plants.
- Station IV-B NCR about 5 mi above Shawnee at Interstate Highway No. 40.
- Station V-A NCR at Interstate Highway No. 40 bridge, about 7 river miles below Shawnee.
- Station V-B Turkey Creek tributary to the NCR at Interstate Highway No. 40 bridge, 10 mi east of Station V-A.
- Station V-C Sand Creek tributary to the NCR at Interstate Highway No. 40, 3 mi east of Turkey Creek.
- Station VI-A NCR at Interstate Highway No. 40 bridge, 1 mi west of Bearden-Castle Interchange.
- Station VI-B Wewoka Creek tributary to the NCR, located 3 mi east of Wetumka on State Highway No. 9 bridge.
- Station VII-A NCR at State Highway No. 84 bridge, 2 mi north of Dustin and below the Wewoka Creek tributary.
- Station VII-B Upper Bad Creek tributary to NCR, located 1 mi south of Pharoah on U.S. Highway No. 75 bridge.
- Station VII-C Lower Bad Creek tributary to NCR, located on State Highway No. 84 bridge, 2 mi upstream from Station VII-A.

Station VIII-A Lake Eufaula, in the vicinity of the mouth of the NCR including samples taken in the area included in:

- a) SE 1/4 of SW 1/4 of SE 1/4 of Sec. 19, T 11 N - R 15 E, Hoffman, Oklahoma quadrangle.
- b) SE 1/4 of NW 1/4 of NW 1/4 of Sec. 29, T 11 N - R 15 E, Hoffman, Oklahoma quadrangle.
- c) SW 1/4 of NW 1/4 of NE 1/4 of Sec. 28, T 11 N - R 15 E, Hoffman, Oklahoma quadrangle.

Station VIII-B The upper-middle NCR arm of Lake Eufaula at Dogwood Acres 2 mi south of Pierce, Oklahoma, which represents the base station for Lake Eufaula.

Station VIII-C Lake Eufaula, 3 mi below Station VIII-B, including samples taken in the area of:

- a) Center of NE 1/4 of Sec. 25, T 11 N - R 15 E, Pierce, Oklahoma quadrangle.
- b) Old Channel, NE 1/4 of NE 1/4 of SE 1/4 of Sec. 25, T 11 N - R 15 E, Pierce, Oklahoma quadrangle.

Station VIII-D The lower NCR arm of Lake Eufaula above the confluence with the Deep Fork River, and about 2 mi above Fountain-head Lodge. Samples taken in the area to include:

- a) NE 1/4 of SW 1/4 of Sec. 32, T 11 N - R 16 E, Pierce, Oklahoma quadrangle.
- b) Old NCR Channel, SW 1/4 of SW 1/4 of SE 1/4 of Sec. 32, T 11 N - R 16 E, Pierce, Oklahoma quadrangle.

Duplication of effort in the trace metal pollution study was

minimized and liaison was established with the USCE, Tulsa District, Hydrology Branch and the USGS, Oklahoma District, Water Resources Division at Oklahoma City concerning routinely scheduled stream discharge data on the upper and lower sections of the Lower NCR Basin and for chemical and physical analyses of water samples from the middle and lower sections. These analyses included determinations of sodium (Na), bicarbonates (HCO_3), carbonates (CO_3), sulfates (SO_4), chlorides (Cl), nitrates (NO_3), phosphates (PO_4), dissolved solids (DS), hardness and specific conductance, as shown on Tables 18 through 26 in Appendix B.

The Oklahoma City Municipal Water Pollution Control Laboratory provided waste flow data on treated municipal wastes from the Southside Sewage Treatment Plant at Oklahoma City and current routine data on chemical and biochemical analyses of the waters in the upper section of the Lower NCR Basin. These analyses included determinations of biochemical oxygen demand (BOD), chlorides, alkalinity (Alk), nitrates and phosphates as shown in Tables 18 through 22.

Mr. LeRoy K. Rachels, Entomologist for the Oklahoma State Health Department, Water Quality Control Division, Water Pollution Control Section, identified and quantified the phytoplankton and zooplankton fish food chain organisms in the samples collected and prepared during the trace metal study. The tabulated data are included in Table 49, Appendix G. Dr. Carl D. Riggs identified the species and the individual ecological positions in terms of food preference and environmental habitats of those fish collected for analysis in the trace metal study. Fish species along with tissue weight data are tabulated in Table 50, Appendix H.

In order to provide an objective check on atomic absorption

analyses and to provide additional parameters of trace materials included in lower NCR waters, and to further establish a known base for future water research in the Lower NCR Basin, 20 water samples representing all mainstream and lake stations for various seasons of the year and including both surface and bottom waters, were selected for duplicate and additional analyses for trace materials by emission spectrograph, the results of which are shown in Table 47, Appendix F. This service was provided in part by Dr. Bobby J. Gunter and by Mr. John F. Kopp, Metals Analyses Group Leader and his Analytical Quality Control Laboratory staff, of the Division of Water Quality Research, Federal Water Pollution Control Administration, U. S. Department of the Interior, Cincinnati, Ohio. Such thoughtfulness and expertise have added significantly to the aims of this study.

The spectrographic analyses served a final purpose in the trace metal study by making possible correlation of the results of this study with trace metal studies performed in the 65 major river basins of the world. The 12 most representative river basins in the United States and Canada (49) were selected for comparison (Table 48, Appendix F) of trace metal content with the Lower NCR Basin.

Thus, desirable additional parameters of water quality, stream flows, and waste flows were planned and built into the execution of the trace metal study, which encompassed a relatively comprehensive environmental survey of waters of the Lower NCR Basin and included parameters for: Ag, Al, B, Ba, Be, Cd, Co, Cr, Cu, Fe, Mn, Mo, Ni, P, Pb, Sr, V, Zn, temperature, pH, DO, BOD, Na, Cl, Alk, NO_3 , PO_4 , HCO_3 , SO_4 , DS, hardness, specific conductance, natural streamflow, municipal waste flows and industrial waste flows, as well as an inventory on phytoplankton and

zooplankton as fish food chain organisms and their trace metal content, trace metal concentrations in lake bottom sediments, and trace metal concentrations in a selected ecological cross-section of fish species from Lake Eufaula waters.

In order that the samples might represent daily as well as seasonal variations in both the stream characteristics and effluent discharges, the scheduling of sample collection was based on irregular intervals, at different hours and varying days of the week and periods of the month.

Sample collection was accomplished in such a manner as to minimize contamination of the sample from any metal not actually present in the water. Surface samples were taken with a minimum of aeration, from the center of the main volume of stream flow over the side of bridges in a 1-gal, open top, polyethylene sampler which was secured by a nylon cord.

Bottom samples were taken in a weighted 1-l polyethylene bottle designed with a dual purpose two hole cap and a nylon cord attached to a surgical rubber tension device which operated to extract a wooden plug from the cap at any desired depth, thus allowing water to flow directly to the bottom of the sampler through a polyethylene tube inserted through the second hole in the cap, expelling air through the discharge vent in the top of the cap. Thus, a non-aerated, representative bottom sample was obtained without contamination by water from intermediate depths.

Water samples were collected and analyzed immediately in the field for pH, DO and temperature, then placed in 30-ml polyethylene containers, acidized to 1 percent HNO_3 and reserved for trace metal analysis in the laboratory by atomic absorption spectroscopy. All pH determinations were made with pHdrion short-range papers of 0.2 pH unit

discrimination. DO analyses were conducted with equipment furnished in the Hach DR-EL water analysis field kit.

Phytoplankton and zooplankton samples from surface and bottom waters were obtained identically to surface and bottom water samples and placed in 1-l polyethylene bottles. These samples were then concentrated by centrifugation, stored in 30-ml polyethylene bottles and refrigerated until identified and quantified.

Lake bottom sediment samples were obtained from seven locations over 14 mi of the NCR arm of Lake Eufaula. Vertical sediment cores were collected and sealed within 1-cm hollow plastic cylinders contained within a 9-lb steel core sampler designed to be dropped from a boat, driven into the bottom sediments, and then retrieved to the surface. The ends of the plastic tubes were plugged, the cylinder removed from the steel sampler and maintained in a vertical position until analysis in the laboratory for trace metals. The results of sediment analyses are reported in Tables 40 through 46, Appendix E.

Samples of fish representative of both rough and game species as well as varied ecology and habitats, were harvested from the NCR arm of Lake Eufaula and used for a study of trace metal content of various organs and tissues (Table 37, Appendix D) and for comparison against trace metal content of water, food organisms and sediments as shown in Table 6, page 53. Fish samples were collected from Station VIII-B in Lake Eufaula on two different occasions, one of which was during an obvious on-going fish kill. The fish affected appeared to be the gizzard shad and freshwater drum, and the extent of the kill was indicated by a count of 50 fish in a circle 6 ft in diameter along the windward shore.

The other fish selected for trace metal analysis from Lake Eufaula waters included species selected on the basis of specific fish food habits and ecology and included the channel catfish, white crappie and the carp, all of which were collected live by fishermen.

Field and laboratory containers which contacted samples were detergent washed, rinsed in deionized water, acid washed in 2N HNO_3 , triple rinsed in deionized water and sealed until used. Pyrex beakers to be used in ash weight determinations were marked and ignited at 600° C in the muffle furnace. All samples and standards presented for trace metal analysis by atomic absorption spectroscopy were in the liquid state in 1 percent HNO_3 solution.

Weight analyses for wet, dry and ash samples were performed to the nearest 0.00001 g on a Mettler Gram-atic balance. All weight analyses except wet weight were preceded by dessicating at room temperature. Drying of samples was done in a forced draft drying oven at 103° C for 24 hours and ashing was accomplished in a muffle furnace at 500° C overnight. Deionized water was used for all rinsing and dilution procedures. All samples were reconstituted to 5 ml except phytoplankton and zooplankton samples which were reconstituted to original measured sediment volume with 1 percent HNO_3 .

Phytoplankton and zooplankton samples were collected and placed into 1-l polyethylene bottles, refrigerated at 4° C, then centrifuged at 4° C at 2000 x g in 60 ml plastic centrifuge tubes for 30 min, followed by decantation of 90 percent of supernatant. With the aid of a rubber policeman, the sediment was quantitatively transferred into a 30-ml polyethylene bottle and refrigerated at 4° C until identification and

quantification by the drop sedimentation method. Identification and quantification was to include those genera observed in two optical passes of the drop under the cover slip of the microscope slide. One drop was considered to contain approximately 0.05 ml and two optical passes covered about 2 percent of the total area.

Identification and quantification was followed by measuring the total volume of sediment and contained supernatant with a 25-ml graduated cylinder, followed by quantitatively transferring the sample into a 40-ml beaker, drying, weighing, ashing, weighing and reconstituting with 1 percent HNO_3 to the original measured volume. Samples were then agitated and warmed several times and reserved for trace metal analysis by atomic absorption.

Seven lake bottom sediment samples were refrigerated until being divided into three major fractions consisting of the overlying core water, the water-sediment interface fraction and the sediment fraction. The overlying core water was removed to within 1 cm of the sediment into a 30-ml polyethylene bottle, acidized and reserved for direct analysis for trace metals by atomic absorption. The interface fraction consisting of the bottom 1-cm of overlying water and the top 1-cm of sediment was removed into a 20-ml beaker. Each successive 2-cm fraction of core was removed and placed into a 20-ml beaker.

The wet weights of the interface and core fractions were determined, followed by drying, dessicating, weighing, ashing, dessicating and weighing. Preparation of bottom cores for trace metal analysis by atomic absorption was accomplished by reconstituting each interface and core sample to 5 ml with 1 percent HNO_3 , following which the samples were

agitated and warmed to insure solution of the metals.

Five fish were collected, weighed, measured for total length, identified to species and frozen until dissection. Organs and tissues of interest included gills and gill filaments, contents of alimentary canal, the stomach and intestines, liver, skin (with scales, if present) and muscle, each of which were carefully removed and placed into 20-ml beakers.

Dissection was followed by wet weighing, drying, dessicating, dry weighing, ashing, dessicating, and final weighing. Reconstitution of the ashed samples to the liquid form was done in the same manner as described for the core samples.

Trace metal standards for samples in the study (with the exception of cadmium) were prepared by serial dilution from individual Certified Atomic Absorption Standard Metal Reference Solutions obtained from Fisher Scientific Company, Chemical Manufacturing Division, Fair Lawn, New Jersey, and diluted to at least seven standards covering each of the following ranges of concentrations (in mg/l): Fe 0.100 to 25.0; Ni 0.050 to 10.00; Cu 0.025 to 2.50; Zn 0.005 to 1.00; Ag 0.005 to 1.00; Cr 0.025 to 2.50; Cd 0.001 to 0.500. Cadmium reference solution was prepared in the laboratory from 0.996 g of a cadmium metal stick of Baker and Adamson quality obtained from General Chemical Company, New York, New York, dissolved in 10 ml of concentrated HNO_3 , reconstituted to 1000 ml in a volumetric flask and diluted to the desired concentration. Instrument operational parameters typical for atomic absorption analyses performed are shown in Table 2.

The hollow cathode (HC) tubes employed were of the single element type manufactured by Westinghouse and Jarrell-Ash and the

TABLE 2
ATOMIC ABSORPTION OPERATIONAL PARAMETERS
FOR TRACE METAL ANALYSES

Metal	Analytical Line Å	Optic pass	H. C. Current ma	Burner	Burner ht. mm	PM Tube V	Gain %	Fuel (H ₂) psi	Oxidant (Air) psi	Scale Exp.	Sensitivity mg/l
Fe	2483	5	20	Hetco	110	490	25	15	30	2X	.100
Ni	2320	5	18	Hetco	115	520	70	14	30	2X	.100
Cu	3247	5	6	Hetco	109	500	20	8	22	2X	.025
Zn	2139	5	10	Hetco	110	500	80	6	13	1X	.010
Ag	3281	5	8	Hetco	110	520	10	23	33	2X	.010
Cd	2288	5	6	Hetco	123	650	80	10	31	2X	.005
Cr	3579	1	5	Tri-Flame	10	540	10	7	23	5X	.025

photomultiplier (PM) tube was an HTV R-106. Entrance and exit slits to the monochromator were each 100 μ wide. The recorder was a Beckman 10-in operated with a Beckman scale expander (Scale Exp.) having capabilities of 1 to 10X expansion with zero suppression. Chromium was analyzed using the Tri-Flame, 10-cm laminar flow burner with the emitted chromium beam centered 2 mm above the slot of the burner head. The adjustable burner mount was used for the chromium analyses at position 10, but all other burner heights refer to the actual heights of the Hetco burner orifice above the optical bench.

Analytical values for trace metal standards were obtained from the output trace of the 10-in Beckman strip chart recorder in units from 0 to 100, 10 units per inch. Analytical curves for trace metal standards were established on 2 X 3 cycle logarithmic paper by plotting known standard concentrations against units of recorder output. All samples were analyzed in the manner described above and values obtained were plotted against the analytical curve established at the same time sample analyses were performed. Standards were run every tenth sample as a check on instrument stability. Typical values from analytical curves are given in Table 3.

Samples exhibiting concentrations of metals outside the above ranges were analyzed by varying the scale expansion from 1X, 2X, 5X to 10X, and employing the appropriate standards. Linearity of the analytical curves was observed and serial dilution was performed on samples of high concentrations in the effort to maintain readings of trace metals within the linear section of the analytical curve.

TABLE 3
ATOMIC ABSORPTION RECORDER OUTPUT FOR TRACE METAL STANDARDS

Metal	Scale Expansion	Concentration of Metal Standards (mg/l)								
		0.005	0.010	0.050	0.10	0.50	1.0	2.5	5.0	10.
Cd	2X	1	2	8	14	62	-	-	-	-
Ag	2X	.8	1.5	6	11	48	88	-	-	-
Zn	1X	-	1	4	7	25	45	-	-	-
Cu	2X	-	-	2	4	16	30	-	-	-
Cr	5X	-	-	2	4	20	39	-	-	-
Ni	2X	-	-	-	.8	5	11	30	55	89
Fe	2X	-	-	-	.8	3.8	7	14	32	60

CHAPTER V

DISCUSSION OF OBSERVATIONS

The scope of this investigation covers three highly interrelated concepts: (a) the action of trace metal pollutants in the physical and chemical aspects of the aquatic environment, (b) the action of these pollutants in the biological aspects of the aquatic environment, and (c) the impact of these combined effects on the utility of this vital natural resource.

The quantity and kinds of trace metals added to the lower reach of the NCR Basin may be seen in Appendix C. Tables 27 through 35 indicate that trace metal pollution did exist and that these pollutants were added to the environmental waters from industrial and municipal waste effluent and resulted in maximum observed mainstream concentrations (mg/l) of: iron at 12.0, zinc at 0.820, nickel at 0.660, copper at 0.450, chromium at 0.125, cadmium at 0.035, and silver at 0.025. Comparison of these maximum concentrations with Table 1, page 11, reveals potential health hazards with respect to cadmium which is 3.5 times the rejection value for drinking water, and to chromium which is 2.5 times the rejection limit. These maximum mainstream concentration levels are observed to be clustered in the middle four stations of the basin, located downstream from the major sources of industrial and municipal waste effluents.

The highest concentrations were observed in the tributary streams

as shown in Appendix C, Tables 35 and 27 through 33, and include mg/l concentrations for: iron at 14.0, chromium at 7.200, nickel at 6.500, cadmium at 2.800, silver at 2.150, zinc at 1.500, and copper at 0.550. Maximum concentrations appear to be related more to industrial operation loads and processes than to seasonal precipitation fluctuations. Furthermore, observation of these tables indicate this pollution was often intermittent and that occasionally highly concentrated slugs of trace metal releases were observed.

Partial dilution of the heavy slugs of trace metal wastes from tributary streams was usually observed at downstream main channel stations. However, as can be seen from Tables 21 and 22, Appendix B, municipal wastes bearing trace metals were often of such high volume that they could be mapped from station to station downstream for several hundred miles with only slight dilution from downstream tributary flows, and occasionally the concentrations of certain metals were observed to be increased by the tributary flows. Trace metals were observed for possible removal from the system, and further inspection of Appendix C, Tables 27 through 33 shows they were found to be persistent in the mainstream and lake waters. Silver was suspected of being precipitated in the mainstream waters, but concentrations of 0.010 to 0.005 mg/l were traced downstream from station to station for several hundred miles. Sampling of surface and bottom lake waters at the same location and time occasionally revealed higher concentrations of iron and zinc in bottom waters, but for other metals this pattern was reversed or was observed to be without any apparent consistency.

Comparison of municipal waste inflows between Stations II and

III from Tables 27 through 34, Appendix C, reveals trace metals are not removed from municipal and industrial wastes by ordinary waste treatment processes. Treated waste effluents are observed to increase trace metal concentrations in mainstream waters which receive both municipal and industrial waste effluents. The high concentrations of trace metals observed from tributary streams draining the Tinker Air Force Base area of Stations III-B, C and D, and which are added to the mainstream NCR between Stations III and IV, occasionally appear to be grossly inadequately treated, and further inspection of Tables 27 through 35, Appendix C, reveals the impact of 10 MGD inflow of mixed industrial wastes upon the mainstream waters at Station IV. Concentrations were observed to be spotty along the mainstream, suggestive of intermittent discharge of trace metals at the tributary source. Trace metals were found to persist in both the mainstream and NCR arm of Lake Eufaula during and following their downriver and downlake travel. This observation indicates that these pollutants are residual and that they are transported by the river and lake currents and that they persist over long periods of time in the aquatic environment.

The action of these pollutants in the biological aspects of the aquatic ecosystem can be observed from Appendix D, Tables 36 and 37, which reveal that phytoplankton, zooplankton and fish from the river and from the lake contain those same metals found in the environmental waters. Some of these materials are considered "abnormal" and not of an essential nature to these organisms, and are often toxic at levels greatly below those established for drinking water. Plankton samples collected simultaneously with water samples for trace metal analysis were often observed to contain phenomenal concentrations above that level observed in the

water. Concentration factors (CF) for trace metal uptake from environmental waters of several thousand times the level in the water are seen for plankton in Table 38, Appendix D. It is not known which genera are capable of this phenomenon, but 45 genera are classified for these waters and quantified in Appendix G, Table 49. From this table, which includes tributary streams, a noticeable dropout in number of genera and number of organisms occurs at Stations III-B, C and D, indicating that conditions for aquatic life are extremely limited on these tributaries.

Five species of fish representative of an ecological cross-section of Lake Eufaula fish were selected for trace metal analyses on the basis that they include direct plankton feeders, predators, omnivores, bottom feeders, surface algae skimmers, and scavengers, and that they include both rough and game species. Appendix D, Table 37 shows trace metal data for the GI tract, skin and scales (if present), muscle, gills and gill filaments and liver of the channel catfish, white crappie, gizzard shad, freshwater drum and carp. The liver appeared to be uniformly the organ of high metal content and the muscle, which is of importance in this study because of the food link to man, was found to contain the lowest amount of metal for the fish studied. A difference was noted in the fish which were collected during the on-going fish kill because their tissue appeared to have higher metal concentrations than those fish collected alive. Table 39, Appendix D illustrates the concentration of trace metals in the fish above those levels present in the ambient water. The pattern for trace metal accumulation in fish muscle appears to be $Zn > Fe > Ni > Cu > Cr > Cd > Ag$. Cadmium and silver were of relatively low concentrations in comparison with chromium, nickel, zinc and copper.

Analyses of the contents of the stomach and intestinal tract of some species revealed high CFs above the level observed in the water, suggesting ingestion to be the principle mode of entry. For example, inspection of Table 39, Appendix D, shows the carp to have a CF for Zn at 410, the gizzard shad a CF for Ni at 50, Cd in the freshwater drum at a CF of 72, Cu in the carp at a CF of 25, Ag in the white crappie with a CF of 1.0, Cr in the gizzard shad with a CF 15, and in the channel catfish at 11. The observed CFs for most metals in the liver of most species of fish appears to be related to the CFs observed in the gastrointestinal tract and contents, and suggests a possible relationship to metabolic or detoxifying mechanisms from trace metals ingested via the food chain. Differences in CFs for the GI tract and liver also suggest a possible relationship to the time factor involved between feeding and capture. Furthermore, it may occur that specific trace metals are retained in the liver over longer periods of time. The muscle in most species is generally observed to exhibit a lower CF than either the GI tract or liver, and is felt to represent true uptake of trace metals from the environment--either through the aquatic food chain organisms by way of the alimentary canal or by diffusion from the medium. Evidence is offered by the live species that trace metal concentrations in the muscle are related to those concentrations found in the stomach and liver, and that fish do concentrate trace metals above the levels observed in water.

Lake bottom sediments provide an interesting, long term assessment for trace metals entering the lake environment, and the data may be seen in Appendix E, Tables 40 through 46. Vertical core sediment columns were analyzed for trace metals starting at the water-sediment interface

and at each successive 2-cm sediment section thereafter. As can be seen from the tables for each metal, and almost without exception, the interface fraction contained the highest concentration of trace metals. Since this represents the point of greatest benthic biological activity, these metals are, therefore, made readily available for recycling by biological organisms in the fish food chain, and are additionally in a position of semi-suspension--capable of being recycled by water currents or overturn of the lake water and consequently redistributed throughout all layers of lake water. Thus, trace metals are available for recycling at the interface and in the unconsolidated deeper sediments.

Interface fractions also reveal a considerable CF for trace metals above that average concentration observed in the overlying lake waters. The ranges and average CF for seven lake bottom interface samples collected from 14 lake miles in the NCR arm of Lake Eufaula are shown in Table 4. Interestingly, the pattern of CFs observed for fish muscle is followed relatively closely by the CF pattern exhibited at the interface. Another observation is the extreme range found for iron, for which the average value shown is felt to be somewhat unrealistic until much further detailed work is accomplished. However, it is felt that the range is realistic, and that iron may be "pocketed" at times under specific physical and chemical conditions of the water and lake bottom. Furthermore, Oklahoma is noted for its red soil which is high in iron content, and accordingly it is felt that some of this metal originates naturally within the drainage basin. Without exception for the other six metals, the average observed for all samples strikes approximately the middle of the range, and the range is observed to be quite small. Nickel was found to

TABLE 4

RANGE AND CONCENTRATION FACTOR FOR METALS
AT THE WATER-SEDIMENT INTERFACE

	Metals in Water mg/l				Metals in Water-Sediment Interface (mg/kg wet wt)				Average CF
	Range		Average		Range		Average		
Fe	ND	-	3.7	1.93	11.0	-	6,122.	992.	514
Ni	ND	-	0.22	0.027	1.5	-	3.9	2.15	80
Zn	0.015	-	0.42	0.14	4.0	-	10.0	6.00	43
Cr	ND	-	0.050	0.012	0.19	-	0.89	0.49	40
Cu	ND	-	0.34	0.077	0.38	-	1.19	0.69	8
Cd	ND	-	0.013	0.0032	0.012	-	0.040	0.025	8
Ag	ND	-	0.010	0.0015	0.005	-	0.011	0.007	5

concentrate fairly heavily at the interface, and was also consistently found to be highly concentrated in the gill of all species of fish as shown in Table 39, Appendix D. Zinc and chromium were both observed to concentrate at the interface at approximately the same ratio; however, the actual quantity of zinc at the interface was ten times the quantity of chromium. Copper and cadmium appear to have been concentrated equally, but quantitatively, copper contained nearly three times the amount at the interface as did cadmium. Silver is observed to persist throughout the downriver course and throughout the 14 miles of lake and is shown to have been concentrated at the interface by a factor of five times the average level observed in the waters of the lake during the period of study.

Further study of Tables 40 through 46, Appendix E, reveals the 2-cm sediment core fractions to exhibit an interesting pattern of cyclic concentrations for each metal. Such a cycling phenomenon suggests intermittent slugs of trace metals were carried into Lake Eufaula by the NCR over long periods of time, and that trace metal pollution of this river basin was not new. Studies of sedimentation rates with extensive trace metal core studies would serve to delineate the time factor involved which has been shown to exist by core samples observed during this study. Ultimately, it is felt by this observer that the potentially toxic metals present at the interface cannot be dismissed as being non-hazardous merely due to their position at the bottom of the lake, but that these concentrations have significance in that they may play a deleterious role in the future ecology of Lake Eufaula.

The impact of trace metal pollutants from industrial and municipal wastes added to waters of the LNCR basin is revealed by comparison

of the combined individual physical, chemical and biological aspects in their relation to the ultimate effects exerted on the total aquatic system. Trace metal concentrations were observed in Lake Eufaula waters in amounts unacceptable according to USPHS drinking water standards for cadmium and chromium.

These waters exert an effect on the fish and other aquatic organisms within the ecosystem. Levels were observed (Table 5) at which toxicity is known to occur for certain fish and microorganisms (17).

From this table it may be seen that Lake Eufaula waters were observed to, on occasion, contain trace metal concentration levels which varied from 1 to 16 times the level known to be toxic to specific aquatic organisms, and from less than 1 to more than 3 times the known toxic level for certain fish.

Previous observations have indicated that the NCR waters contained, transported and caused trace metals to be reconcentrated in the lake bottom sediments to relatively high concentrations and that these waters caused plankton and fish to exhibit abnormal metals in their tissues and caused the plankton, lake bottom sediment and fish to exhibit trace metal levels above that level found in ambient lake waters. The behavior of trace metals in these materials and the relationship between them and average lake water concentrations is reviewed in Table 6. Interestingly, metal content levels in the fish muscle generally appear to follow the pattern established by the water, the plankton, and the interface. Relative trace metal accumulating characteristics were observed for these concentrating systems, and are compared as ratios based on ashed concentrations in Table 7. This comparison is necessarily based

TABLE 5
TOXICITY OF TRACE METALS IN THE AQUATIC ECOSYSTEM

Metal	Lake Eufaula Waters (mg/l)	Toxicity to Aquatic Organisms (17) (mg/l)	Toxicity to Fish (17) (mg/l)	Species	Form (17)
Ag	.010	.005 <u>D. Magna</u>	.003	Stickleback	AgNO ₃
Cd	.013	.003 <u>D. Magna</u>	.030	Salmon fry	Cd + Zn
Cr	.050	.050 <u>D. Magna</u>	1.200	Stickleback	Cr ₂ (SO ₄) ₃
Cu	.340	.050 <u>D. Magna</u>	.140	Trout	CuSO ₄
Ni	.220	.050 <u>Microregma</u>	.800	Stickleback	Ni(NO ₃) ₂
Zn	.420	.024 <u>D. Magna</u>	.300	Stickleback	ZnSO ₄
Fe	3.700	Variable	.2 to 50	General	Variable

TABLE 6
TRACE METALS IN THE NCR ARM OF LAKE EUFAULA

Metal	Water (mg/l)	Phyto- and Zooplankton (mg/kg of Ash)	Water-Sediment Interface (mg/kg of Ash)	Fish Muscle (mg/kg of Ash)
Fe	2	7,000	1,400	128
Zn	0.14	270	45	216
Cu	0.08	90	6	30
Ni	0.03	25	22	41
Cr	0.013	50	4	9
Cd	0.003	8	0.3	1.5
Ag	0.001	6	0.1	0.4

on ashed weight determinations due to the diversity of materials represented among the samples of plankton, the water-sediment interface and the fish muscle, and is relative to the concentrations observed between the water and these three materials.

TABLE 7
RATIOS OF CONCENTRATIONS OF TRACE METALS
IN VARIOUS MATERIALS IN LAKE EUFAULA

Metal	Lake Water (mg/l)	Lake Plankton and other Suspended Material (Ratio)	Lake Water-Sediment Interface (Ratio)	Lake Fish Muscle (Ratio)
Fe	2.	55	11	1
Zn	0.14	6	1	5
Cu	0.08	15	1	5
Ni	0.03	1 ⁺	1	2
Cr	0.013	12	1	2
Cd	0.003	26	1	5
Ag	0.001	60	1	4

With the exception of iron, the following relationships are observed: the interface was the lowest accumulator system with respect to ambient concentrations in the lake waters; intermediate in trace metal accumulating propensity was the fish muscle; and the highest apparent accumulator system studied appears to be the plankton and other suspended materials which, with the exception of nickel, was outstandingly high. These interesting ratios appear to indicate specific accumulator system affinities for specific trace metals. The extremely variable plankton/interface ratios seem to indicate the need for a more detailed study of

the plankton accumulator system for each metal than limitations of time allowed during this study. However, a consistent pattern of trace metal accumulation is observed for these three concentrator systems shown to be operating in the aquatic ecosystem.

It has been observed that LNCR waters not only cause residual pollutants to be concentrated within the ecosystem, but that they are observed to be cumulative in the lacustrine environment which ultimately increases the environmental background level of trace metals with respect to time. Observations of the behavior of these residual materials have revealed them to be transported by stream waters, to be concentrated by various mechanisms, to be cumulative and not readily removed from the system, to be available in increasingly concentrated forms for recycling throughout the aquatic environment by the physical, chemical and biological mechanisms, and to possibly exert their ultimate effects over and over again in the natural cycles associated with the lacustrine ecology.

These waters were observed to cause the flesh of fish to reach trace metal levels above those considered to be the upper limit for normal dietary intake of trace metals for humans as is revealed in Table 8.

Normal adult dietary intake for chromium is observed to be exceeded from a similar diet of Lake Eufaula fish by a factor of ten, and for nickel by a factor of 5. Since nickel and chromium are known to be carcinogens in man, a diet of fish from these waters is felt to pose a potential health hazard to man.

Further inspection of Table 8 reveals that although silver and cadmium in fish muscle are at concentrations well below that level considered to be a normal dietary intake, it should be noted that a diet of

TABLE 8
DIETARY SIGNIFICANCE OF TRACE METAL CONTENT
OF LAKE EUFAULA FISH

mg of Metal per 750 g of Dry Daily Diet					Comparison of metal intake from Lake Eufaula fish relative to established normal daily dietary metal intake
Metal	Lake Eufaula Fish Muscle	Dry Daily Diet (16)			
		Normal	Toxic	Lethal	
Cr	0.495	0.05	200	3000	10x
Ni	2.18	0.3 - 0.5	---	---	5x
Zn	11.25	10 - 15	---	---	1x
Cu	1.58	2 - 5	350	---	0.5x
Fe	6.0	12 - 15	---	---	0.5x
Ag	0.025	0.06 - 0.08	60	1300	0.33x
Cd	0.080	0.6	3	---	0.14x

lake fish can add considerably to the total body burden of these metals, and that other environmental sources may serve to increase silver and cadmium intake to a level exceeding the normal level of 0.00008 g for silver and 0.0006 g for cadmium, thereby posing a potential health hazard to man. Those levels observed in fish for zinc, copper and iron are not considered to pose health hazards to the human.

These waters were observed to contain exceptionally high trace metal concentrations relative to the values observed in other major river basins of North America. This is illustrated in Table 9 in which the maximum trace metal concentrations of the LNCR mainstream waters are compared with the maximum concentrations observed over a 2-yr period in twelve of the major river basins of the U. S., Canada and Alaska.

TABLE 9

TRACE METALS IN WATERS OF LOWER NCR BASIN COMPARED
TO WATERS OF THE 12 MAJOR RIVER BASINS
OF NORTH AMERICA

Metal	Lower NCR Basin ($\mu\text{g/l}$) Max.	Major River Basins of USA and Canada	
		($\mu\text{g/l}$) Max.	River Basin
Ag	0 - 25	0 - 1	Colorado R., Arizona
Cr	0 - 125	2 - 84	Mississippi R., Louisiana
Cu	0 - 500	4 - 105	Susquehanna R., Maryland
Cd	0 - 35	----	----
Fe	0 - 12,000	663 - 1,670	Mississippi R., Louisiana
Ni	0 - 660	5 - 71	Hudson R., New York
Zn	0 - 820	0 - 140	St. Lawrence R., Canada

In all cases the LNCR waters revealed the highest maximum trace metal concentrations by factors of from 2 to 25 times. This comparison

takes on more significance when it is realized that the major river basins listed drain some of the most highly industrialized, populated or mineralized areas of North America. In this light, it is alarming that the LNCR basin mainstream waters were observed to contain maximum silver concentrations at a factor of 25 times greater than was observed in any other basin; nickel which was observed at 9 times greater; iron at 8 times, zinc at 6 times, copper at 5 times, and chromium at 2 times greater. Unfortunately cadmium was not included in Durum's report (49).

Twenty water samples, representative of 280 river miles of the LNCR basin at eight mainstream and lake stations including at least one sample from each station and representing samples spanning the Spring, Summer and Winter seasons as well as samples taken under varying hydrological conditions, were selected for trace element analysis by emission spectrography. This method provided a different analytical technique, an objective check for verification of atomic absorption analyses, a means for spectrographic comparison of LNCR waters with the waters of the major river basins of North America, and additional insight for future water studies in the LNCR basin.

The results of duplication of atomic absorption analyses on identical water samples by the Direct Reading Emission Spectrograph compared favorably and while differences were noted both sets of analyses were within the same order of magnitude. This range is not only acceptable by emission spectroscopists, but is even to be expected among the several spectrographic methods currently utilized for trace element determinations. Not only was the desired verification of the atomic absorption analyses provided by the Federal Water Pollution Control Administration

Laboratory at Cincinnati, but also the concern over the extent and degree of trace metal pollution was corroborated. Mr. John F. Kopp, Director of the Metal Analyses Laboratory, expressed his concern over the consistently high concentrations of trace element pollutants in LNCr waters when compared to his analytical experience with several thousand water samples from river basins of the United States (50).

Spectrographic data for the 20 water samples at various stations in the LNCr basin are presented in Appendix F, Table 47, and are compared in Table 48 with maximum concentrations reported by Durum (49) for 12 of the major river basins of the United States, Canada and Alaska. Inspection of these tables for LNCr mainstream and Lake Eufaula waters reveals a succession of interesting concentrations, ranges and comparisons.

Aluminum concentrations ranged from 520 $\mu\text{g/l}$ to 40,000 $\mu\text{g/l}$, with the highest concentration observed at Station VII. Comparison with Durum's report (Table 48) indicates a concentration in the LNCr 16 times greater than the maximum reported for the major river basins of North America. Generally, lake bottom water samples (taken 2 ft above the undisturbed lake bottom) contained considerably higher concentrations than did lake surface samples, as can be observed from Table 47.

Boron ranged from 180 $\mu\text{g/l}$ in the lake to 2,225 $\mu\text{g/l}$ at Station IV, and compares at 43 times the maximum reported from the Colorado River in Arizona during the 2-yr study.

Barium was observed from 90 $\mu\text{g/l}$ in Lake Eufaula surface waters to a maximum of 625 $\mu\text{g/l}$ at Station II and represents a maximum concentration ratio of five times that reported for the Colorado River.

Chromium concentrations ranged from a minimum of 112 $\mu\text{g/l}$ in lake

waters to 500 $\mu\text{g/l}$ at Station III and was six times the maximum reported for the Mississippi River in Louisiana.

The predetermined lower limit of detection prescribed for a "semi-quantitative run" for copper using the emission spectrograph, was established at 67 $\mu\text{g/l}$; thus limiting the minimum observable range of copper in LNCR waters. The maximum concentration of 730 $\mu\text{g/l}$ was observed at Station III and was seven times the maximum concentration reported for the Susquehanna River in Maryland.

Iron was consistently high in LNCR waters and ranged from 1,500 $\mu\text{g/l}$ to beyond the upper spectrographic limit established at 14,000 $\mu\text{g/l}$. The upper limit or "cutoff concentration" was reached at several downstream stations and was observed to be greater than eight times the maximum reported concentration for the Mississippi River.

Manganese concentrations ranged from 97 $\mu\text{g/l}$ in lake waters to 1,560 $\mu\text{g/l}$ at Station IV thus indicating a maximum concentration eight times that reported for the Mississippi River. Nickel ranged from a minimum detectable concentration of 130 $\mu\text{g/l}$ to a maximum of 550 $\mu\text{g/l}$ at Station III, and represents a maximum concentration ratio of eight times that reported for the Hudson River in New York.

Phosphorus concentrations in LNCR waters ranged from a lower limit of detection of 670 $\mu\text{g/l}$ to a maximum of 6,925 $\mu\text{g/l}$ at Station IV. This yields a maximum concentration ratio of 27 when compared to the Mackenzie River in the North West Territory, Canada. Strontium in LNCR waters ranged from less than 27 $\mu\text{g/l}$ to a maximum in excess of 6,600 $\mu\text{g/l}$. Inspection of Table 47 reveals a highly concentrated source of strontium apparently entering the NCR downstream from Station I. Strontium was

observed at greater than eight times the maximum reported for the Colorado River.

Zinc concentrations in the LNCR basin ranged from less than 130 $\mu\text{g/l}$ in Lake Eufaula surface waters to 2,500 $\mu\text{g/l}$ at Station IV, and indicates a maximum concentration ratio of 18 when compared to the values reported for the St. Lawrence River in Canada.

Other metals analyzed by emission spectrography included Ag, Be, Cd, Co, Mo, Pb and V, and the results are entered on Tables 47 and 48. Unfortunately, the lower limits of detection predetermined for each of these metals were established at unrealistically high cut-off concentrations for environmental waters, thereby limiting further meaningful comparisons.

Spectrographically speaking, and without exception, the best quality of water was found at Station I, the control station located upstream from Oklahoma City. With the exceptions of iron at several downstream stations and of aluminum at Station VII, Stations II, III and IV produced waters bearing the maximum concentrations of all trace elements observed at mainstream stations during the study.

Spectrographic comparison of waters of the Lower North Canadian River basin with 12 of the major river basins of North America reveals that, without exception, the North Canadian River of Oklahoma contained greater maximum concentrations of metals, nutrients and other trace elements than any North American river basin reported by Durum.

Possible reasons for the existing high concentrations observed downstream from Oklahoma City might include: natural mineralogical contributions from geological formations within the drainage basin; certain

peculiar uses of water in industrial operations in Oklahoma; maximum utilization of a limited water resource, thus causing a buildup of residual pollutants; minimum dilution of waste waters due to a limited water resource available for dilution purposes; and inadequate treatment of industrial and municipal wastes prior to discharge of the waste effluent to the North Canadian River.

These are extremely high concentrations to be expected in environmental waters due to natural geological or vegetative concentrating mechanisms; consequently, this places the burden of responsibility for the gross defilement of this natural resource primarily upon industrial and municipal polluters. Regardless of how "explainable" these high pollution values might be, no degree of rationalization can ameliorate their effects or toxicity, nor does it infer toleration or acceptance.

Thus, the impact of trace metals added to the relatively high quality LNCR waters by industrial and municipal wastes has been observed to degrade the quality and limit the utility of this vital natural resource. Since residual pollutants are one of the primary limiting factors to be considered in assessing the quality of any water resource for multi-use or re-use applications--the beneficial use of this vital resource could be maximized by protective control measures taken at the source or point of generation of trace metal wastes, thus preventing their entry into natural water courses.

Additional parameters of water quality observed throughout the trace metal study, and considered to be of great importance in an environmental water investigation are included in Table 10. More detailed data are included in Tables 19 through 26, Appendix B.

TABLE 10
ADDITIONAL PARAMETERS OF LOWER NCR WATER QUALITY

Parameter		Ranges Observed At			
		I	II	III	IV
Temp	(°C)	5 - 30	2 - 35	6 - 34	6 - 34
pH		6.5 - 7.5	6.4 - 7.8	5.8 - 7.4	6.6 - 7.5
DO	(mg/l)	6 - 19	7 - 16	3 - 9	1 - 8
BOD	(mg/l)	0 - 7	6 - 38	8 - 25	8 - 28
Cl	(mg/l)	130 - 188	346 - 1,967	401 - 830	386 - 607
NO ₃	(mg/l)	0 - 0.6	0 - 2.5	0.6 - 7.0	0.4 - 4.0
PO ₄	(mg/l)	0.2 - 1	0.5 - 2.9	8 - 36	14 - 36
Na	(mg/l)	---	---	---	---
Alk	(mg/l)	138 - 203	134 - 313	153 - 217	177 - 220
HCO ₃	(mg/l)	---	---	---	---
CO ₃	(mg/l)	---	---	---	---
SO ₄	(mg/l)	---	---	---	---
DS	(mg/l)	---	---	---	---
Hardness	(mg/l)	---	---	---	---
Spec. Cond.	(μ mhos)	---	---	---	---
Streamflow	(MGD)	0.8 - 5.6	0.8 - 5.4	0.8 - 5	0.7 - 5
Waste water Input (Est. Avg)	(MGD)	0	5	30	40
TOTALS Streamflow	(MGD)	0.8 - 5.6	5.8 - 10.4	30.8 - 35	41 - 45

TABLE 10--Continued

Mainstream Stations				Range, All Mainstream Stations
V	VI	VII	VIII	
4 - 28	4 - 31	5 - 31	4 - 30	2 - 35
5.5 - 7.5	5.5 - 7.5	6.0 - 7.0	5.5 - 7.8	5.5 - 7.8
4 - 12	5 - 13	7 - 14	6 - 14	1 - 19
---	---	---	---	0 - 68
92 - 500	92 - 500	6 - 500	210 - 500	6 - 1,967
0.6 - 18	0.6 - 20	0 - 27	0.6 - 18	0 - 27
0.4 - 13	0.4 - 14	0.3 - 14	0.4 - 13	0.2 - 36
54 - 287	54 - 287	21 - 280	114 - 28	21 - 287
---	---	---	---	134 - 313
132 - 260	168 - 260	64 - 192	90 - 260	64 - 260
0 - 14	0 - 14	0 - 20	0 - 12	0 - 20
18 - 118	18 - 118	38 - 100	38 - 118	18 - 118
289 - 1,220	289 - 1,220	611 - 6,360	599 - 6,360	289 - 6,360
198 - 396	296 - 396	68 - 306	168 - 396	68 - 396
496 - 2,120	496 - 2,120	235 - 1,980	973 - 2,020	235 - 2,120
---	---	---	---	---
43	45	50	50	0 - 50
19 - 1,260	22 - 853	34 - 301	37 - 384	1 - 1,260

The importance of water temperatures in any pollution study is directly related to the effect exerted on the total aquatic system due to the change produced by a waste influent on the ambient water temperature. The toxicities of trace metals to aquatic organisms and fish are increased at higher temperatures thereby exhibiting a synergistic effect due to temperature. Elevated water temperatures increase the rate of decomposition of stream bottom sludge causing increased formation of sludge gas, increased multiplication of saprophytic bacteria and fungi in organic wastes, increased oxygen consumption by putrefaction processes, a lowering of the dissolved oxygen concentration of the stream, and thus, collectively affecting the esthetic value of the water.

Temperature extremes observed during the trace metal study ranged from 2 to 35° C and occurred at Station II in an open, unsheltered area of the river between Lake Overholser and N.E. 4th Street. Lake waters at Station VIII having a depth of 17 feet were somewhat tempered and showed extremes of 4 to 30° C, and waters to a depth of 42 ft revealed no thermocline in the NCR arm of Lake Eufaula during the study. All values observed throughout the study were within the range attributable to environmental conditions; consequently, the NCR was observed to be relatively free of thermal pollution.

pH is not only a measure of a potential pollutant, but also a major factor affecting the solubility of practically all solutes, especially trace metals. Often undissociated compounds are more toxic than ionic forms, which is exemplified by ammonia. The toxicity of nickel cyanide to fish has been shown to increase 1,000-fold by decreasing the pH from 8.0 to 6.5. pH levels observed in the Lower NCR mainstream

ranged between 5.5 and 7.8. Three of the downstream stations had the low of 5.5 and Stations II and VIII had the high of 7.8. Lake bottom water at a depth of 42 feet had a pH of 6.5. The lowest pH values occurred during times of heavy rainfall and high water. The range of pH observed throughout this study varied from neutral to acid, thus tending to maintain solubility of most of the metallic pollutants.

Dissolved oxygen (DO) can cause problems in water if the concentration is either too high or too low. Oxygen requirements of the fish vary with the species, activity, age, temperature of the water, concentrations of other substances in the water and several other factors. Decreased DO causes a synergistic effect by increasing the toxicity of metals such as Zn, Pb, Ni, Cu, Cr, Cd, Ag and other toxic substances. Fish appear to do well with as little as 5 mg/l of DO, but less than 2 mg/l is lethal for most fish. Lower NCR waters provided a range of DO concentrations of 1 mg/l at Station IV to 19 mg/l at Station I. Intermediate low concentrations of 3 mg/l were observed at Station III below the waste treatment plant and 4 mg/l at Station V below Shawnee. Lake Eufaula had a range of 6 to 14 mg/l at Station VIII, and for bottom waters at 42 ft the observed DO concentration was 5 mg/l. It appears that the treatment provided for Oklahoma City municipal wastes is usually adequate, but the minimum DO concentrations observed for Stations III, IV, V and VI, which are located immediately downstream from major waste effluents and which include approximately 50 MGD of waste water input to a stream which has an approximate 8-mo daily average flow of 2 MGD, reveals DO concentrations of 3, 1, 4, and 5 mg/l respectively. It is not until Station VII below Weleetka that the minimum DO concentration returns to 7 mg/l. Occasionally high

volumes of runoff from rains or snows, or low quality waters which are released or allowed to bypass Lake Overholser and Lake Hefner serve to flush the channel, but this is the exception rather than the rule. With a daily ratio of 50 MGD of waste water input into 2 MGD streamflow for approximately 8 mo of the year of this study, a ratio of 25:1 is observed as a realistic figure of waste input to streamflow. Thus, it is not surprising that the minimum DO content of the NCR plunges from 7 mg/l at Station II to 3 mg/l at Station III and 1 mg/l at Station IV below the combined effluents of Oklahoma City, Midwest City, Del City, Spencer and Tinker Air Force Base.

The majority of fish kills reported in the United States are due to the reduction of the DO content of the water resulting, primarily, from pollution with municipal sewage. Low DO may be directly lethal to fish or cause synergistic effects which function to increase the toxicity of less toxic substances present in the water and result in massive fish kills. However, it is believed that the fish kill observed during this investigation should be attributed to environmental factors other than a lack of DO especially since the on-going fish kill observed at Lake Eufaula was associated with a DO content of 8 mg/l, both at the surface and at a bottom depth of 17 ft. Surprisingly, in 1965 Oklahoma was rated in the top three states of the nation for the reported numbers of fish killed due to water pollution, being led only by two highly populated, highly industrialized northeastern states (51). The range of DO observed throughout this study indicates that conditions existed occasionally which are known to be directly or indirectly detrimental to aquatic life, or otherwise degrade the quality of the resource, and such conditions are presumed to be

the result of high volume organic wastes added to low volume stream waters.

Biochemical oxygen demand (BOD) measures the effect and not the concentration of a combination of substances and conditions. It is related to the decrease of DO in water relative to the quantities of organic matter present. Each stream and body of water has its own reaeration characteristics. A large, slow moving, warm-water river may be incapable of aerobically biodegrading the quantities of domestic or other organic waste effluents discharged into it, thus producing decreased DO concentrations, septicity and increased growth of saprophytic bacteria which increases turbidity or other undesirable characteristics of stream and lake waters, which in turn produce fish kills and a decrease in the numbers of species and a limitation to the general utility of the water resource. The ranges of BOD for the upstream stations above Shawnee include 0 mg/l for Station I to 68 mg/l at Station II. This high measure was observed upstream from the major waste input from the Southside Sewage Treatment Plant located between Stations II and III and serves as an indication of untreated organic waste discharge entering the NCR between Stations I and II, possibly from the southwestern or south-central section of lower Oklahoma City. The streamflow between these stations is relatively swift, open to reaeration and revealed a minimum DO content of 7 mg/l and a maximum of 16 mg/l. This stretch of stream appears to have reaeration characteristics capable of biodegrading the organic load carried at the time water samples were taken. The minimum BOD noted at Station II was 6 mg/l. The minimum BOD of 8 mg/l was observed at Stations III and IV and maximum values at these stations were 25 and 28 mg/l. BOD values were not

determined for Station V at Shawnee or other downstream stations but the minimum DO relationship indicates that continuous BODs from 8 to 68 mg/l at Stations II, III and IV exerted an increased oxygen demand on the downstream waters which was observed past Stations V and VI. Consequently, recovery to a minimum DO concentration of 7 mg/l was not noted until Station VII which was located in the lower 100 mi of the Lower NCR basin.

Chlorides (Cl) are among the most troublesome anions in irrigation waters and are generally more toxic than are sulfates to most plants. Harmful effects are noted at chloride levels of 100 to 1,500 mg/l. USPHS limits of 250 mg/l have taste implications rather than health effects, and the World Health Organization limits are shown to be 600 mg/l. A general guide for the beneficial use of waters includes maximum chloride concentrations of 250 mg/l for domestic supply, about 50 mg/l for industrial waters, 100 mg/l for irrigation waters and 1,500 mg/l for livestock and wildlife. The range of chloride concentrations in lower NCR waters was observed from 6 mg/l to 1,967 mg/l with the minimum observed at Station VII during a period of very high runoff following several days of heavy rain. The highest value was observed at Station II during normal flow for that station. Upstream chlorides at Station I included a range of 130 to 188 mg/l indicating that the upper reaches of the lower NCR consistently provided waters of the highest quality observed throughout the study and lends support to statements made previously concerning the relatively high quality of NCR waters prior to the addition of industrial and municipal waste effluents. A continuous source of chloride pollution is observed throughout the study between Stations I and II. Municipal and industrial waste effluents are observed to add high volumes of chloride

contaminated waters to the NCR as observed at Station III, which consistently ranged between 401 and 830 mg/l. The maximum concentration observed at all four downstream stations was 500 mg/l, and the minimum value recorded for Station VIII waters was 210 mg/l. Such mainstream values at the downstream stations reveal that chlorides are persistent pollutants and that chloride contaminated wastes of approximately 50 MGD alter the quality of natural waters significantly. Yet waters of the NCR basin are still of relatively high quality with respect to chlorides in comparison with waters of those basins to the north and south which drain areas of natural salt outcrops.

Nitrates (NO_3) represent the end product of aerobic stabilization of organic nitrogen from waste organic material and are found to occur in polluted waters which have undergone aerobic waste treatment processes or self-purification in stream waters. Nitrates are rarely added to environmental stream waters by natural rock disintegration processes or from inorganic industrial wastes. Excessive application of fertilizer to field crops results in nitrates in percolating ground waters, and waste effluents from chemical fertilizer industries are found to increase the concentrations of nitrates found in natural waters. Nitrates are seldom found in high concentrations in natural waters because they are consumed as a major nutrient for all plants including phytoplankton and trees. The USPHS has placed the upper limit of 45 mg/l for domestic water supplies due to the relationship of nitrates in water with the disease infant methemoglobinemia. Fish production is enhanced from high concentrations of nitrates from waste effluents due to increased growth of fish food organisms such as plankton and weeds--which also hasten

eutrophication. Nitrate concentrations observed in lower NCR waters ranged from 0 to 27 mg/l with the minimum station range being expressed as 0 to 0.6 mg/l at Station I and the maximum range observed from 0 to 27 mg/l at Station VII. Minimum observed concentrations of 0 mg/l were expressed at Stations I, II and VII, with the additional stations having less than 1 mg/l as minimum concentrations. The high concentration of 27 mg/l which was located upstream from the Wewoka Creek tributary indicates the maximum concentrations observed are from the NCR mainstream watershed and apparently originated between Shawnee and the Castle-Bearden-Wetumka area. This is a higher concentration than was observed below the Oklahoma City major waste sources which exhibited maximum concentrations of only 4 and 7 mg/l. Thus, concentrations of 18 and 20 mg/l at stations below Shawnee and near the Castle-Bearden-Wetumka area appear suggestive of agricultural crop fertilizer applications or commercial beef cattle feed lot operations. The nutrient value of nitrates at these concentrations indicates a potential hazard for these waters entering Lake Eufaula since this residual pollutant has the potential for causing an algal bloom and the myriad of associated problems in that it appears to have approximately 100 times the concentration for which algal blooms are known to occur.

Phosphates (PO_4) are relatively soluble in water and occur in surface or groundwaters as a result of leaching from minerals or ores in natural processes, from agricultural drainage, as a stabilized product of decomposition of organic matter, from industrial wastes and from municipal sewage due to the increased use of synthetic detergents. Phosphates are rare in surface waters because they act as a fertilizer for plants which

transform phosphates into cell growth by photosynthesis. High concentrations in groundwaters are the result of excessive fertilizer applications to agricultural crops and from nearby commercial beef cattle feedlot operations. Phosphates buffer the acids of the stomach and are detrimental to digestion. Irrigation waters are benefitted by phosphates because they increase the permeability of the soil and act as fertilizer to plants. Excessive discharges of phosphates and nitrates to streams and lakes promote algal blooms which ultimately die and thus result in unpleasant odors, impose additional BOD loads on the water, decrease the DO content and thereby become detrimental to fish, and some may be directly toxic to many forms of animal life. Phosphates can also be beneficial to fish life due to the increased plankton growth which serve as fish food organisms. The average concentration of phosphates in waters of the Columbia River have doubled since the initiation of the Basin Irrigation Project, possibly due to the application of fertilizer to the crops under irrigation. Phosphates in the lower NCR waters are observed to range from 0.2 to 1 mg/l at Station I to the maximum ranges observed at Stations III and IV consisting of 8 to 36 mg/l, and 14 to 36 mg/l, respectively. The high volume of municipal and industrial waste inflow at these two stations reveals minimum concentrations of 8 and 14 mg/l which indicates a constant source of phosphates added on a year-round basis to lower NCR waters. Downstream stations had relatively consistent maximum concentrations of 14 mg/l and minimum concentrations of 0.4 mg/l. Thus, highly concentrated phosphate wastes added to upstream waters are observed to remain in relatively high concentrations throughout the downriver course and into Lake Eufaula. It is known that algal blooms and other detrimental eutrophic effects have

been produced at much lower phosphate concentrations and that the concentrations observed for waters of the lower NCR basin have nearly 100 times the phosphate concentration required for algal blooms.

Other factors that may alter the effects of residual pollutants, especially trace metals, include alkalinity, total dissolved solids and related parameters. Alkalinity (Alk), specifically carbonate (CO_3) and bicarbonate (HCO_3) act as buffering agents against sudden changes in pH, and the concentrations observed serve to protect aquatic organisms from the harmful effects of rapid fluctuation of pH levels, but additionally contribute to the total dissolved load of substances carried by lower NCR waters. The dissolved solids (DS) consist mainly of CO_3 , HCO_3 , Cl, SO_4 , PO_4 and NO_3 , and trace metals such as Fe, Ni, Zn, Cu, Ag, Cd and Cr and other substances, and is increased by chemical waste influents, oilwell brines, irrigation drainage, acids, alkalies, and wash-ins from surface runoff during periods of heavy rainfall. All salts in solution effectively change the chemical and physical nature of the water and can exert harmful osmotic pressure on aquatic organisms. Interactions between these mixed salts and their effects toward other toxic substances may be either of a synergistic or antagonistic nature. Antagonism is generally noted by the decrease in toxicity of toxic metals towards aquatic organisms. Specific conductance (SC) is a measure of the electrical conductivity of a water due to the ion concentration and relates directly to the dissolved solids concentration. Those waters observed to be high in mineral salts may be suspected of pollution by brines and various chemical wastes.

Thus, these additional parameters of water quality, in relation

to trace metals, are observed to have their own effect and interaction within the medium which may affect living organisms. Some may be directly or indirectly toxic, or may act synergistically or antagonistically towards the effects of other toxic substances, or they may effect the beneficial use of the water resource as it pertains to man, fish, aquatic organisms, recreation, livestock, wildlife, irrigation, industry, municipalities and esthetics.

CHAPTER VI

SUMMARY AND CONCLUSION

This investigation was concerned with trace metal pollution in the North Canadian River, its principal tributaries and its terminus - Lake Eufaula. Water sampling sites along the 280 river miles of the Lower NCR Basin from above Oklahoma City to Lake Eufaula included eight mainstream stations, eight tributary stream stations and four lake stations contained within 14 miles of the NCR arm of Lake Eufaula and include samples covering the full range of seasonal variations. Atomic absorption spectroscopy provided the primary means of trace metal analysis for Ag, Cd, Cr, Ni, Cu, Zn and Fe, with emission spectrography providing duplicate and additional parameters for a total of 18 trace elements. Additional chemical, physical and biochemical analyses were correlated with trace metal analyses to include 15 other parameters of environmental water quality such as pH and DO, which were incorporated with hydrological and waste flow data. In addition to the water samples, portions of the aquatic ecosystem were sampled, including 43 genera of phyto- and zooplankton, vertical lake bottom sediment cores and 5 species of lake fish, all of which were analyzed for the same seven metals observed in the water.

Based on the results of the various analytical determinations made during this investigation, the following conclusions have been

drawn:

1. Certain trace metal pollutants have been and, at this writing, are continuing to be added to the North Canadian River from industrial and municipal sources located primarily in the Oklahoma City area. In fact, the maximum concentration of trace element pollutants observed in this river greatly exceeded those reported for the major river basins in North America.
2. During this study, this pollution was primarily in the form of tributary "slugs" of trace metal-bearing wastes which occurred intermittently and were diluted by mainstream flows; in spite of this, concentrations were still observable at values significant with respect to human and aquatic life toxicity.
3. Even when detected at concentrations below the current levels of concern with respect to direct toxicity, trace metals were found to be concentrated to significant levels in the aquatic environment within the planktonic fish food chain organisms, in lake bottom sediments, and in the gastrointestinal tract and tissues of lakewater fish to levels above those observed in the water, and in fact, existed in fish tissues at concentrations potentially toxic to man.
4. Trace metal concentrations in lake bottom sediments were not completely isolated or removed from the environment, but were observed to be available for direct uptake by benthos organisms for re-entry into the fish food chain and also available from the water-sediment interface for recycling throughout the aquatic ecosystem by physical, chemical and biological mechanisms.

5. Trace metals can persist in the environment over long periods of time and for great distances and thus should be classed as "residual pollutants" which limit the utility of the water resource. In view of the peculiar persistent and cumulative characteristics of trace metals as a group, their effects, even at low levels of pollution are inevitable. Such effects should manifest themselves to a greater degree in the more hydrologically stable phases of the aquatic environment such as lakes and reservoirs rather than in the more dynamic, constantly flowing rivers; consequently, Lake Eufaula is the eventual and most vulnerable target of trace metal pollution. If present conditions are allowed to continue it is predictable that residual pollution of the North Canadian River will result in future limitations on the utility of Lake Eufaula waters. Trace metal pollution in the North Canadian River Basin is a measurable result of man's technological neglect of his environmental responsibility to this vital natural resource. This basin and its resources are essential to the future development of eastern and central Oklahoma and its loss is too staggering to consider.

Traditionally, water pollution surveys have tended to limit themselves and the utility of the acquired data by being unnecessarily narrow, or insufficiently comprehensive, to the extent that all factors which influence the quality of water as a natural resource are not considered. Also, studies of this type have relegated to a minor concern that class of pollutants which are termed "residual pollutants" and it is this class of pollutants which may ultimately hold the key to water resource

management. This study, including a comprehensive river basin survey, has attempted to provide a pattern for future water resource surveys, and while being necessarily limited in time it has opened the door to several previously overlooked relationships and indicates several areas of much needed future research. It is hoped that the study of trace metal pollution in the lower NCR basin will provide a worthy ecological contribution and be of benefit to man in the continuing struggle between "Man and his Environment".

REFERENCES

1. Nace, R. L., "World Water Balance", Env. Sci. Tech., 1: 550-560 (1967).
2. Stein, M., "Problems and Programs in Water Pollution", Reprinted from Nat. Res. J., 2: 388-415 (1962), by University of New Mexico School of Law.
3. "Conservation and Water Management", House of Rep. Document No. 273, 90th Congress, Second Session, March 11, 1968. (Message from the President).
4. Canham, R. A., "Status of Federal Water Pollution Control Legislation", J. Water Pollut. Contr. Fed., 38: 1-9 (1966).
5. Waste Management and Control, Pub. 1400, National Academy of Sciences, National Research Council, App. 5, Pollution Abatement Technology, pp. 181-202, Washington, D. C., 1966.
6. "Washington Report", Willing Water, J. AWWA, 12: No. 21, pp. 3-4, November 15, 1968.
7. "Water Reclamation and Re-use", A Review by Weber, W. J., Jr., J. Water Pollut. Contr. Fed., 40: 969-974 (1968).
8. Dryden, F. D. and Stern, G., "Renovated Waste Water Creates Recreational Lake", Env. Sci. and Tech. 2: 268-278 (1968).
9. Gully, A. J., Wells, D. M., "A Supplemental Water Supply for Lubbock Industries Through Water Re-Use", Proc. Eighth Industrial Water and Wastewater Conf., Texas Water Pollut. Control Assoc., Austin, Tex., Lubbock, Tex., June 6, 7, 1968, pp. 60-81.
10. Garthe, E. C. and Gilbert, W. C., "Wastewater Re-use at the Grand Canyon", J. Water Pollut. Contr. Fed., 40: 1582-1585 (1968).
11. Sawyer, C. N., "The Need for Nutrient Control", J. Water Pollut. Contr. Fed., 40: 363-370 (1968).
12. McKee, J. E. and Wolf, H. W., "Quality Criteria for the Major Beneficial Uses of Water", Chapter V, Water Quality Criteria, Publication No. 3-A, State Water Quality Control Board, Sacramento, California, 1963, pp. 88-122.

13. Stewart, C. P. and Stolman, A., Toxicology: Mechanisms and Analytical Methods. Vol. 2, Academic Press, Inc., New York, 1961, pp. 1-15.
14. Cecil-Loeb Textbook of Medicine, 12th Edition, Vol. 2, Beeson, P. B. and McDermott, W., Editors, W. B. Saunders Pub. Co., Philadelphia, 1967, pp. 1688-1695.
15. Lenihan, J. M. A., "Technology and Humanity", Proc. First Annual Conf. on Trace Subst. in Env. Health, July 10-11, 1967, U. of Mo., pp. 141-151.
16. Bowen, H. J. M., Trace Elements in Biochemistry, Academic Press, Inc., 1966, pp. 173-210.
17. McKee, J. E. and Wolf, H. W., "Potential Pollutants", Chapters VI and VII, Water Quality Criteria, Publication No. 3-A, State Water Quality Control Board, Sacramento, Calif., 1963, pp. 123-298.
18. Schreiner, G. E., Cecil-Loeb Textbook of Medicine "Toxic Nephropathy", 12th Edition, Vol. 1, 1967, pp. 818-821.
19. Kroner, R. C. and Kopp, J. F., "Trace Elements in Six Water Systems of the United States", J. AWWA, 57: 150-156 (1965).
20. Schroeder, H. A., "Some Prospects for Research on Biologically Active Trace Elements", Proc. First Annual Conf. on Trace Substances in Env. Health, U. of Mo., July 11-12, 1967, pp. 20-28.
21. Health of Workers in the Chromate Producing Industry, Public Health Service Pub. No. 192, U. S. Government Printing Office, Washington, 25, D. C. (1953) 131 pages.
22. Byerrum, R. U., Statement made during the "Open Discussion", Proc. Conf. on Physiological Aspects of Water Quality, Washington, D. C., Sept. 8-9, 1960.
23. Underwood, E. J., Trace Elements in Human and Animal Nutrition, Academic Press, Inc., 1962, pp. 325-356.
24. Nemerow, L. N., Theories and Practices of Industrial Waste Treatment, Addison-Wesley Pub. Co., Inc., 1963, pp. 397-429.
25. Underwood, E. J., Trace Elements in Human and Animal Nutrition, Academic Press, Inc., 1962, p. 93.
26. Hueper, W. C., "Cancer Hazards from Natural and Artificial Water Pollutants", Proc. Conf. on Physiological Aspects of Water Quality, Washington, D. C., Sept. 8-9, 1960.

27. Cotzias, G. C., Importance of Trace Substances in Environmental Health as Exemplified by Manganese", Proc. First Annual Conf. on Trace Subst. in Env. Health, U. of Mo., July 10-11, 1967, pp. 5-19.
28. Warren, H. V., Delavault, R. E., Cross, C. H., "Geological Considerations in Some Disease Patterns", Arch. Env. Health, 13: 412-413, (1966).
29. U. S. Public Health Service, The National Water Quality Network (brochure), (1962).
30. Kopp, J. F. and Kroner, R. C., "Tracing Water Pollution with an Emission Spectrograph", J. Water Pollut. Contr. Fed., 39: 1659-1668 (1967).
31. Lichti, E. L. and Adler, J. L., "A Study of Some of the Metallic Ions of Oklahoma's Potable Waters (Municipal Water Supplies)", J. Okla. State Med. Assoc., Sept. 1966, pp. 490-498.
32. Pringle, B. H., Hissong, D. E., Katz, E. L. and Mulawka, S. T., "Trace Metal Accumulation by Estuarine Mollusks", Proc. of the National Symposium on Estuarine Pollution, August 23-25, 1967, Stanford Univ., pp. 60-106.
33. Bowen, H. J. M., Trace Elements in Biochemistry, Academic Press, Inc., 1966, pp. 85-101.
34. de Sylva, D. P., "Estuarine Pollution", Oceanology International Yearbook, 2: 25-26 (1968).
35. Hedgepeth, J. W., "Marine Ecology", Oceanology International Yearbook, 2: 28-29 (1968).
36. Koczy, F. F., "Geochemistry", Oceanology International Yearbook, 2: 27-28 (1968).
37. Underwood, E. J., Trace Elements in Human and Animal Nutrition, Academic Press, Inc., 1962, pp. 291-324.
38. Åberg, B. and Hungate, F. B., Editors, "Radioecological Concentration Processes", Proc. of International Symposium held in Stockholm, April, 1966, Pergamon Press, New York, 1967, 1040 pages.
39. Polikarpov, G. G., Radioecology of Aquatic Organisms, North Holland Publishing Co., Amsterdam, distributed by (Reinhold Book Div., New York), 1966, pp. 161-182.
40. Bowen, H. J. M., Trace Elements in Biochemistry, Academic Press, Inc., 1966, pp. 102-118.

41. "1967 Literature Review on Water Pollution", Reviewed by Katz, M., Sparks, A. K., Pederson, G. L., Woellke, C. E. and Woodey, J., J. Water Pollut. Contr. Fed., 40: 1007-1033, (1968).
42. Schiffman, R. H. and Fromm, P. O., "Chromium-Induced Changes in the Blood of Rainbow Trout, Salmo gairdnerii," Sewage and Indust. Wastes J., 31: 205-211 (1959).
43. Strain, W. H., "Summary of the Conference on Trace Substances in Environmental Health", Proc. First Annual Conf. on Trace Substances in Env. Health, U. of Mo., July 10-11, 1967, pp. 226-232.
44. Arkansas-White-Red River Basins, A Report on the Conservation and Development of the Water and Land Resources, Parts I and II, Arkansas-White-Red Basins Inter-Agency Committee, 1955.
45. Ground Water in Oklahoma, Publication No. 10, Oklahoma Water Resources Board, Oklahoma City, 1965.
46. Schoff, S. L., "Map Showing Ground-Water Reservoirs in Oklahoma", Oklahoma Geological Survey, 1955, prepared in cooperation with the USGS.
47. Dover, T. B., Leonard, A. R. and Laine, L. L., Water for Oklahoma, Geological Survey Water Supply Paper 1890, 1968.
48. "Oklahoma's Water Resources", Publication No. 16, Oklahoma Water Resources Board, Oklahoma City, 1967.
49. Durum, W. H., "Occurrence of Trace Elements in Water", Proc. Conf. on Physiological Aspects of Water Quality, Sept. 8-9, 1960, Washinton, D. C.
50. Kopp, J. F., Director of the Metal Analyses Laboratory, USPHS, Cincinnati, Ohio, (A personal communication).
51. "Pollution-Caused Fish Kills in 1965" 6th Annual Report, Federal Water Pollution Control Administration, Basic Data Program, WP-12, Washington, D. C., 1966.

APPENDIXES

APPENDIX A

NORTH CANADIAN RIVER BASIN SURVEY

TABLE 11

PHYSICAL DESCRIPTION OF THE NORTH CANADIAN RIVER BASIN

		<u>Upper Basin</u>	<u>Middle Basin</u>	<u>Lower Basin</u>	<u>Basin Total</u>
<u>Geographical</u>					
Surface Elevation					
Upper Elevation	(ft)	6000	1830	1300	6000
Lower Elevation	(ft)	1830	1300	550	550
Drop in Elevation	(ft)	4170	530	750	5450
River Miles Above Mouth	(mi)	845 to 460	460 to 307	307 to 0	
Basin Length	(mi)	385	153	307	845
Stream Gradient	(ft/mi)	10.831	3.464	2.443	6.4497
Drainage Area	(sq mi)	11,589	1,453	1,658	14,700
Contributing Watershed		6,777	1,366	1,658	9,801
Noncontributing		4,812	87	0	4,899
<u>Meteorological</u>					
Precipitation	(in/yr)	15 to 22	22 to 30	30 to 42	---
Seasonal, 30 yr avg.					
Spring	(in)	5.15	8.78	11.71	---
Summer	(in)	7.01	7.92	10.67	---
Fall	(in)	4.31	5.61	8.60	---
Winter	(in)	1.81	2.98	5.10	---
Temperature	(F°)				
Spring		57.7	58.8	60.3	
Summer		78.2	79.5	80.9	
Fall		59.9	61.7	62.9	
Winter		40.2	39.4	41.6	

TABLE 11--Continued

		<u>Upper Basin</u>	<u>Middle Basin</u>	<u>Lower Basin</u>	<u>Basin Total</u>
Evaporation, lake	(in/yr)	56 to 64	64 to 60	60 to 52	
Runoff	(in/yr)	0.4	2.0	5.0	
<u>Hydrological</u>					
Streamflow, 30 year Average	(AF/yr)	165,800	175,200	492,300	
Potential Recharge from Runoff	(AF/yr)	144,576	145,706	442,130	
Streamflow 1967 Water Year	(AF)	69,560	38,150	202,000	
Streamflow During this Study (July 1967 through May 1968)	(AF)	87,620	70,168	301,540	
Tributary Streams to NCR		Corrumpa Cr	Indian Cr	Mustang Cr	
		Coldwater Cr	Persimmon Cr	Crutcho Cr	
		Palo Duro Cr	Bent Cr	Soldier Cr	
		Kiowa Cr	Purcell Cr	Deer Cr	
		Clear Cr	Shell Cr	Turkey Cr	
		Wolf Cr		Wewoka Cr	
				Grief Cr	
				Fish Cr	
				Bad Cr	
<u>Geological</u>					
Physiographic Province:		Great Plains	Central Lowlands	Central Lowlands	
Section:		High Plains	Osage Plains	Osage Plains	
Outcrops (Age)		Quaternary & Recent	Permian	Permian & Pennsylvanian	

TABLE 11--Continued

	<u>Upper Basin</u>	<u>Middle Basin</u>	<u>Lower Basin</u>	<u>Basin Total</u>
Surface Geology:	Ogallala & Younger	Rush Springs ss	Hennessey sh	
	Dakota ss	Marlow Fm	Garber ss	
	Morrison Fm	Dog Creek sh	Wellington Fm	
	Entrada ss	Blaine Gypsum	Vanoss Fm	
	Dockum Group	Flowerpot sh	Ada Fm	
	Cloud Chief Fm		Vamoosa Fm	
	Rush Springs ss		Barnsdall (Hilltop) Fm	
	Marlow Fm		Chanute Fm	
			Dewey Fm	
			Nellie Bly Fm	
			Coffeyville Fm	
			Checkerboard ls	
			Seminole Fm	
			Holdenville sh	
			Wewoka Fm	
			Wetumka sh	
			Calvin ss	
			Senora Fm	

TABLE 12

POLITICAL DESCRIPTION OF THE NORTH CANADIAN RIVER BASIN

State	Upper Basin County & Population*		Middle Basin County & Population*		Lower Basin County & Population*		Basin Total Population
New Mexico	Union Co	5,800					5,800
Kansas	Edwards	4,400					12,900
	Stevens	4,600					
	Morton	3,900					
Texas	Dallam	6,400					44,800
	Sherman	3,400					
	Hansford	7,100					
	Ochiltree	10,400					
	Lipscomb	3,900					
	Moore	13,600					
	Cimarron	4,496	Dewey	6,051	Oklahoma	504,400	716,339
Oklahoma	Texas	14,162	Major	7,808	Pottawatomie	41,486	
	Beaver	6,965	Blaine	12,077	Seminole	28,066	
	Harper	5,956	Canadian	26,700	Okfuskee	10,500	
	Ellis	5,457			Hughes	15,144	
	Woodward	14,700			McIntosh	12,371	
Totals	Oklahoma	51,736	Oklahoma	52,636	Oklahoma	611,967	26 Counties <u>779,839</u>
	Other States	<u>63,500</u>	Other States	<u>0</u>	Other States	<u>0</u>	
	16 Counties	<u>115,236</u>	4 Counties	<u>52,636</u>	6 Counties	<u>611,967</u>	

*Total county populations are shown, although portions of some counties may not be included in the drainage basin.

TABLE 13

ECONOMIC DESCRIPTION OF THE NORTH CANADIAN RIVER BASIN

Economy	Upper Basin	Middle Basin	Lower Basin	Basin Total	Oklahoma Total
Agriculture (Acres 1967) Okla.	5,537,000	2,278,000	1,957,000	9,772,000	36,077,000
Cropland (Acres 1967)	2,320,000	1,000,000	440,000	3,760,000	13,053,416
Non-Irrigated	2,047,438	982,939	428,494	3,458,871	12,494,613
Irrigated	272,562	17,061	11,506	301,129	558,803
Farm Income (1962) (in Dollars)	27,260,000	17,255,000	11,745,000	56,260,000	250,000,000
Industry					
Mineral Production (1965) (in Dollars)	134,055,000	41,290,000	68,475,000	243,820,000	907,914,000
Source*	He, NG, Pet, NG Liq, Sand, Grav, Stone & Vol Ash	Pet, NG, NG Liq, Gyps, Sand, Grav & Clay	Pet, NG Liq, Stone, Sand, Grav & Clay	-----	-----
Beef Cattle Feed Lots Cattle fed in 1967	478,370	35,200	5,000	518,570	425,000
Major Type of Industry	Pet Produc- tion, Cattle Feedlots, Meat Process- ing	Petroleum, Bldg Mater- ials	Commo, Elect- ronics, air- craft, Di- verse In- dustry	-----	-----

*He = Helium; NG = Natural Gas; Pet = Petroleum; NG Liq = Natural gas liquids; Grav = Gravel; Vol Ash = Volcanic ash; Gyps = Gypsum, Commo = Communications.

TABLE 14

WATER USE AND WASTEWATERS GENERATED IN THE
NORTH CANADIAN RIVER BASIN

	Upper Basin	Middle Basin	Lower Basin	Basin Total	Oklahoma Total
<u>WATER USE</u> (1967 in Acre-Ft/yr)	424,529	24,942	164,980	614,451	1,538,492
Surface Water	7,176	1,508	149,302	157,986	825,256
Ground Water	417,353	23,434	15,678	456,465	713,236
Municipal	7,547	7,282	138,962	153,791	378,919
Surface Water	737	199	131,070	132,006	303,659
Ground Water	6,810	7,083	7,892	21,785	75,260
Agriculture	413,800	16,505	8,840	439,145	714,349
Surface Water	5,550	1,099	4,267	10,916	121,844
Ground Water	408,250	15,406	4,573	428,229	592,505
Industry	1,812	803	14,959	17,574	393,512
Surface Water	0	2	13,118	13,120	368,862
Ground Water	1,812	801	1,841	4,454	24,650
Other	1,370	352	2,219	3,941	51,712
Surface Water	889	208	847	1,944	30,891
Ground Water	481	144	1,372	1,997	20,821
<u>WASTE WATERS GENERATED</u>					
Municipal (.70 X Reported water use)	5,250	5,110	98,000	108,360	265,300
Industrial (.95 X Reported water use)	1,721	763	14,450	16,934	374,300

TABLE 15

WATER RESOURCES IN THE NORTH CANADIAN RIVER BASIN

POTENTIAL RESOURCES	Upper Basin	Middle Basin	Lower Basin
Surface Water			
Runoff (Recharge)	144,576	145,706	442,130
(AF/yr Calculated) 1967			
Stream Flow (30-yr Avg.)	165,800	175,200	492,300
(AF/yr Measured)			
Ground Water (Aquifers)			
River Alluvium:	Cimarron Co. Texas Co. Beaver Co. Harper Co. Ellis Co. Woodward Co.	Dewey Co. Major Co. Blaine Co. Canadian Co.	Oklahoma Co. Okfuskee Co. Hughes Co. McIntosh Co.
Terrace Deposits:	Beaver Co. Harper Co. Ellis Co. Woodward Co.	Dewey Co. Major Co. Blaine Co. Canadian Co.	Oklahoma Co. Seminole Co. Hughes Co.
Bedrock Formations:	Ogallala Fm. & Younger Dakota Sandstone Dockum Group Rush Springs Sandstone Marlow Formation	Rush Springs Sandstone Marlow Formation	Hennessey Shale Garber Sandstone Wellington Fm. Vanoss Formation Vamoosa Formation Barnsdall (Hilltop) Fm. Seminole Fm. Wewoka Formation Calvin Sandstone Senora Formation

TABLE 16

WATER RESOURCE DEVELOPMENT IN THE NORTH CANADIAN RIVER BASIN

Use*	Location*†	Upper Basin*	Middle Basin*	Lower Basin	Status and Agency*	Maximum Capacity (AF)*
FC-Con-Rec	Wolf Cr Ft. Supply	Fort Supply Res. and Dam			1942, USCE	101,800
FC-Irr-Rec	NCR Mi 623	Optima Res & Dam			WIP, USCE	(260,000)
FC-Irr-WS- Con-Rec	NCR Mi 394 Canton, Okla.		Canton Res and Dam		1948, USCE	386,000
WS-Res	NCR Mi 281 Okla. City			Lake Overholser- Dam	1917, Okla City Munic.	15,600
Diver-WS- Rec	Okla. City, Cim. R. Basin†			L. Hefner Diversion Canal & Dam	1944, Okla. City Munic.	75,355
Diver-WS- Rec	Okla. City, E. Elm Creek†			L. Draper & Pipeline 100 mi, 600 ft. Lift	1964, Okla. City Munic.	100,000
Diver-WS- Rec	Southeastern Oklahoma†			(L. Atoka) SE Okla. Source for L. Draper	1959, Okla. City Munic.	125,000
FC,45000cfs	NCR, Okla.City			Okla. City Floodway	1956, USCE	---
FC-Sed-P- Rec-Con-Nav	Canadian R.Mi 27 Eastern Okla.			Lake Eufaula & Dam	1964, USCE	3,844,000
Irrigation	Wells on Okla. Farms & Ranches	1,477 wells	191 wells	84 wells	1967, Farmers and Ranchers	428,229
TOTAL						5,335,984

*Abbreviations: FC = Flood Control; Con = Conservation; Rec = Recreation; Irr = Irrigation; WS = Water Supply; Diver = Diversion; Sed = Sediment Control; P = Power; Nav = Navigation; USCE = US Army Corps of Engineers; NCR = North Canadian River; Res = Reservoir; WIP = Work in Progress; AF = Acre-Feet.

†Located outside the NCR Basin.

TABLE 17

WATER RESOURCE PLANNING IN THE NORTH CANADIAN RIVER BASIN

Use	Location	Upper Basin
Reservoir	NCR, New Mexico	Corrumpa Reservoir
Reservoir	NCR, Oklahoma	Beaver Reservoir
Reservoir	NCR, Oklahoma	Gate Reservoir
Reservoir	Coldwater Cr., Tex.	Stratford Reservoir
Reservoir	Coldwater Cr., Tex.	Alexander Reservoir
Reservoir	Palo Duro Cr., Tex.	Spearman Reservoir
Reservoir	Wolf Creek, Oklahoma	Fargo Reservoir
Reservoir	NCR, Oklahoma	
Reservoir	NCR, Oklahoma	
Reservoir	NCR, Oklahoma	
Irrigation	NCR, Canton-Calumet	
Sewage Irrigation	NE Okla. City, NCR	
Wetlands Drainage	NCR, above L. Eufaula	
Navigation Canal	Okla. City-L.Eufaula-Ark.R.	
Navigation Canal	Okla. City-Boswell-Red. R.	
NCR water to Cim. R.	NCR at Gate	Gate Diversion
NCR water to Cim. R.	Canton Res.-Hitchcock	
NCR water to SCR Basin	NCR, Watonga	
NCR water to SCR Basin	NCR, El Reno	
Flood Control	Lower NCR Basin	
Flood Control-Water Sup.	NCR, NE New Mexico	Corrumpa Cr. Proj.
Flood Protection	Palo Duro Cr., Tex.	Palo Duro Cr. Proj.
Flood Protection	Lost Cr., Laverne, Okla.	Lost Cr. Proj.
Flood Protection	Wewoka Cr., Wetumka, Okla.	
River Survey	NCR Basin	North Canadian R.
River Survey	NCR Basin (Texas)	East Amarillo Cr.
River Survey	NCR Basin - Texas & Okla.	Palo Duro Creek
River Survey	NCR Basin - Texas & Okla.	Clear Creek

TABLE 17--Continued

Middle Basin	Lower Basin	Agency
		USCE USCE USCE USCE USCE
	Okmulgee Reservoir Weleetka Reservoir Wetumka Reservoir	USCE USCE USCE USCE USCE
Canton Irrig. Proj.	Okla. City Irrig. Proj. Local Agri. Drainage Deep Fork Navigation Central Okla. Proj.	Bur. Reclam. - F & W Bur. Reclam. Bur. Reclam. USCE USCE
Canton Diversion Watonga Diversion El Reno Diversion	Squirrel Cr. Diversion	USCE USCE USCE USCE Bur. Reclam.
North Canadian R.	Wewoka Cr. Proj. North Canadian R.	USCE USCE USCE USCE AWRBIAC
		Bur. Reclam. Bur. Reclam. Bur. Reclam.

TABLE 18

STREAMFLOW, WATER USE AND WASTE WATER INPUT IN THE
LOWER NORTH CANADIAN RIVER BASIN

Month	Streamflow El Reno (MG/mo)	Streamflow Oklahoma City (MG/mo)	Water Use Oklahoma City (MG/mo)	Waste Input Oklahoma City (MG/mo)	Streamflow Wetumka (MG/mo)
June 1967	3,607	22	1,460	770	2,854
July	508	36	1,600	760	2,043
August	512	505	1,769	783	775
September	6,530	84	1,179	765	2,320
October	1,949	233	1,171	772	3,389
November	472	94	1,091	728	2,353
December	336	33	1,093	817	1,529
January 1968	234	41	1,158	850	5,930
February	3,483	42	1,026	706	4,432
March	873	49	1,100	826	14,533
April	1,496	111	1,167	781	17,270
May	2,864	932	1,246	852	43,664
TOTALS (MG)	22,864	2,182	15,060	9,410	101,092

APPENDIX B

CHEMICAL, PHYSICAL, BIOCHEMICAL AND HYDROLOGICAL ANALYSES
FOR LOWER NORTH CANADIAN RIVER WATERS

TABLE 19

CHEMICAL, PHYSICAL, BIOCHEMICAL AND HYDROLOGICAL
ANALYSES FOR STATION I

Date	Sample Number	Stream Flow* MGD	Wastewater Input MGD	Total Stream Flow MGD	Water Temp. °C	pH	Concentrations in mg/l												
							DO	BOD	Cl	Alk	NO ₃	PO ₄	Fe	Ni	Cu	Zn	Ag	Cd	Cr
7-11-67	1	.84	0	.8	29	7.5	6	0	130	179	.3	.6	.440	.440	.220	.500	.010	ND	ND
7-19	9	1.36	0	1.4	28	7.4	8	--	131	181	.1	.5	.440	.220	ND	.130	ND	ND	ND
7-25	20	.97	0	1.0	30	7.2	6	0	152	177	0	.4	ND	ND	ND	.100	ND	ND	ND
7-27	12	.97	0	1.0	31	7.5	10	0	152	177	0	.4	.440	ND	ND	.075	ND	ND	ND
8-8	21	.71	0	.7	28	7.0	7	7	136	173	.1	.3	.900	ND	.400	.130	ND	ND	ND
10-13	44	3.49	0	3.5	21	6.7	10	2	172	139	.1	.2	1.950	.100	.250	.190	ND	.005	ND
11-13	51	5.43	0	5.4	14	7.0	10	3	172	138	.4	1.0	2.500	ND	ND	.280	ND	ND	ND
11-18	52	2.07	0	2.1	11	6.8	9	1	179	171	.6	.4	2.100	ND	ND	.046	ND	ND	ND
12-10	64	.98	0	1.0	5	6.5	12	2	184	171	.4	.5	.900	ND	ND	.022	ND	ND	ND
1-29-68	83	2.33	0	2.3	12	6.8	15	5	171	181	.5	.8	.740	ND	ND	ND	ND	ND	ND
2-20	105	.84	0	.8	11	6.8	19	5	166	203	.4	1.0	.440	.220	ND	.022	ND	.005	--
4-2	133	1.68	0	1.7	13	7.0	8	4	188	142	.3	.6	1.050	ND	.400	.220	ND	.010	.050

*NCR streamflow data obtained from USGS stream gaging station at Oklahoma City, which is located at Station I.

TABLE 20

CHEMICAL, PHYSICAL, BIOCHEMICAL, AND HYDROLOGICAL
ANALYSES FOR STATION II

Date	Sample Number	Stream Flow*	Wastewater Input	Total Stream Flow	Water Temp. °C	pH	Concentrations in mg/l												
							DO	BOD	Cl	Alk	NO ₃	PO ₄	Fe	Ni	Cu	Zn	Ag	Cd	Cr
7-11-67	2	.84	5	5.84	35	7.8	12	17	1100	205	.05	1.9	.600	.100	ND	.700	.010	.010	ND
7-19	10	1.36	5	6.36	33	7.0	6	--	539	177	.05	1.8	.150	.220	ND	.258	ND	.010	ND
7-27	13	.97	5	5.97	34	7.0	10	68	1967	313	.35	1.6	.300	.220	ND	.100	ND	ND	ND
8-8	22	.71	5	5.71	30	7.8	12	11	953	191	.05	1.0	.300	.220	ND	.010	ND	ND	ND
10-13	45	3.49	5	8.49	23	7.0	11	6	1489	134	2.50	.6	1.500	.100	ND	.160	.010	.015	ND
11-13	50	5.43	5	10.43	17	6.9	16	22	951	189	.40	.6	1.600	ND	ND	.035	.005	.005	ND
11-18	53	2.07	5	7.07	11	6.9	11	6	735	215	.35	.6	1.350	ND	.150	.280	.005	.015	.050
12-10	65	.98	5	5.98	4	6.8	11	15	646	207	.50	.8	.740	ND	ND	.022	ND	ND	.020
12-24	70	.97	5	5.97	9	6.8	10	15	603	209	0	1.2	1.200	ND	ND	.700	ND	ND	ND
1-28-68	84	2.07	5	7.07	15	6.8	9	24	674	197	.15	.5	.300	ND	ND	ND	ND	ND	ND
2-14	86	.97	5	5.97	2	6.4	7	21	824	190	.65	2.9	.600	ND	.200	.190	ND	.005	ND
2-20	104	.84	5	5.84	15	7.0	9	16	860	229	.25	1.7	.900	.220	.150	.046	ND	.010	ND
3-30	115	1.49	5	6.49	20	7.0	8	13	792	217	.05	1.6	.150	.220	.100	.280	.010	.010	ND
4-5-68	152	2.78	5	7.78	15	7.0	--	8	346	178	.25	.7	.600	ND	ND	.022	ND	.005	ND

*NCR streamflow data obtained from USGS stream gaging station at Oklahoma City, which is located at Station I.

TABLE 21

CHEMICAL, PHYSICAL, BIOCHEMICAL AND HYDROLOGICAL
ANALYSES FOR STATION III

Date	Sample Number	Stream Flow* MGD	Wastewater Input MGD	Total Stream Flow MGD	Water Temp. °C	pH	Concentrations in mg/l												
							DO	BOD	Cl	Alk	NO ₃	PO ₄	Fe	Ni	Cu	Zn	Ag	Cd	Cr
7-11-67	3	.84	30	30.84	33	7.4	6	18	645	172	5.10	33.0	.300	.220	.180	.660	ND	ND	ND
7-18	11	1.62	30	31.62	34	7.2	5	--	469	153	3.60	22.5	.150	.220	ND	.100	ND	ND	ND
7-27	14	.97	30	30.97	32	7.2	3	17	812	210	.65	33.0	.740	.440	.150	.190	.010	.005	ND
8-8	23	.71	30	30.71	29	7.0	6	13	585	169	3.60	33.0	.150	.220	ND	.100	ND	ND	ND
9-5	30	1.55	30	31.55	21	6.8	5	8	572	217	.60	19.0	1.600	.440	.180	.220	.010	ND	.050
9-6	39	1.40	30	31.40	20	5.8	4	8	572	217	.60	19.0	1.600	.220	ND	.160	ND	.010	ND
10-13	40	3.49	30	33.49	22	7.0	4	18	830	170	7.00	36.0	1.950	.330	.500	.810	.025	.016	.050
11-12	46	4.98	30	34.98	20	7.0	7	12	744	171	1.50	23.0	.900	.100	.180	.190	.010	.010	ND
11-20	58	1.87	30	31.87	14	6.8	8	13	641	176	3.15	24.0	1.200	.100	ND	.075	ND	ND	ND
12-10	66	.98	30	30.98	7	6.5	8	18	626	197	1.95	30.0	.600	ND	ND	.075	ND	ND	ND
2-13-68	85	.97	30	30.97	6	6.8	7	24	678	181	2.15	18.0	.600	ND	.200	.160	.005	.010	.050
2-14	87	.97	30	30.97	6	6.8	9	24	678	181	2.15	18.0	.600	.220	ND	.075	ND	.005	ND
2-14	88	.97	30	30.97	7	6.8	7	24	678	181	2.15	18.0	1.600	.220	.150	.160	.005	.010	ND
2-20	103	.84	30	30.84	16	6.8	5	25	563	201	1.55	30.0	.600	.440	.340	.220	.010	.010	.050
4-2	129	1.68	30	31.68	12	6.0	5	23	752	193	2.80	33.0	.600	ND	.340	.620	ND	.023	.050
4-5	153	2.78	30	32.78	13	6.8	6	12	401	173	1.35	8.0	.600	.220	.180	.160	.005	.005	.050

*NCR streamflow data obtained from USGS stream gaging station at Oklahoma City, which is located at Station I.

TABLE 22

CHEMICAL, PHYSICAL, BIOCHEMICAL AND HYDROLOGICAL
ANALYSES FOR STATION IV

Date	Sample Number	Stream Flow* MGD	Wastewater Input MGD	Total Stream Flow MGD	Water Temp. °C	pH	Concentrations in mg/l												
							DO	BOD	Cl	Alk	NO ₃	PO ₄	Fe	Ni	Cu	Zn	Ag	Cd	Cr
7-27-67	15	.97	40	40.97	33	7.4	5	11	499	220	.40	30.5	.300	.220	.150	.130	ND	.005	ND
8-10	24	.71	40	40.71	34	7.5	4	8	519	189	2.55	29.5	.300	.050	ND	.045	ND	ND	ND
10-13	41	3.49	40	43.49	19	7.1	5	14	594	178	2.20	36.0	2.800	.660	ND	.820	.010	.023	.050
11-12	49	4.98	40	44.98	16	6.8	4	13	607	180	1.30	23.0	1.350	.130	ND	.220	.005	.035	ND
11-20	59	1.87	40	41.87	13	6.8	6	14	502	198	2.30	34.0	1.800	.220	.150	.130	ND	.010	ND
12-10	68	.98	40	40.98	6	6.8	7	16	507	205	1.85	36.0	1.200	.220	ND	.075	.005	ND	ND
12-24	71	.97	40	40.97	9	6.8	8	19	468	207	4.00	25.0	.300	ND	ND	.075	ND	.005	ND
1-29-68	81	2.33	40	42.33	15	6.8	5	17	498	195	1.00	27.0	.900	ND	ND	.046	ND	.010	ND
2-20	101	.84	40	40.84	14	6.8	5	28	523	188	.95	29.0	.600	.100	.180	.100	.010	.023	ND
3-30	119	1.49	40	41.49	19	7.0	1	15	549	204	1.75	26.0	.440	.100	.150	.315	.005	.016	ND
4-5	155	2.78	40	42.78	16	6.8	5	13	386	177	1.65	13.6	.440	ND	.180	.075	.005	.015	.050
4-6	156	2.97	40	42.97	17	7.0	5	13	386	177	1.65	13.6	.440	.100	.100	.350	ND	.013	.050
5-8	171	2.84	40	42.84	18	6.6	4	17	472	198	3.40	31.0	6.500	ND	ND	.220	.005	.013	ND

*NCR streamflow data obtained from USGS stream gaging station at Oklahoma City, which is located at Station I.

TABLE 23

CHEMICAL, PHYSICAL AND HYDROLOGICAL ANALYSES FOR STATION V

Sample Date	Sample Number	Stream Flow* MGD	Water Temp. ° C	pH	Concentrations in mg/l																	
					DO	Na	HCO ₃	CO ₃	SO ₄	Cl	NO ₃	PO ₄	DS	Hard.	Spec. Cond.	Fe	Ni	Cu	Zn	Ag	Cd	Cr
1967																						
7-14	5	39	25	7.5	--	280	168	10	82	500	.6	1.5	1220	306	1980	.300	.440	.180	.250	ND	ND	ND
7-31	16	21	26	7.0	7	287	240	14	70	500	3.2	2.0	1220	392	2120	.300	.220	ND	.045	ND	ND	ND
8-12	25	19	28	6.0	12	280	192	8	78	460	1.7	1.9	1140	296	1970	.150	.050	.340	.074	ND	ND	ND
10-13	43	72	22	6.8	10	178	----	--	55	285	13.0	----	729	----	1320	2.400	.100	ND	.075	ND	.005	ND
11-12	48	57	14	7.0	7	184	216	0	94	300	18.0	7.4	870	314	1520	1.050	.130	.180	.075	ND	.005	ND
12-9	60	46	8	6.4	11	268	260	0	118	430	3.2	13.0	1200	396	2020	.600	ND	ND	.022	ND	ND	ND
1968																						
1-28	75	866	15	5.5	4	54	----	--	18	92	3.6	1.5	289	----	496	12.000	ND	ND	.250	.005	ND	ND
2-18	93	83	4	6.8	9	236	252	0	79	400	16.0	9.6	1130	370	1860	.440	.220	ND	.022	ND	.010	ND
3-30	117	275	20	7.0	8	114	132	0	38	210	6.1	.4	611	198	973	1.500	ND	.150	.350	.010	.010	.050
4-6	159	149	16	7.0	--	210	----	--	68	365	7.0	.7	984	----	1620	1.200	ND	.150	.190	ND	.013	ND
5-8	173	1260	20	6.0	--	134	----	--	56	240	8.3	3.4	670	----	1110	.300	ND	.150	.760	ND	.005	.125

*Streamflow data obtained from USCE stream gaging station near Wetumka at NCR mile 84.4 which is, at average stream flow, 2 days below Station V.

TABLE 24

CHEMICAL, PHYSICAL AND HYDROLOGICAL ANALYSES FOR STATION VI

Sample Date	Sample Number	Stream Flow* MGD	Water Temp. °	pH	Concentrations in mg/l																	
					DO	Na	HCO ₃	CO ₃	SO ₄	Cl	NO ₃	PO ₄	DS	Hard.	Spec. Cond.	Fe	Ni	Cu	Zn	Ag	Cd	Cr
1967																						
7-14	6	41	29	7.5	8	280	168	10	82	500	.6	1.5	1220	306	1980	ND	ND	.180	.090	ND	ND	ND
7-31	17	22	25	8.0	6	287	240	14	70	500	3.2	2.0	1220	392	2120	.150	ND	.180	.130	ND	ND	ND
8-12	26	23	31	7.0	12	280	192	8	78	460	1.7	1.9	1140	296	1970	.150	ND	ND	.130	.010	ND	ND
11-19	54	47	12	6.8	13	258	---	---	100	418	20.0	14.0	1140	---	1970	.740	ND	ND	.050	ND	ND	ND
12-9	61	51	8	6.8	12	268	260	0	118	430	3.2	13.0	1200	396	2020	.600	ND	.450	.035	ND	ND	--
1968																						
1-28	76	853	14	5.5	5	54	---	---	18	92	3.6	1.5	289	---	496	9.000	ND	.150	.160	.010	ND	ND
2-18	95	83	4	6.8	12	236	252	0	79	400	16.0	10.0	1130	370	1860	.740	ND	ND	.022	ND	ND	ND
3-30	118	301	20	6.5	10	135	---	---	47	242	7.9	.4	711	---	1130	1.950	ND	.225	.250	.005	.010	ND
4-6	163	167	18	7.0	10	210	---	---	68	365	7.0	.7	984	---	1620	2.400	ND	.150	.500	ND	ND	.020
5-8	175	291	21	7.0	8	210	180	12	100	370	2.9	1.9	994	304	1600	3.500	ND	ND	.380	ND	ND	ND

*Streamflow data obtained from stream gaging station near Wetumka, which is, at average stream flow, 1 day below Station VI.

TABLE 25
CHEMICAL, PHYSICAL AND HYDROLOGICAL ANALYSES FOR STATION VII

Sample Date	Sample Number	Stream Flow* MGD	Water Temp. °C	pH	Concentrations in mg/l																	
					DO	Na	HCO ₃	CO ₃	SO ₄	Cl	NO ₃	PO ₄	DS	Hard.	Spec. Cond.	Fe	Ni	Cu	Zn	Ag	Cd	Cr
1967																						
7-14	7	50	31	7.0	-	280	168	10	82	500	.6	1.5	1220	306	1980	.150	.220	.180	.045	ND	ND	ND
7-29	18	41	30	7.0	7	240	168	20	70	428	0	1.4	1070	292	1740	.440	.220	ND	.100	ND	ND	ND
8-12	27	34	30	7.0	11	280	192	8	78	460	1.7	1.9	1140	296	1970	.440	.050	ND	.045	ND	.010	ND
11-19	55	48	12	6.8	14	258	---	---	100	418	20.0	14.0	1140	---	1970	1.500	ND	ND	.046	.005	ND	ND
1968																						
1-28	77	220	14	6.0	9	138	---	---	59	220	17.0	5.4	6360	---	1080	6.000	ND	ND	.022	ND	ND	ND
2-18	96	85	5	6.8	10	21	64	0	---	6	27.0	.3	---	68	235	.900	ND	ND	.034	ND	.005	ND
4-1	124	301	14	6.0	9	114	132	0	38	210	6.1	.4	611	198	973	6.400	ND	.340	.280	ND	.010	.050
4-6	167	259	15	6.4	-	210	---	---	68	365	7.0	.7	984	---	1620	3.300	.100	ND	.310	.005	ND	.050
4-6	166	259	16	6.8	-	210	---	---	68	365	7.0	.7	984	---	1620	3.000	ND	ND	.220	.003	ND	.050
5-8	178	105	23	7.0	10	210	180	12	100	370	3.0	1.9	994	304	1600	.900	ND	.250	.250	ND	.013	ND

*Streamflow data obtained from USCE stream gaging station near Wetumka, which is, at average stream flow, 1 day above Station VII.

TABLE 26

CHEMICAL, PHYSICAL AND HYDROLOGICAL ANALYSES FOR STATION VIII

Sample Date	Sample Number	Stream Flow* MGD	Water Temp. °C	pH	Concentrations in mg/l																		
					DO	Na	HCO ₃	CO ₃	SO ₄	Cl	NO ₃	PO ₄	DS	Hard.	Spec. Cond.	Fe	Ni	Cu	Zn	Ag	Cd	Cr	
1967																							
7-14	8	57	30	7.3	-	280	168	10	82	500	.6	1.5	1220	306	1980	ND	.220	.150	.045	ND	ND	ND	
7-29	19	90	28	7.0	8	148	90	0	41	310	7.8	2.0	599	168	1090	.300	ND	ND	.160	ND	ND	ND	
8-12	28	37	27	7.0	13	280	192	8	78	460	1.7	1.9	1140	296	1970	.600	ND	ND	.250	.010	ND	ND	
11-19	56	47	12	6.4	8	184	216	0	94	300	18.0	7.4	870	314	1520	2.250	ND	ND	.046	ND	ND	ND	
12-9	62-1	39	9	6.8	14	268	260	0	118	430	3.2	13.0	1200	396	2020	.900	.005	.180	.022	ND	ND	ND	
12-9	62-2	39	8	7.8	13	268	260	0	118	430	3.2	13.0	1200	396	2020	1.600	ND	ND	.075	ND	ND	ND	
1968																							
1-28	78	105	13	5.5	9	138	----	--	59	220	17.0	5.4	6360	----	1080	2.700	ND	ND	.022	ND	ND	ND	
1-28	79	105	12	5.5	9	138	----	--	59	220	17.0	5.4	6360	----	1080	3.300	ND	ND	.046	ND	ND	ND	
2-18	97	85	4	6.5	9	195	236	0	77	340	18.0	7.5	998	340	1620	2.400	ND	ND	.015	ND	ND	ND	
2-18	98	85	4	6.5	9	195	236	0	77	340	18.0	7.5	998	340	1620	1.800	.100	ND	.022	ND	ND	ND	
4-1	125	162	15	6.0	8	135	----	--	47	242	7.9	.4	711	----	1130	2.400	ND	.340	.190	.005	.010	.050	
4-1	126	162	12	6.0	7	135	----	--	47	242	7.9	.4	711	----	1130	3.700	ND	.225	.420	ND	.010	.050	
4-6	168	384	14	6.4	8	114	132	0	38	210	6.1	.4	611	198	973	3.300	ND	ND	.220	ND	.005	.050	
4-6	169	384	15	6.2	8	114	132	0	38	210	6.1	.4	611	198	973	3.600	ND	ND	.280	ND	.005	.050	

*Streamflow data obtained from stream gaging station near Wetumka, which is, at average stream flow, 2 days above Station VIII.

TABLE 26--Continued

Sample Date	Sample Number	Stream Flow* MGD	° Water Temp.	pH	Concentrations in mg/l																	
					DO	Na	HCO ₃	CO ₃	SO ₄	Cl	NO ₃	PO ₄	DS	Hard.	Spec. Cond.	Fe	Ni	Cu	Zn	Ag	Cd	Cr
4-6 1968	170	384	**	**	**	114	132	0	38	210	6.1	.4	611	198	973	.740	ND	.150	.450	ND	.013	.020
5-8	179	114	20	7.0	7	210	180	12	100	370	2.9	1.9	994	304	1600	1.050	ND	ND	.250	ND	.005	ND
5-9	180	105	--	---	--	210	180	12	100	370	2.9	1.9	994	304	1600	.740	ND	.150	.250	ND	.005	ND
5-9	181	105	--	---	--	210	180	12	100	370	2.9	1.9	994	304	1600	.740	ND	ND	.320	ND	.005	ND
5-10	182	120	--	---	--	210	180	12	100	370	2.9	1.9	994	304	1600	.740	ND	.150	.420	ND	.013	ND
5-10	186	120	20	6.5	8	210	180	12	100	370	2.9	1.9	994	304	1600	2.400	ND	.150	.380	ND	.005	.020
5-10	190	120	19	6.8	6	210	180	12	100	370	2.9	1.9	994	304	1600	2.250	ND	.150	.350	ND	.013	ND
5-10	192	120	18	6.5	5	210	180	12	100	370	2.9	1.9	994	304	1600	2.800	ND	.150	.310	.003	.005	.050
5-10	193	120	20	6.5	7	210	180	12	100	370	2.9	1.9	994	304	1600	1.500	ND	.150	.310	ND	.005	ND

*Streamflow data obtained from stream gaging station near Wetumka, which is, at average stream flow, 2 days above Station VIII.

**Treated tap water, source from Lake Eufaula at Station VIII.

APPENDIX C

TRACE METAL CONTENT OF LOWER NORTH CANADIAN RIVER WATERS

TABLE 27

IRON CONCENTRATIONS (mg/l) AT VARIOUS STATIONS AND DATES

Date	Stream Stations															Lake Stations			
	I	II	III A	III B	III C	III D	IV	V A	V B	V C	VI A	VI B	VII A	VII B	VII C	VIII A	VIII B	VIII C	VIII D
1967																			
7/11	.44	.60	.30																
7/14								.30			ND		.15				ND		
7/18			.15																
7/19	.44	.15																	
7/25	ND																		
7/27	.44	.30	.74				.30												
7/29													.44				.30		
7/31								.30			.15								
8/8	.90	.30	.15																
8/10							.30												
8/12								.15			.15		.44				.60		
8/16				.74															
9/5			1.60	2.80	4.00														
9/6			1.60		2.70														
10/13	1.95	1.50	1.95	5.00			2.80	2.40											
11/9											.74								
11/12			.90	2.10			1.35	1.05											
11/13	2.50	1.60																	
11/18	2.10	1.30																	
11/19				.44									1.50				2.25		
11/20			1.20				1.80												
12/9				.90				.60			.60						1.60		
12/10	.90	.74	.60		1.20		1.20												
12/24		1.20		1.95			.30												
12/31				.90															

TABLE 27--Continued for Iron

Date	Stream Stations															Lake Stations			
	I	II	III A	III B	III C	III D	IV	V A	V B	V C	VI A	VI B	VII A	VII B	VII C	VIII A	VIII B	VIII C	VIII D
1968																			
1/28								12.00			9.00		6.00				3.30		
1/29	.74	.30		.74			.90												
2/13			.60																
2/14		.60	1.60																
2/16				2.10															
2/18								.44	.74		.74		.90				2.40		
2/20	.44	.90	.60		.15		.60												
3/27				1.95															
3/29				14.00	.60														
3/30		.15					.44	1.50			1.95								
4/1				1.80					1.05	1.50			6.40	1.00	1.50		3.70		
4/2	1.05		.60	.90															
4/3				.60															
4/4				.74															
4/5		.60	.60	2.25	.30	3.60	.44												
4/6				.60			.44	1.20	.60	.74	2.40		3.00	2.10	2.10		3.60		
5/8				5.00		.74	6.50	.30	.90		3.50	.900	.90				1.05		
5/9																	.74		
5/10																2.40	.74	2.25	2.80
Max.																			
Obs.	2.50	1.60	1.95	14.00	4.00	3.60	6.50	12.00	1.05	1.50	9.00	.900	6.40	2.10	2.10	2.40	3.70	2.25	2.80

TABLE 28

NICKEL CONCENTRATIONS (mg/l) AT VARIOUS STATIONS AND DATES

Date	Stream Stations															Lake Stations			
	I	II	III A	III B	III C	III D	IV	V A	V B	V C	VI A	VI B	VII A	VII B	VII C	VIII A	VIII B	VIII C	VIII D
1967																			
7/11	.440	.100	.220																
7/14								.440			ND		.220				.220		
7/18			.220																
7/19	.220	.220																	
7/25	ND																		
7/27	ND	.220	.440				.220												
7/29								.220			ND		.220				ND		
7/31																			
8/8	ND	.220	.220																
8/10							.050												
8/12								.050			ND		.050				ND		
8/16				2.200															
9/5			.440	.440	1.10														
9/6			.220		.220														
10/13	.100	.100	.330	1.100			.660	.100											
11/9											ND								
11/12			.100	.150			.130	.130											
11/13	ND	ND																	
11/18	ND	ND																	
11/19				.220									ND				ND		
11/20			.100				.220												
12/9				.660				ND			ND						.005		
12/10	ND	ND	ND		.005		.220												
12/13			ND																
12/14			.220																
12/24		ND		1.800															
12/31				2.600															

TABLE 28--Continued for Nickel

Date	Stream Stations															Lake Stations			
	I	II	III A	III B	III C	III D	IV	V A	V B	V C	VI A	VI B	VII A	VII B	VII C	VIII A	VIII B	VIII C	VIII D
1968																			
1/28								ND			ND		ND				ND		
1/29	ND	ND		.220			ND												
2/13			ND																
2/14		ND	.220																
2/16				.660															
2/18								.220	.220		ND		ND				.100		
2/20	.220	.220	.440		.100		.100												
3/27				.660															
3/29				2.000	.440														
3/30		.220					.100	ND			ND								
4/1				.540					.440	ND			ND	.220	.220		ND		
4/2	ND		ND	.440															
4/3				.440															
4/4				.900															
4/5		ND	.220	.900	ND	1.80	ND												
4/6				.440			.100	ND	ND	ND	ND		ND	ND	ND		ND		
5/8				6.500		.220	ND	ND	.220		ND	ND	ND				ND	ND	
5/9																			
5/10																ND	ND	ND	ND
Max. Obs.	.440	.220	.440	6.500	1.10	1.80	.660	.440	.440	ND	ND	ND	.220	.220	.220	ND	.220	ND	ND

TABLE 29
COPPER CONCENTRATIONS (mg/l) AT VARIOUS STATIONS AND DATES

Date	Stream Stations															Lake Stations			
	I	II	III A	III B	III C	III D	IV	V A	V B	V C	VI A	VI B	VII A	VII B	VII C	VIII A	VIII B	VIII C	VIII D
1967																			
7/11	.220	ND	.180																
7/14								.180			.180		.180				.150		
7/18			ND																
7/19	ND	ND																	
7/25	ND																		
7/27	ND	ND	.150				.150												
7/29																			
7/31								ND			.180		ND				ND		
8/8	.400	ND	ND																
8/10							ND												
8/12								.340			ND		ND				ND		
8/16				.150															
9/5			.180	.180	.180														
9/6			ND		ND														
10/13	.250	ND	.500	.180			ND	ND											
11/9											ND								
11/12			.180	ND			ND	.180											
11/13	ND																		
11/18	ND	.150																	
11/19				ND									ND				ND		
11/20			ND				.150												
12/9				.150				ND			.450						.180		
12/10	ND	ND	ND		.150		ND												
12/24		ND		.225			ND												
12/31				ND															

TABLE 29--Continued for Copper

Date	Stream Stations															Lake Stations			
	I	II	III A	III B	III C	III D	IV	V A	V B	V C	VI A	VI B	VII A	VII B	VII C	VIII A	VIII B	VIII C	VIII D
1968																			
1/28								ND			.150		ND				ND		
1/29	ND	ND	.200	.180			ND												
2/13		.200	.150																
2/14																			
2/16				.340															
2/18								ND	ND		ND		ND				ND		
2/20	ND	.150	.340		.250		.180												
3/27				.400															
3/29				.400	.150														
3/30		.100					.150	.150			.225								
4/1				.500					.340	.230			.340	.340	.400		.340		
4/2	.400		.340	.400															
4/3				.400															
4/4				.340															
4/5		ND	.180	.340	.180	.550	.180												
4/6				ND			.100	.150	ND	ND	.150		ND	.150	ND		ND		
5/8				.400		.250	ND	.150	.150		ND	.225	.250				ND		
5/9																	.150	.150	.150
5/10																.150	.150	.150	.150
Max.																			
Obs.	.400	.200	.500	.500	.250	.550	.180	.340	.340	.230	.450	.225	.340	.340	.400	.150	.340	.150	.150

TABLE 30

ZINC CONCENTRATIONS (mg/l) AT VARIOUS STATIONS AND DATES

Date	Stream Stations															Lake Stations			
	I	II	III A	III B	III C	III D	IV	V A	V B	V C	VI A	VI B	VII A	VII B	VII C	VIII A	VIII B	VIII C	VIII D
1967																			
7/11	.500	.700	.660																
7/14								.250			.090		.045				.045		
7/18			.100																
7/19	.130	.258																	
7/25	.100																		
7/27	.075	.100	.190				.130												
7/29													.100				.160		
7/31								.045			.130								
8/8	.130	.010	.100																
8/10							.045												
8/12								.074			.130		.045				.250		
8/16				.130															
9/5			.220	.280	.51														
9/6			.160		.10														
10/13	.190	.160	.810	.500			.820	.075											
11/9											.050								
11/12			.190	.160			.220	.075											
11/13	.280	.035																	
11/18	.046	.280																	
11/19				.075									.046				.046		
11/20			.075				.130												
12/9				.045				.022			.035						.075		
12/10	.022	.022	.075		.05		.075												
12/24		.700		.160			.075												
12/31				.100															

TABLE 30--Continued for Zinc

Date	Stream Stations															Lake Stations			
	I	II	III A	III B	III C	III D	IV	V A	V B	V C	VI A	VI B	VII A	VII B	VII C	VIII A	VIII B	VIII C	VIII D
1968																			
1/28								.250			.160		.022				.046		
1/29	ND	ND		.022			.046												
2/13			.160																
2/14		.190	.160																
2/16				.280															
2/18								.022	.220		.022		.034				.022		
2/20	.022	.046	.220		.05		.100												
3/27				.220															
3/29				.550	1.50														
3/30		.280					.315	.350			.250								
4/1				1.100					.350	.450			.280	.280	.350		.420		
4/2	.220		.620	.280															
4/3				.380															
4/4				.350															
4/5		.022	.160	.350	.10	.580	.075												
4/6				.130			.350	.190	.075	.280	.500		.220	.280	.350		.280		
5/8				.310		.450	.220	.760	.760		.380	.280	.250				.250		
5/9																	.320		
5/10																.380	.420	.350	.310
Max.																			
Obs.	.500	.700	.810	1.10	1.50	.580	.820	.760	.760	.450	.500	.280	.280	.280	.350	.380	.420	.350	.310

TABLE 31

SILVER CONCENTRATIONS (mg/l) AT VARIOUS STATIONS AND DATES

Date	Stream Stations															Lake Stations			
	I	II	III A	III B	III C	III D	IV	V A	V B	V C	VI A	VI B	VII A	VII B	VII C	VIII A	VIII B	VIII C	VIII D
1967																			
7/11	.010	.010	ND																
7/14								ND			ND		ND				ND		
7/18			ND																
7/19	ND	ND																	
7/25	ND																		
7/27	ND	ND	.010				ND												
7/29													ND				ND		
7/31								ND			ND								
8/8	ND	ND	ND																
8/10							ND												
8/12								ND			.010		ND				.010		
8/16				.025															
9/5			.010	.010	.005														
9/6			ND		ND														
10/13	ND	.010	.025	.025			.010	ND											
11/9											ND								
11/12			.010	.025			.005	ND											
11/13	ND	.005																	
11/18	ND	.005																	
11/19				.010									.005				ND		
11/20			ND				ND												
12/9				.005				ND			ND						ND		
12/10	ND	ND	ND		.005		.005												
12/24		ND	.005	.010			ND												
12/31				.025															

TABLE 31--Continued for Silver

Date	Stream Stations															Lake Stations			
	I	II	III A	III B	III C	III D	IV	V A	V B	V C	VI A	VI B	VII A	VII B	VII C	VIII A	VIII B	VIII C	VIII D
1968																			
1/28								.005			.010		ND				ND		
1/29	ND	ND		.025			ND												
2/13			.005																
2/14		ND	.005																
2/16				.025															
2/18								ND	.010		ND		ND				ND		
2/20	ND	ND	.010		ND		.010												
3/27				.070															
3/29				2.150	.010														
3/30		.010					.005	.010			.005								
4/1				.075					.005	ND			ND	ND	ND		.005		
4/2	ND		ND	.015															
4/3				.010															
4/4				.025															
4/5		ND	.005	.017	.005	.042	.005												
4/6				.005			ND	ND	ND	.003	ND	ND	.003	ND	ND		ND		
5/8				.025		.003	.005	ND	.005		ND	ND	ND				ND		
5/9																	ND		
5/10																ND	ND	ND	.003
Max.																			
Obs.	.010	.010	.025	2.150	.010	.042	.010	.010	.010	.010	.010	ND	.005	ND	ND	ND	.010	.003	.003

TABLE 32

CADMIUM CONCENTRATIONS (mg/l) AT VARIOUS STATIONS AND DATES

Date	Stream Stations															Lake Stations			
	I	II	III A	III B	III C	III D	IV	V A	V B	V C	VI A	VI B	VII A	VII B	VII C	VIII A	VIII B	VIII C	VIII D
1967																			
7/11	ND	.010	ND																
7/14								ND										ND	
7/18			ND																
7/19	ND	.010																	
7/25	ND																		
7/27	ND	ND	.005			.005													
7/29														ND				ND	
7/31								ND				ND							
8/8	ND	ND	ND																
8/10						ND													
8/12								ND										ND	
8/16				.050															
9/5			ND	.065	.025														
9/6			.010		.025														
10/13	.005	.015	.016	.410		.023		.005											
11/9												ND							
11/12			.010	.030		.035		.005											
11/13	ND	.005																	
11/18	ND	.015																	
11/19				.100														ND	
11/20			ND				.010												
12/9				.150				ND				ND						ND	
12/10	ND	ND	ND		.030		ND												
12/24		ND		.300			.005												
12/31				.150															

TABLE 32--Continued for Cadmium

Date	Stream Stations															Lake Stations			
	I	II	III A	III B	III C	III D	IV	V A	V B	V C	VI A	VI B	VII A	VII B	VII C	VIII A	VIII B	VIII C	VIII D
1968																			
1/28								ND			ND		ND				ND		
1/29	ND	ND		.050			.010												
2/13			.010																
2/14		.005	.010																
2/16				1.100															
2/18								.010	.010		ND		.005				ND		
2/20	.005	.010	.010		.080		.023												
3/27				.150															
3/29				.410	.023														
3/30		.010					.016	.010			.010								
4/1				2.800					.023	.010			.010	.010	.010		.010		
4/2	.010		.023	.115															
4/3				.150															
4/4				.380															
4/5		.005	.005	.900	.025	2.00	.015												
4/6				.050			.013	.013	.013	.013	ND		ND	ND	ND		.005		
5/8				1.300		.500	.013	.005	.030		ND	.013	.013				.005		
5/9																	.005		
5/10																.005	.013	.013	.005
Max.																			
Obs.	.010	.015	.023	2.800	.080	2.00	.035	.013	.030	.013	.010	.013	.013	.010	.010	.005	.013	.013	.005

TABLE 33

CHROMIUM CONCENTRATIONS (mg/l) AT VARIOUS STATIONS AND DATES

Date	Stream Stations															Lake Stations			
	I	II	III A	III B	III C	III D	IV	V A	V B	V C	VI A	VI B	VII A	VII B	VII C	VIII A	VIII B	VIII C	VIII D
1967																			
7/11	ND	ND	ND																
7/14								ND			ND		ND				ND		
7/18			ND																
7/19	ND	ND																	
7/25	ND																		
7/27	ND	ND	ND				ND												
7/29													ND				ND		
7/31								ND			ND								
8/8	ND	ND	ND																
8/10							ND												
8/12								ND			ND		ND				ND		
8/16				.760															
9/5			.050	.250	.90														
9/6			ND		.58														
10/13	ND	ND	.050	3.500			.050	ND											
11/9											ND								
11/12			ND	.350			ND	ND											
11/13	ND	ND																	
11/18	ND	.050																	
11/19				3.200									ND				ND		
11/20			ND				ND												
12/9				.358				ND										ND	
12/10	ND	.020	ND		ND		ND												
12/24		ND		.820			ND												
12/31				.700															

TABLE 33--Continued for Chromium

Date	Stream Stations															Lake Stations			
	I	II	III A	III B	III C	III D	IV	V A	V B	V C	VI A	VI B	VII A	VII B	VII C	VIII A	VIII B	VIII C	VIII D
1968																			
1/28								ND			ND		ND				ND		
1/29	ND	ND		.880			ND												
2/13			.050																
2/14		ND	ND																
2/16				.710															
2/18								ND	ND		ND		ND				ND		
2/20	.050	ND	.050		.05		ND												
3/27				3.000															
3/29				3.400	1.80														
3/30		ND					ND	.050			ND								
4/1				1.400					ND	.050			.050	.050	.050		.050		
4/2	.050		.050	1.100															
4/3				1.900															
4/4				1.500															
4/5		ND	.050	1.100	.05	7.20	.050												
4/6				.980			.050	ND	ND	.020	.020	ND	.050	.050	.050		.050		
5/8				2.500		1.50	ND	.125	ND		ND	ND	ND				ND		
5/9																			
5/10																.020	ND	ND	.050
Max.																			
Obs.	.050	.050	.050	3.500	1.80	7.20	.050	.125	ND	.050	.020	ND	.050	.050	.050	.020	.050	ND	.050

TABLE 34

RANGE OF TRACE METAL CONCENTRATIONS IN MAINSTREAM WATERS
OF THE LOWER NORTH CANADIAN RIVER BASIN (mg/l)

Metals		Water Sampling Stations							
		I	II	III	IV	V	VI	VII	VIII
Ag	(Min.)	ND	ND	ND	ND	ND	ND	ND	ND
	(Max.)	.010	.010	.025	.010	.010	.010	.005	.010
Cd	(Min.)	ND	ND	ND	ND	ND	ND	ND	ND
	(Max.)	.010	.015	.023	.035	.013	.010	.013	.013
Cr	(Min.)	ND	ND	ND	ND	ND	ND	ND	ND
	(Max.)	.050	.050	.050	.050	.125	.010	.050	.050
Cu	(Min.)	ND	ND	ND	ND	ND	ND	ND	ND
	(Max.)	.400	.200	.300	.180	.340	.450	.340	.340
Ni	(Min.)	ND	ND	ND	ND	ND	ND	ND	ND
	(Max.)	.440	.220	.440	.660	.440	ND	.220	.220
Zn	(Min.)	ND	ND	ND	.045	.022	.022	.022	.015
	(Max.)	.500	.700	.810	.820	.760	.500	.280	.420
Fe	(Min.)	ND	.150	.150	.300	.150	ND	.150	ND
	(Max.)	2.500	1.600	1.950	6.500	12.000	9.000	6.400	3.700

TABLE 35

RANGE OF TRACE METAL CONCENTRATIONS IN TRIBUTARY STREAMS
OF THE LOWER NORTH CANADIAN RIVER BASIN (mg/l)

Metals		Water Sampling Stations							
		III-B	III-C	III-D	V-B	V-C	VI-B*	VII-B	VII-C
Fe	(Min.)	.440	.150	.740	.600	.740		1.000	1.500
	(Max.)	14.000	4.000	3.600	1.050	1.500	.900	2.100	2.100
Ni	(Min.)	.150	ND	.220	ND	ND		ND	ND
	(Max.)	6.500	1.100	1.800	.440	ND	ND	.220	.220
Cu	(Min.)	ND	ND	.250	ND	ND		.150	ND
	(Max.)	.500	.250	.550	.340	.230	.225	.340	.400
Zn	(Min.)	.022	.050	.450	.075	.280		.280	.350
	(Max.)	1.100	1.500	.580	.760	.450	.280	.280	.350
Ag	(Min.)	.005	ND	.003	ND	ND		ND	ND
	(Max.)	2.150	.010	.042	.010	.003	ND	ND	ND
Cd	(Min.)	.030	.023	ND	.010	.010		ND	ND
	(Max.)	2.800	.080	2.000	.030	.013	.013	.010	.010
Cr	(Min.)	.250	ND	1.500	ND	.020		.050	.050
	(Max.)	3.500	1.800	7.200	ND	.050	ND	.050	.050

*Values given are based on a single sample taken at this tributary stream location.

APPENDIX D

TRACE METAL CONTENT OF PLANKTON AND FISH

TABLE 36

TRACE METAL CONTENT OF ALGAE AND OTHER SUSPENDED SOLIDS

Station	Water Sample Number	Microorganisms					Trace Metal Content of Total Suspended Solids (in µg/g of Ash)						
		Type and Percentage of Relative Abundance											
		Phytoplankton				Zoo plank-ton							
		Blue Green Algae	Flagellated Green Algae	Diatoms	Green Algae								
							Fe	Ni	Cu	Zn	Ag	Cd	Cr
I	44	29	7	13	51	1	9,908	57	142	91	2	5	85
	51	4	2	17	70	5	2,782	143	123	357	4	ND	ND
	52	9	0	12	58	21	8,953	207	186	538	3	8	31
	64	9	0	17	67	7	6,267	108	130	454	3	5	135
II	50	7	0	60	26	7	376	42	197	155	ND	3	27
	65	12	1	25	54	13	1,374	ND	49	80	2	ND	72
III-A	46	2	2	21	35	39	453	151	91	203	2	6	49
	58	0	8	28	46	16	1,020	227	453	204	ND	3	113
	66	7	0	20	41	32	1,328	166	161	277	3	3	100
III-B	42	33	0	0	33	33	29,968	3,371	562	450	50	2,360	3,820
	47	0	0	0	0	100	3,504	1,001	401	284	20	40	1,168
	57	0	0	0	0	100	4,837	1,191	298	397	15	248	6,201
	63	0	0	0	0	0	4,207	2,980	1,017	2,805	21	526	631
III-C	67	0	3	21	24	51	1,258	210	180	1,089	6	59	210

TABLE 36---Continued

Station	Water Sample Number	Microorganisms					Trace Metal Content of Total Suspended Solids (in µg/g of Ash)						
		Type and Percentage of Relative Abundance											
		Phytoplankton				Zoo plank-ton							
		Blue Green Algae	Flagellated Green Algae	Diatoms	Green Algae								
Fe	Ni	Cu	Zn	Ag	Cd	Cr							
IV	41	10	3	20	10	57	2,502	616	411	449	8	24	160
	49	3	0	9	66	24	421	211	126	84	ND	13	46
	59	0	15	24	45	18	1,644	146	161	88	2	6	132
	68	5	0	37	42	16	1,638	243	176	364	4	7	61
V	43	20	5	5	59	1	8,518	102	85	256	2	4	102
	48	11	0	40	37	10	1,798	153	42	382	ND	8	ND
	60	11	4	19	43	21	2,306	140	105	161	ND	6	45
VI	54	1	1	53	39	7	1,353	150	41	26	ND	6	ND
	61	2	1	63	19	17	3,000	70	60	188	ND	7	45
VII	55	0	1	59	40	4	4,630	89	107	178	ND	5	58
VIII	56	0	1	23	72	12	10,080	66	114	88	8	ND	166
	62-1	3	0	47	51	2	4,896	ND	73	265	4	7	ND
	62-2	1	0	51	48	3	4,777	ND	71	452	4	13	ND

TABLE 37

TRACE METAL CONCENTRATIONS IN FISH FROM LAKE EUFAULA

Fish	Weight (g)	Length (cm)	Gills	Skin: With or Without Scales	Muscle	G.I. Tract and Contents	Liver
<u>CADMIUM (in µg/g of Ash)</u>							
Gizzard Shad (dead)	48	19	.537	3.43	2.65	10.1	-
Freshwater Drum (dead)	79	20	.408	1.11	1.46	33.1	14.8
Catfish, Channel	560	41	.283	1.97	.893	3.68	1.63
Crappie, White	73	18	.694	.488	1.31	5.54	7.08
Carp	478	32	.631	.542	1.12	7.52	12.1
<u>SILVER (in µg/g of Ash)</u>							
Gizzard Shad (dead)	48	19	.413	1.29	ND	ND	-
Freshwater Drum (dead)	79	20	.314	.816	.275	.331	ND
Catfish, Channel	560	41	.177	1.48	.282	.289	.388
Crappie, White	73	18	.219	.360	.691	.693	5.31
Carp	478	32	.210	.226	.651	.191	.525
<u>NICKEL (in µg/mg of Ash)</u>							
Gizzard Shad (dead)	48	19	.04	.13	.07	.22	-
Freshwater Drum (dead)	79	20	.02	.06	.05	.02	.11
Catfish, Channel	560	41	.01	.05	.02	.02	.02
Crappie, White	73	18	.02	.01	.03	.05	.04
Carp	478	32	.02	.01	.03	.04	.02

TABLE 37--Continued

Fish	Weight (g)	Length (cm)	Gills	Skin: With or Without Scales	Muscle	G.I. Tract and Contents	Liver
<u>ZINC (in µg/mg of Ash)</u>							
Gizzard Shad (dead)	48	19	.045	.352	.318	3.13	-
Freshwater Drum (dead)	79	20	.007	.030	.168	2.21	1.25
Catfish, Channel	560	41	.004	1.28	.165	.589	1.13
Crappie, White	73	18	.015	.008	.187	.623	.726
Carp	478	32	.921	.047	.242	10.000	9.84
<u>COPPER (in µg/mg of Ash)</u>							
Gizzard Shad (dead)	48	19	.009	.052	.060	.165	-
Freshwater Drum (dead)	79	20	.005	.011	.033	.049	.205
Catfish, Channel	560	41	.003	.054	.019	.052	.097
Crappie, White	73	18	.008	.005	.015	.074	.195
Carp	478	32	.008	.005	.020	.202	.636
<u>CHROMIUM (in µg/mg of Ash)</u>							
Gizzard Shad (dead)	48	19	.010	.043	.011	.007	-
Freshwater Drum (dead)	79	20	.004	.011	.012	ND	.034
Catfish, Channel	560	41	.002	ND	.006	.006	.007
Crappie, White	73	18	.007	.003	.010	ND	ND
Carp	478	32	.005	.004	.007	.005	.004

TABLE 38

METAL CONCENTRATION FACTORS OF ALGAE AND OTHER SUSPENDED
SOLIDS AT VARIOUS SAMPLING STATIONS

Station	Sample Number	Fe	Ni	Cu	Zn	Ag	Cd	Cr
I	44	374	*	*	*	*	20	2,104
	51	*	126	90	*	*	*	*
	52	129	123	107	614	*	73	*
	64	1,647	130	200	**	*	100	814
II	50	*	125	14,400	**	*	75	*
	65	608	*	136	7,800	*	*	1,121
III-A	46	*	148	*	55	*	*	255
	58	57	474	**	678	*	91	3,065
	66	875	3,590	3,158	8,375	133	100	40,666
III-B	42	65	203	17	*	*	73	*
	47	*	158	237	*	*	*	*
	57	630	153	182	146	*	*	*
	63	55	47	169	**	20	*	*
III-C	67	*	**	*	**	*	*	*
IV	41	*	*	60	*	*	*	*
	49	*	220	547	*	*	*	275
	59	28	*	56	*	*	*	2,448
	68	215	134	2,131	149,000	42	650	757
V	43	525	82	170	486	41	55	470
	48	141	61	*	880	*	110	*
	60	7,571	1,400	653	**	*	500	460
VI	54	175	467	11	*	*	22	*
	61	12,333	178	*	**	*	500	315
VII	55	333	113	168	508	*	73	*
VIII	56	187	*	51	29	73	*	325
	62-1	1,142	*	*	**	*	133	*
	62-2	194	*	12	807	*	400	240

*No concentration observed.

**Very high concentration observed but interference prohibited calculation of concentration factor.

TABLE 39

CONCENTRATION FACTORS FOR METALS IN LAKE EUFAULA FISH

Lake water Station VIII-B 4/1 to 4/6/68 (in mg/l)	G.I. Tract and Contents				
	Gill	Skin	Muscle		Liver
<u>C.F. GIZZARD SHAD 4/6/68</u>					
Ni (ND = .05)	53	104	16	50	-
Cu = .125	5	17	5	15	-
Zn = .250	12	56	14	143	-
Ag = .005	6	1	*	*	-
Cd = .005	7	27	6	23	-
Cr = .05	13	34	22	15	-
<u>C.F. FRESHWATER DRUM 4/6/68</u>					
Ni (ND = .05)	27	12	12	4	24
Cu = .125	3	1	3	4	18
Zn = .250	2	1	8	95	56
Ag = .005	4	2	0.6	0.7	*
Cd = .005	5	2	3	72	33
Cr = .05	5	2	3	*	8
<u>C.F. CHANNEL CATFISH 4/6/68</u>					
Ni (ND = .05)	10	8	5	4	5
Cu = .125	1	4	2	4	10
Zn = .250	1	41	8	22	59
Ag = .005	2	2	0.6	0.5	1
Cd = .005	3	3	2	7	4
Cr = .05	2	*	2	11	2

*= No apparent change.

$$CF = \frac{\text{mg of metal per kg of fresh tissue}}{\text{mg of metal per liter of lake water}}$$

TABLE 39--Continued

Lake water Station VIII-B 5/8 to 5/10/68 (in mg/l)	Gill	Skin	Muscle	G.I. Tract and Contents	Liver
<u>C.F. CARP 5/9/68</u>					
Ni (ND = .05)	16	2	8	10	6
Cu = .100	3	0.5	3	25	96
Zn = .300	123	1	11	410	490
Ag (ND = .010)	0.8	0.2	1	0.2	0.8
Cd = .005	5	1	3	19	36
Cr (ND = .050)	4	0.7	2	1	1
<u>C.F. WHITE CRAPPIE 5/9/68</u>					
Ni (ND = .05)	32	4	8	18	17
Cu = .100	6	1	2	13	41
Zn = .300	4	0.5	9	37	51
Ag (ND = .010)	2	0.7	1	1	11
Cd = .005	11	2	4	20	30
Cr (ND = .050)	10	1	3	*	*

*= No apparent change.

$$CF = \frac{\text{mg of metal per kg of fresh tissue}}{\text{mg of metal per liter of lake water}}$$

APPENDIX E

TRACE METAL CONTENT OF LAKE EUFAULA BOTTOM SEDIMENTS

TABLE 40
IRON CONCENTRATIONS IN BOTTOM SEDIMENTS OF LAKE EUFAULA

	CORE SAMPLE						
	<u>185</u> VIII-A	<u>187</u> VIII-A	<u>188</u> VIII-A	<u>80</u> VIII-B	<u>99</u> VIII-B	<u>189</u> VIII-C	<u>191</u> VIII-D
Location							
Date (1968)	5/10	5/10	5/10	1/28	2/18	5/10	5/10
Bottom Depth (ft)	3.5	4.5	10	17	18	17	24
Core Water (mg/l)	2.500	3.300	.440	5.400	3.000	.740	.600
Interface (μ g/mg of Ash)	.4699	5.3820	.0640	15.5120	.1150	.0798	.0798
Sediment (μ g/mg of Ash)	.0196	.0465	.0810	.0750	.0330	.0284	.0142
(Successive 2-cm core portions)	.0517	.2898	.0594	.3306	.0200	.0588	
	.0176	.2070	.0192	.1440	.0283		
		.2436	.0242	.0992	.0230		
		.2184			.0193		
		.2376			.0371		
		.1617					
		.0306					
Maximum Concentra- tion in survey (μ g/mg of Ash)	.4699	5.3820	.0810	15.5120	.1150	.0798	.0798

TABLE 41

NICKEL CONCENTRATIONS IN BOTTOM SEDIMENTS OF LAKE EUFAULA

	CORE SAMPLE						
	<u>185</u> VIII-A	<u>187</u> VIII-A	<u>188</u> VIII-A	<u>80</u> VIII-B	<u>99</u> VIII-B	<u>189</u> VIII-C	<u>191</u> VIII-D
Location							
Date (1968)	5/10	5/10	5/10	1/28	2/18	5/10	5/10
Bottom Depth (ft)	3.5	4.5	10	17	18	17	24
Core Water (mg/l)	.100	.100	.100	ND	ND	.200	.100
Interface (μ g/mg of Ash)	.0127	.0224	.0089	.0365	.0212	.0111	.0071
Sediment (μ g/mg of Ash)	.0080	.0139	.0073	.0098	.0089	.0049	.0036
(Successive 2-cm core portions)	.0079	.0131	.0046	.0107	.0082	.0046	.0029
	.0028	.0127	.0036	.0096	.0088		
		.0116	.0056	.0099	.0085		
		.0123			.0078		
		.0084			.0053		
		.0086					
		.0037					
Maximum Concentra- tion in survey (μ g/mg of Ash)	.0127	.0224	.0089	.0365	.0212	.0111	.0071

TABLE 42

COPPER CONCENTRATIONS IN BOTTOM SEDIMENTS OF LAKE EUFAULA

	CORE SAMPLE						
	<u>185</u> VIII-A	<u>187</u> VIII-A	<u>188</u> VIII-A	<u>80</u> VIII-B	<u>99</u> VIII-B	<u>189</u> VIII-C	<u>191</u> VIII-D
Location							
Date (1968)	5/10	5/10	5/10	1/28	2/18	5/10	5/10
Bottom Depth (ft)	3.5	4.5	10	17	18	17	24
Core Water (mg/l)	ND	ND	.025	ND	.025	.025	ND
Interface (μ g/mg of Ash)	.0040	.0075	.0024	.0099	.0037	.0027	.0018
Sediment (μ g/mg of Ash)	.0009	.0017	.0009	.0017	.0008	.0006	.0005
(Successive 2-cm core portions)	.0008	.0015	.0006	.0013	.0007	.0004	.0004
	.0002	.0012	.0006	.0007	.0007		
		.0010	.0012	.0011	.0006		
		.0010			.0005		
		.0008			.0012		
		.0009					
		.0002					
Maximum Concentra- tion in survey (μ g/mg of Ash)	.0040	.0075	.0024	.0099	.0037	.0027	.0018

TABLE 43

ZINC CONCENTRATIONS IN BOTTOM SEDIMENTS OF LAKE EUFAULA

	CORE SAMPLE						
	<u>185</u> VIII-A	<u>187</u> VIII-A	<u>188</u> VIII-A	<u>80</u> VIII-B	<u>99</u> VIII-B	<u>189</u> VIII-C	<u>191</u> VIII-D
Location							
Date (1968)	5/10	5/10	5/10	1/28	2/18	5/10	5/10
Bottom Depth (ft)	3.5	4.5	10	17	18	17	24
Core Water (mg/l)	.020	.050	.020	.160	.066	.010	.010
Interface (μ g/mg of Ash)	.0203	.0418	.0359	.1108	.0500	.0302	.0436
Sediment (μ g/mg of Ash)	.0170	.0259	.0270	.0316	.0244	.0288	.0172
(Successive 2-cm core portions)	.0189	.0290	.0351	.0336	.0240	.0088	.0105
	.0073	.0290	.0069	.0298	.0248		
		.0255	.0179	.0310	.0250		
		.0257			.0185		
		.0118			.0085		
		.0255					
		.0054					
Maximum Concentra- tion in survey (μ g/mg of Ash)	.0203	.0418	.0359	.1108	.0500	.0302	.0436

TABLE 44
SILVER CONCENTRATIONS IN BOTTOM SEDIMENTS OF LAKE EUFAULA

	CORE SAMPLE						
	<u>185</u> VIII-A	<u>187</u> VIII-A	<u>188</u> VIII-A	<u>80</u> VIII-B	<u>99</u> VIII-B	<u>189</u> VIII-C	<u>191</u> VIII-D
Location							
Date (1968)	5/10	5/10	5/10	1/28	2/18	5/10	5/10
Bottom Depth (ft)	3.5	4.5	10	17	18	17	24
Core Water (mg/l)	ND	ND	ND	.003	.0015	ND	.003
Interface (μ g/g of Ash)	ND	.0897	.0291	.1662	.0750	.0363	.0504
Sediment (μ g/g of Ash)	ND	ND	.0324	.0237	ND	.0216	ND
(Successive 2-cm core portions)	ND	.0104	.0162	ND	.0134	.0095	.0119
	.0072	.0207	.0090	.0144	.0265		
		.0174	.0059	ND	.0150		
		.0168			.0252		
		.0264			.0159		
		.0147					
		.0051					
Maximum Concentra- tion in survey (μ g/g of Ash)	.0072	.0897	.0324	.1662	.0750	.0363	.0504

TABLE 45

CADMIUM CONCENTRATIONS IN BOTTOM SEDIMENTS OF LAKE EUFAULA

	CORE SAMPLE						
	<u>185</u> VIII-A	<u>187</u> VIII-A	<u>188</u> VIII-A	<u>80</u> VIII-B	<u>99</u> VIII-B	<u>189</u> VIII-C	<u>191</u> VIII-D
Location							
Date (1968)	5/10	5/10	5/10	1/28	2/18	5/10	5/10
Bottom Depth (ft)	3.5	4.5	10	17	18	17	24
Core Water (mg/l)	ND	.008	ND	.008	.008	.010	ND
Interface (μ g/g of Ash)	.1524	.3588	.1164	.2270	.3000	.1210	.0840
Sediment (μ g/g of Ash)	.1590	.1152	.0648	.0948	.0792	.0468	.0429
(Successive 2-cm core portions)	.1800	.2070	.0540	.1160	.1068	.0525	.0680
	.0640	.1380	.0600	.2400	.0708		
		.1160	.0975	.1240	.0600		
		.1680			.1680		
		.1320			.0265		
		.1960					
		.0680					
Maximum Concentra- tion in survey (μ g/g of Ash)	.1800	.3588	.1164	.2770	.3000	.1210	.0840

TABLE 46

CHROMIUM CONCENTRATIONS IN BOTTOM SEDIMENTS OF LAKE EUFAULA

	CORE SAMPLE						
	<u>185</u> VIII-A	<u>187</u> VIII-A	<u>188</u> VIII-A	<u>80</u> VIII-B	<u>99</u> VIII-B	<u>189</u> VIII-C	<u>191</u> VIII-D
Location							
Date (1968)	5/10	5/10	5/10	1/28	2/18	5/10	5/10
Bottom Depth (ft)	3.5	4.5	10	17	18	17	24
Core Water (mg/l)	ND	ND	ND	ND	ND	ND	ND
Interface (μ g/mg of Ash)	.00292	.00448	.00097	.01550	.00375	.00182	.00126
Sediment (μ g/mg of Ash)	.00199	.00173	.00035	.00098	.00060	.00036	.00050
(Successive 2-cm core portions)	.00067	.00104	.00027	.00073	.00205	.00026	.00011
	.00048	.00069	.00084	.00158	.00088		
		.00073	.00098	.00143	.00100		
		.00068			.00105		
		.00145			.00132		
		.00049					
		.00048					
Maximum Concentra- tion in survey (μ g/mg of Ash)	.00292	.00448	.00098	.01550	.00375	.00182	.00126

APPENDIX F
SPECTROGRAPHIC ANALYSES FOR LOWER
NORTH CANADIAN RIVER WATERS

TABLE 47
SPECTROGRAPHIC ANALYSES FOR WATERS OF THE LOWER NORTH
CANADIAN RIVER (IN $\mu\text{g/l}$)

Station Location	Mainstream									
	I			II		III			IV	
Sample Number	44	52	133	45	53	40	85	129	41	101
Element*										
Al	6,400	2,500	9,750	1,900	1,240	10,700	2,125	3,725	2,500	520
B	430	450	800	375	390	900	650	1,300	1,000	850
Ba	360	430	270	625	430	510	390	350	290	350
Cr	140	260	205	290	400	500	470	390	370	325
Cu	120	<67	<67	<67	<67	730	130	150	<67	100
Fe	9,900	7,600	8,000	2,200	4,070	6,275	4,300	2,525	6,500	2,325
Mn	310	270	600	390	670	800	440	690	1,560	475
Ni	<130	<130	<130	<130	<130	550	150	<130	350	150
P	<670	<670	<670	<670	<670	2,150	3,900	4,000	3,900	6,925
Sr	590	790	480	>6,600	5,600	>6,600	4,100	4,125	3,100	1,725
Zn	640	150	650	505	640	1,730	425	1,400	2,500	260

*The following metals were included in the analyses and their lower limits of detection are as indicated: Ag 13; Be 1.33; Cd 130; Co 130; Mo 270; Pb 270; V 270.

TABLE 47--Continued

Mainstream						Lake			
	V		VI		VII	VIII			
						B	B	B	D
156	48	117	61	163	124	62-1 Surface	126 Bottom	179 Surface	192 Bottom
3,725	1,800	17,000	2,000	27,000	40,000	1,200	27,000	1,070	22,000
2,225	670	1,100	530	1,400	2,130	180	1,400	500	1,400
415	410	490	270	460	285	170	330	90	390
495	210	390	270	360	160	195	220	112	145
140	180	90	360	96	<67	<67	<67	<67	<67
1,800	2,225	12,000	2,190	>14,000	>14,000	2,025	>14,000	1,500	>14,000
570	175	1,000	120	720	750	140	575	97	870
200	<130	<130	<130	170	<130	<130	<130	<130	<130
6,525	5,100	<670	4,300	<670	<670	<670	<670	<670	<670
3,675	2,400	2,200	2,000	1,125	<27	590	136	<27	44
2,075	250	1,000	170	950	670	<130	900	300	1,200

TABLE 48

RANGES IN THE CONCENTRATION ($\mu\text{g/l}$) OF TRACE ELEMENTS IN THE
 LOWER NORTH CANADIAN RIVER BASIN COMPARED TO THE
 MAJOR RIVER BASINS OF NORTH AMERICA

River Basin	Trace Element						
	Ag	Al	B	Ba	Be	Co	Cr
North Canadian R. Okla.	<13	520 40,000	180* 2,225	90* 625	<1.33	<130	112* 500
Apalachicola R. Fla.		73 2,550					
Atchafalaya R. La.					0 0.2		
Susquehanna R. Md.							
Mississippi R. La.						0 6	3 84
Hudson R. New York							
Mackenzie R. N.W. Terr., Can.							
Colorado R. Ariz.	0 1		34 52	135			
Sacramento R. Calif.							
St. Lawrence R. Can.							
Max. Concentration Ratio: NCR/Other River	--	16x	43x	5x	--	--	6x

*Observed in Lake Eufaula surface water.

TABLE 48--Continued

Trace Element									
Cu	Fe	Mn	Mo	Ni	P	Pb	Sr	V	Zn
<67 730	1,500* >14,000	97* 1,560	<270	<130 550	<670 6,925	<270	<27 >6,600	<270	<130* 2,500
4 105									
	663 1,670	12 185	1 3						
				6 71					
					0 259				
							700 800		
								7 80	
						3 55			0 140
7x	>8x	8x	--	8x	27x	--	>8x	--	18x

APPENDIX G

PHYTO- AND ZOOPLANKTON IN LOWER
NORTH CANADIAN RIVER WATERS

TABLE 49

TRACE METAL CONCENTRATING ORGANISMS IN THE FISH FOOD CHAIN

Station Location	I				II				III-A		
Sample Number	44	51	52	64	45	50	53	65	46	58	66
Number of Organisms per ml (in 1000's)	12	1.8	2.1	2.3	3.0	1.3	1.2	2.1	.5	1.0	2.5
PHYTOPLANKTON (percentage of sample):											
Blue Green Algae											
Anacystis	15	3	6	9		7		12	2		7
Arthrospira					1						
Oscillatoria	9	1	3		1		2				
Spirulina	5				1						
Flagellated Green Algae											
Chlamydomonas	1						2			6	
Euglena		2						1	2	2	
Lepocinclis	5				1						
Phacotus											
Stephanoptera	1										
Diatoms	13	17	12	17	10	60	40	25	21	28	20
Green Algae											
Actidesmium											
Actinastrum											
Ankistrodesmus	5	2	6	29	3	3	13	13		8	11
Chlorella	8	40	21	22	1	9	7	14	10	24	17
Chlorococum	2										
Chodatella											
Closteriopsis											
Closterium	5		3			1	2				
Coelastrum									2		
Coronastrum											
Crucigenia											
Desmidium											
Dimorphococcus	5										
Elakotothrix								2			
Franceia											
Golenkinia	5				1						
Kirchneriella				4	1			6		2	5
Oocystis		24	14	12	1	1	11	13	19	6	4
Ourococcus	5										2
Pediastrum											
Scenedesmus	5	2	1		15	2	5	6	2		2
Selenastrum	5	2	3		1	10	2		2	2	

TABLE 49--Continued

III-B				III-C	IV				V			VI		VII	VIII-B		
42	47	57	63	67	41	49	59	68	43	48	60	54	61	55	56	62-1	62-2
.06	.02	.56	ND	.66	1.0	.3	.7	1.8	16	.7	1.4	4.1	3.0	10.4	2.6	16.2	15.4
33	33 33				5	3		4	5 5	10	11	1	2			3	1
					5			1	3 7	1							
				3	3		3 12		1		4	1	1	1			
									4						1		
				21	20	9	24	37	5	40	19	53	63	59	23	47	51
									5 5						1	1	1
33				24	10	14 14	15 9	7 21	2 10	4 23	9 21	3 13	2 4	2 30	6 35	4 35	3 38
									1			2		1			
						3			5		1	2	1			1	1
							3								2		
								1			1						
									5		3						
										1							
								6	5	3					1	1	1
						29	12 3	7	5	4 1	7	5	7 3	2	7	6 1	3
						6	3		10 5	1	1	3 2	1	1 1	12 3	1 1	2

TABLE 49--Continued

Station Location	I				II				III-A		
Sample Number	44	51	52	64	45	50	53	65	46	58	66
Number of Organisms per ml (in 1000's)	12	1.8	2.1	2.3	3.0	1.3	1.2	2.1	.5	1.0	2.5
Green Algae (Continued)											
Sphaerocystis			10							4	
Tetraedon	1				1						
Tetrastrum	5										
ZOOPLANKTON:											
Amoeba		2			1			3	4		3
Paramecium									12		
Rotifer											
Round Worm											
Spiral Bacteria						2					
Testaceous rhizopoda							2				
Zoociliates				2	1				15		
Zooflagellates	1	3	21	5	60	5	15	10	8	16	29

TABLE 49--Continued

III-B				III-C	IV				V			VI		VII	VIII-B		
42	47	57	63	67	41	49	59	68	43	48	60	54	61	55	56	62-1	62-2
.06	.02	.56	ND	.66	1.0	.3	.7	1.8	16	.7	1.4	4.1	3.0	10.4	2.6	16.2	15.4
												9		3	5		
									5								
				3	3	6		3			1					1	2
					2				1	1							
						6							1				
33	33				2 50	3 9	18	13		9	20	1 6	5 11	1 3	12		1

APPENDIX H
WEIGHT RATIOS FOR FISH TISSUES

TABLE 50

WET, DRY AND ASH WEIGHT RATIOS FOR FISH TISSUES

Fish Species	Total Weight (g)	Length (cm)	Gill	Skin (and Scales)	Muscle	GI Tract and Contents	Liver
			Wet Dry Ash	Wet Dry Ash	Wet Dry Ash	Wet Dry Ash	Wet Dry Ash
Gizzard Shad <u>Dorosoma cepedianum</u>	48	19	15 : 3 : 1	25 : 5 : 1	88 : 13 : 1	88 : 13 : 1	- - -
Freshwater Drum <u>Aplodinotus grunniens</u>	79	20	15 : 3 : 1	97 : 29 : 1	86 : 13 : 1	92 : 14 : 1	90 : 16 : 1
Channel Catfish <u>Ictalurus punctatus</u>	561	41	21 : 6 : 1	125 : 44 : 1	87 : 18 : 1	106 : 24 : 1	76 : 16 : 1
White Crappie <u>Pomoxis annularis</u>	73	18	13 : 3 : 1	49 : 24 : 1	71 : 14 : 1	56 : 11 : 1	48 : 11 : 1
Carp <u>Cyprinus carpio</u>	478	32	26 : 5 : 1	110 : 43 : 1	73 : 15 : 1	81 : 19 : 1	66 : 16 : 1