TOXICITY AS A FACTOR INFLUENCING THE DISTRIBUTION OF *GAMMARUS PULEX* (L) IN SOME MIDLAND RIVERS

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SUMMARY

The literature covering river biology, biology of Gammarus pulex, river pollution and toxicity has been reviewed.

The Rivers Blythe, Cole, Rea, Tame and tributaries were surveyed to enable distribution maps of Gammarus, Asellus, Chironomidae and Oligochaeta to be drawn. The results of chemical analysis of 24 widespread stations over a 2 year period were used to determine field threshold concentrations. Using the thresholds for copper, zinc, chromium and nickel, a Toxicity Index was calculated, and related to the occurrence of Gammarus. Application to additional sampling stations supported the validity of the method. Analysis on a monthly basis suggested that the Toxicity Index would need to be below 1.0 for at least 70% of the time to allow Gammarus to exist.

Laboratory experiments with Gammarus were performed to determine the toxicity of known chemicals. These experiments lasted for either 48 hours, or were continued for periods of up to 600 hours, and were used to obtain the 48hrLC50 or threshold values. The effects of water hardness and dissolved oxygen concentration were investigated. Copper, zinc and chromium were found to be very toxic, while nickel was shown to be a long-term toxic material. Mixtures of metals were studied and it was confirmed that the toxicity could be predicted from the sum of the toxicities of the components.

Application of the laboratory results to the field data gave a field threshold sum of proportions of 0.05, above which Gammarus was absent from the streams studied. This value was examined in relation to literature on fish survival. When related to the laboratory results, after allowing for factors such as water hardness and dissolved oxygen, it would probably account for approximately 5% mortality.

The advantages of using Gammarus as a test animal in place of fish are discussed.

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1. INTRODUCTION AND AIMS

The natural drainage system of the Birmingham and "Black Country" area of the West Midlands is a network of streams and rivers, principally the rivers Tame, Rea, Cole and Blythe, together with their tributaries (Fig. 2). These combine to the east of Birmingham to continue as the Tame, in turn forming a tributary of the Trent, to finally discharge to the North Sea by the Humber.

The area is one of the most highly populated and industrial areas in the country. The rivers are used as the means of transport of much of the water-borne waste, both organic and inorganic, which is discharged from sewage treatment works or other sources.

Most of the organic load discharged to river will eventually be oxidised by natural purification occurring in the rivers, provided the river is long enough or the load is not too great. The toxic material however, can exist in a harmful form until diluted by cleaner water, or otherwise reduced in concentration, so as to be of no consequence to natural processes.

Historically the Tame has had a very varied past. In 1826 the Birmingham Waterworks Company was granted permission to abstract water from the Tame, and reported it "a perfectly satisfactory source from which a supply could be drawn for the needs of the town and was certified to contain nothing injurious either for domestic or other users" (Lester, 1967). A newly constructed reservoir of 30 million gallons at Salford Bridge, Aston was brought into use on 17th August,1831, for the storage of river water, which was then pumped into a service reservoir at Monument Lane, Edgbaston (Clay, 1946; Lester, 1971). In 1854 a tank at the Willenhall Gasworks burst, releasing gas liquor to the river, and killing all the fish. The Waterworks Company was fortunately warned of the incident, and prevented any polluted water from entering the reservoir. An Act of 1865 limited the abstraction of water from the Tame for domestic purposes. The quantity of water supplied in 1859 had reached 3.4 mil gal/d, and 6.4 mil gal/d in 1865. However, by the late 60's abstraction from the Tame had ceased, and was prohibited from 1st January, 1872, except in an emergency.

The Tame was considered one of the best trout fishing streams in the Midlands in 1876 (Clay, 1946) and fish up to and over 2 lbs in weight could be caught at Perry Barr. After this, and up to about 1880, the river contained an abundance of coarse fish - roach, dace, chub, gudgeon, pike and minnows. Over 3,000 salmon were caught in the Trent in 1887, either by nets or rod and line. The 1888 returns described the fishing as "fairly good", but as "poor" in 1889, and the "worst for years" in 1890. After this the numbers were either nil, or barely reaching double figures.

The deterioration of the Tame was probably caused by the increase of industrial effluents, such as gas liquors and galvanizing wastes. During the 1914-1918 war, many untreated factory effluents were discharged into the rivers, and by the end of the war the Tame entered Birmingham resembling an open sewer. Butcher (1946) found parts of the Tame, at Castle Bromwich and Water Orton, completely devoid of any fauna. Effluents containing copper, zinc, nickel and chromium were being discharged to the Tame, and Butcher, in discussion, suggested that pollution by these metals was the cause of the biological sterility (Clay, 1946). Under present day conditions, the Tame, Rea and Cole receive much pollution, whereas the Blythe receives only a small amount of organic pollution, and almost no toxic pollution and so remains a very clean river for most of its length.

The aim of the present study has been the examination of the role of the toxic inorganic pollution as a factor influencing the distribution of the freshwater shrimp, Gammarus pulex in the streams and rivers of the area. Towards this end, surveys have been made of the rivers to determine the distribution of Gammarus and some other common animals, and of organic and inorganic substances at a number of stations. Experiments have been conducted under laboratory conditions to determine the effects of known amounts of different substances on Gammarus. The results from these experiments have been analysed and correlated with the biological and chemical surveys in an attempt to account for the observed distribution of Gammarus in the area.

2. LITERATURE REVIEW

General River Biology

Water arising from the earth, either as springs, or as run-off, is normally unpolluted and the stream may therefore be expected to support a varied fauna and flora community. The bottom dwelling, or benthic organisms, living on or within the substratum are the most useful in assessing water quality since these reflect conditions at that point rather than the past history of the water (Hawkes, 1968). The benthic community is dependent upon the physical and chemical quality of the water at that point.

The main factor influencing benthic communities is the nature of the river bed, either 'eroding' or 'depositing', which is related to the water velocity. This is summarised in Table 1, based on Minnikin (1920), Butcher (1933) and Hynes (1960).

Table 1. Relation between current speed and nature of river bed.

Velocity of Current (ft/sec)	(m/sec)	Nature of bed	Type of habitat
Greater than 4.0	1.21	Rock	Torrential
" " 3.0	0.91	Heavy shingle	Torrential
" " 2.0	0.60	Light shingle	Non-silted
" " 1.0	0.30	Gravel	Partly silted
" " 0.67	0.20	Sand	Partly silted
" " 0.42	0.12	Silt	Silted
Less than 0.42	0.12	Mud	Pond-like

Velocities of more than 1 ft/sec are of an eroding nature, while those less than 1 ft/sec are depositing. However, conditions are rarely uniform, either along or across a stream bed, and therefore different micro habitats can occur in close proximity. Larger stones present in a shingle stretch help to stabilise it, producing a more hospitable environment (Hynes, 1960).

Closely related with the water velocity is the dissolved oxygen content. This is highest at greater flows, where the water movement produces a larger surface area for oxygen uptake, and lower under still pond-like conditions. If green plants are present, however, the oxygen produced by photosynthesis on a bright sunny day can greatly increase the dissolved oxygen content in slow flowing parts, and may produce a supersaturated condition. The temperature of the water also determines the amount of dissolved oxygen. As the temperature increases, the dissolved oxygen content at saturation decreases. Thus, saturated water at 5°C can hold 12.8 mg/l of oxygen, but at 25°C only 8.3 mg/l.

Water temperature can also have a direct effect on the animal community. In summer, sluggish lowland water may become very warm, whereas highland streams will maintain a more uniform temperature throughout the year (Hynes, 1960). This increase in temperature may have lethal effects, so controlling the distribution of some organisms, as occurs with *Crenobia alpina*.

Streams derived from highland areas of hard rock often have a small dissolved chemical content. Where these rocks are overlain by peat, the run-off water may become acidic, especially during floods after dry weather (Jones, 1948). Water from areas of limestone, chalk, or other basic rocks, however, have a higher dissolved chemical content, especially of calcium, and form 'hard' water. This water has a greater chemical buffering capacity, and rarely becomes acidic.

Some animals of the stream community show adaptations to live within a particular habitat. Animals living in the faster stretches may have flattened bodies, such as the mayfly Ecdyonurus. Simulium produces a silken thread mat on the substratum, to which it clings by a number of caudal hooks.

Alternatively they may have developed prehensile claws for clinging to small surface irregularities, as occurs with some caddis larvae, and some stonefly and mayfly nymphs. In areas of slow flow the difficulty of animals maintaining their position is much less. Tubificid worms and chironomid larvae are found partly within the substratum, while Sialis and Asellus live on the substratum surface (Hawkes, 1968). The dissolved oxygen requirements of various species of animals differ, those requiring much oxygen are found in the fast, well aerated regions, while those able to withstand lower oxygen concentrations can survive in the slower, more stagnant stretches.

The chemical content of the water, especially of calcium, may produce large changes in the associated animal community. Many animals requiring calcium for their exoskeleton, such as molluscs and crustaceans are absent or reduced in numbers in very soft water, with less than about 20 mg/l calcium (Hynes, 1960).

Biology of Gammarus pulex

Gammarus pulex has been recorded from most counties of England, Scotland and Wales, and introduced into the Isle of Man. It is absent from Ireland, part of West Cornwall and from part of Northern Scotland, where its place may be taken by Gammarus duebeni Lillj. (Hynes, 1955a). Gammarus pulex is believed to have entered Britain at the time of the post-glacial bridge from the Continent, and to be gradually displacing G. duebeni. It is intolerant of salinity, and is absent from brackish water and estuaries (Hynes et al., 1960). The distribution was thought to be related to the amount of calcium in the water. Jones (1948)

Fig.1. Gammarus pulex

found it in only one of the four streams he looked at in the Black Mountain district of South Wales. Although present in the Clydach, it was absent from the Amman, Garw and Pedol. The Clydach was moderately calcareous and usually alkaline, whereas the other three were soft water streams which often became acidic, especially during floods. In the Rheidol, Jones (1949) again found that G. pulex was absent, with calcium levels of not greater than 3.4 mg/l calcium, but Whitehead (1935) found it common in a chalkstream in Yorkshire. Hynes (1954), however, does not believe that calcium concentration is the governing factor controlling distribution. Gammarus pulex is found in Llyn Tegid (Lake Bala), Merionethshire, where the calcium concentration is less than 4 mg/l, and has been bred and matured in Liverpool tapwater of 13 mg/l calcium. He also shows that the calcium/magnesium ratio is unimportant, G. pulex being found in some streams, but absent from others, apparently suitable, with a similar calcium/magnesium ratio.

Gammarus pulex is usually found in small clean streams with a moderate water flow as a member of the riffle community. Hawkes (1964) defines riffles as areas of non-silted gravel, normally with less than 1 foot (30 cm) depth of water, and with a water flow of over 1 foot/second (30 cm/second). In these riffle areas, the dissolved oxygen content is usually high, due to turbulence of the surface. Huet (1942) noted Gammarus more abundant in small streams than in rivers, and suggested that the greater volume of water in rivers would wash Gammarus away. Alternatively, this may be due to the rivers having a slower flow and therefore depositing silt which is an unsuitable substratum for Gammarus. Macan and Mackereth (1957) suggest the distribution is related to predation by the Bullhead, Cottus gobio, which is plentiful in rivers, but absent from most streams. When Gammarus is dislodged from its habitat, its reactions are to face upstream and swim down to the shelter of the stones (Macan, 1963).

Gammarus does not possess any morphological adaptations to survive in fast flows and is a poor swimmer. Riffles are a stable substratum for animal and plant life, usually consisting of larger stones within a matrix of smaller stones, gravel and possibly coarse sand. Most of the water will flow over the stones, with relatively little passing between them. Once within the spaces, Gammarus is probably subjected to little direct flow. The natural behaviour pattern of seeking shelter as quickly as possible therefore allows survival within riffles. The faster flow of the stream above the bottom will ensure that the dissolved oxygen concentration is maintained, and carry leaves and other organic debris downstream, which may become trapped between the stones and thus providing food. Davies (1965) states that Gammarus will quickly die if the oxygen content of the water falls below 30% saturation. This may happen in slow flowing areas, where deposition and subsequent decomposition of organic material occurs, and where the reabsorption rate of oxygen is reduced by the lack of surface turbulence.

Hynes (1955b) and Sexton (1924) describe the life-cycle of Gammarus pulex in some detail. During mating the adult male holds the female in a precopula position for a few days before the female moults. Copulation occurs after moulting of the female but before the cuticle hardens. The eggs are laid in the brood-pouch made by the interlacing of the bristles of the four pairs of oostegites. At first the eggs are contained in a gelatinous sac which slowly dissolves and fertilisation takes place. Eggs are never deposited in the brood-pouch unless mating has occurred. Relative to the size of the adult the eggs are large and the number laid is dependent on the size of the female.

Table 2. Mean number of eggs related to size of female of *Gammarus pulex* (Hynes, 1955b)

Length of female(mm)	6-7	7-8	8-9	9-10	10-11	11-12
Number of specimens	20	117	300	297	123	17
Mean number of eggs	5.8	8.9	13.4	18.0	23.6	29.1

Table 3. Mean number of eggs related to size of female of *Gammarus pulex* (Berg, 1948)

Size (mm)	7	8	9	10	11	12	13	14
Number of egg carrying females found	8	21	86	68	22	6	6	1
Maximum number of eggs	14	19	40	42	40	45	65	46
Minimum number of eggs	6	5	3	5	8	12	9	
Mean number of eggs	8.8	10.4	17.4	20.1	25.3	24.3	39.0	

Berg also found that the number of eggs carried by females varied during the year, with a maximum during spring, the main breeding period.

Table 4. Mean number of eggs carried by female Gammarus pulex at different periods of the year

	Spring	Summer	Autumn
Number of specimens investigated (m + f)	326	99	158
Females carrying eggs	51%	19%	20%
Maximum number of eggs	65	42	20
Minimum number of eggs	3	6	5
Mean number of eggs	20.4	15.5	11.7

Hatching takes 16-17 days in summer, the young being retained within the brood-pouch for a few days before they are expelled. Precopula may re-occur before the eggs in the brood-pouch, from the previous mating, have hatched.

The young gammarids moult every 5-7 days, increasing to over 20 days in adults and longer in winter. During the summer, with temperatures of 10-15^{o}C, the young mature in 3-4 months, but with a winter temperature of 5-10^{o}C, maturation takes 7 months. The brood-plates of the female begin developing at the 7th moult, but eggs cannot be laid until after the 10th moult.

Females may begin producing eggs in December. The number of egg carrying females increases to a peak in April and May, and then slowly declines. The first young appear in early March, with larger numbers up to June. The first of the new generation, born in March, become mature in July, and breed during August and September. After over-wintering, they breed again during the next spring, and probably die in April or May. Young from the May and June hatchings overwinter as immatures and do not start breeding until reaching maturity in the following spring. These females then have 5 or 6 clutches of eggs, in early March, mid April, early May, late May, mid June and possibly early July before dying.

During the year the sex ratio of individuals over 6 mm and the mean size change. During January the sex ratio is 1 : 1 but in the spring the female become dominant by 5 : 4 as some of the males die. The mean size drops in the summer period as the overwintered adults die, and the young begin maturing. Berg (1948) found the maximum number of individuals in June, the population consisting of small animals with a few large ones. He found the average size a maximum in April at 11.2 mm and a minimum in September at 9.5 mm. In the autumn the sex ratio is 3 male : 1 female as the males are larger and reach 6 mm earlier. The females reach 6 mm during the early winter, and by the following January the sex ratio is again equal. Some adults may die over the winter period, and also some overwintering juveniles may never reach maturity.

River Pollution

Pollution has been defined legally as "the addition of something to water which changes its natural qualities so that the riparian proprietor does not get the natural water of the stream transmitted to him" (Coulson and Forbes, 1952). Hawkes, in Parker and Krenkel (1969) uses the definition "as the discharge of something to the river which so changes its nature that the general amenities of the river are adversely affected, its suitability for man's legitimate use being impaired".

These changes may be nutritional, physical or chemical in nature, and one discharge will usually produce changes in more than one property. Effluent from a sewage works treating domestic sewage will be mainly organic, whereas industrial processes will produce toxic or inorganic effluents.

Organic pollution produces an additional supply of nutrients in the water. This increased food supply supports a large number of bacteria, which, due to respiration, use available oxygen from the water. This decrease of dissolved oxygen in turn leads to a reduction in the number of animals dependent upon a high oxygen content for survival. Stoneflies and mayflies are reduced in number, or become absent if the oxygen level falls too low. Suspended solids settle out onto the substratum, forming a blanket, eliminating light and preventing algal growth (Hynes, 1960). If this reduction of dissolved oxygen continues, more tolerant animals, such as Gammarus will decrease. Asellus, chironomid larvae and tubificid worms are commonly found in organically polluted zones, since they can withstand the reduced oxygen levels. Normally they are found in slow rivers and ponds, but can colonise polluted rivers because of the changed conditions, and form a replacement fauna. As repurification by bacteria proceeds, the numbers of protozoa increase, feeding on the bacteria. Oxygen level increases as re-absorption occurs through the surface. Downstream where conditions have improved further, Gammarus may reappear, to be followed later by other clean water fauna.

Toxic pollution acts in a very different manner to organic pollution. Animals vary in sensitivity to different chemicals, and the order of sensitivity may be dissimilar to that with organic pollution.

Lead mining was carried out in Wales during the nineteenth century and the 1914-18 war, but discontinued shortly afterwards. As the river water used in washing the mineral ore was very soft, quantities of lead were dissolved into solution. The effect of this lead pollution was investigated by Carpenter in 1919, who found vegetation sparse, except the algae Batrochospermum and Sacheria, and a few Arthropods, mostly insects. Mollusca, Trichoptera, malacostracan Crustaceae, worms and leeches were all absent, the lead content of the water being estimated as 0.2 - 0.5 mg/l. Zinc ore occurs in conjunction with lead, but originally toxicity was ascribed only to the lead (Jones, 1958). Over many years the level of lead and zinc decreased in solution, and at the same time, the number of species increased, up to 104 in 1937 when lead was no longer detectable (Laurie and Jones, 1938). It was found that some species, particularly mayflies, stoneflies, and some chironomids were very resistant to both lead and zinc poisoning, the stoneflies Leuctra and Nemoura surviving in 60 mg/l zinc (Jones, 1940b). In some cases they were abundant, such as the stonefly Leuctra, possibly due to lack of competitors (Jones, 1940a). Although lead was not detected 35 years after mining, zinc was found at concentrations of 0.2 - 0.7 mg/l (Jones, 1958). This zinc may be responsible for the continued lack of worms, leeches, crustaceans and molluscs, but the unsuitable substratum, with lack of algal food may be restrictive of other fauna still absent.

The effect of copper pollution has been investigated in the river Churnet, a tributary of the Dove (Pentelow and Butcher, 1938). Although organically polluted 7½ miles upstream, repurification had allowed a fauna of tubificids, chironomids, Asellus, leeches and molluscs to recolonise the river. A copper works effluent, producing up to 1 mg/l or more of copper in the river completely eliminated all fauna for the next 11 miles, and a concentration of 0.6 mg/l copper still persisted before joining the Dove. Below the confluence a copper concentration of 0.14 mg/l was found, allowing the reappearance of a few green chironomid larvae. Algae was also seriously affected, being represented by species indicative of organic recovery. The copper content may have been sufficient to act as an algicide, and thus indirectly controlling some of the fauna through lack of food. Thirty miles downstream from the entry of the copper effluent, shrimps and molluscs were still absent, at a copper concentration of only 0.1 mg/l.

The effect of a shock dose of poison can be seen in the occurrence in 1953 of an accidental discharge of copper cyanide to the River Lee (Hynes, 1960). The fauna before the accident was a recovery fauna, consisting of Asellus, caddis larvae, chironomids and Lymnaea peregra, together with some Gammarus pulex and Baetis rhodani. After the accident, the fauna immediately below the discharge consisted of caddis larvae and some chironomids, including Chironomus riparius. Asellus reappeared after 3 miles and Gammarus, Baetis and Tanytarsus after 8 miles. Lymnaea peregra was absent for 16 miles. After a year, most species had recolonised the affected stretch, except for Lymnaea which had only returned to a limited extent.

Because of the toxic nature of industrial effluent, bacteria and protozoa may be affected. The normal repurification of the stream receiving an organic discharge cannot take place. Under these conditions it is possible to have a high dissolved oxygen content, together with a high organic load. In these cases, the replacement fauna is restricted by the toxicity, and the film on the substratum may be dominated by Stigeoclonium (Hawkes, 1956).

General Toxicity

Most of the studies on aquatic toxicity have been on fish, using various substances under different conditions. Trout have been widely used as these are easily obtainable in large numbers from fish hatcheries and are generally more sensitive to toxic conditions than coarse fish, although the latter have been used (Downing and Merkens, 1957). Most toxic substances are inorganic materials but phenols, formaldehyde, pesticides and other organic substances may be found in sewage and rivers. Some of these organic materials can be partially or completely removed by biological treatment in sewage works, but some, such as pesticides, are only slightly reduced in concentration. One of the main sources of inorganic toxic compounds is the metal industry, with the component manufacture and finishing section producing the most waste. The industrial area of the West Midlands is in particular a metal processing area, with many small scale units, making effluent control difficult (Jackson and Brown, 1970). Although a large proportion of most metals is removed in effluent and sewage treatment, some part, especially of nickel, passes through to the river system. This remaining metal may be in sufficient concentration to prevent fish and restrict other forms of life in rivers. Jones, in Klein (1962) gives a table of lethal concentration of many chemicals, including insecticides, herbicides and detergents. These are values of the lowest concentration which exhibits a toxic action, but it cannot be assumed that lower concentration will have no effect. Doudoroff and Katz (1950, 1953) have reviewed the literature on the toxicity of industrial wastes, including metals and their effects on fish.

Temperature, dissolved oxygen concentration and pH can have large modifying effects on the toxicity of chemicals present in rivers. Brown et al. (1967) give data relating the toxicity of pure phenol and "gas-liquor phenols" to rainbow trout at temperatures between 6°C and 18°C. With short exposure times, they found that the toxicity decreased with an increase in temperature. Edwards and Brown (1967) found similar results over 48 hours with phenol and rainbow trout. Over longer exposure times however, Brown et al. (1967) found that the lethal threshold level is less at lower temperatures. Using rainbow trout, Lloyd (1960) found little change in the threshold concentration of zinc between 13.5°C and 21.5°C but at higher concentrations the survival times differed. Brown (1968) shows that over 48 hours, the toxicity of zinc increases with increasing temperature. In the same paper, Brown gives a graph relating the dissolved oxygen concentration to the toxicity of zinc, copper, lead and gas-liquor phenols. Here a reduction of dissolved oxygen decreases the resistance of rainbow trout to withstand these chemicals. Downing (1954) gives details of dissolved oxygen concentration upon the toxicity of potassium cyanide to rainbow trout, which supports the general view that a decrease of dissolved oxygen increases the susceptibility to toxic substances.

The pH of an effluent or river can be important as it may lead to a change in the chemical state of toxic material. Ammonia is the most common chemical affected by pH, as the toxicity is related to the concentration of un-ionized ammonia, which is dependent upon the pH. As the pH becomes more alkaline, the amount of un-ionized ammonia increases (Ball, 1967a). Hydrogen cyanide behaves similarly, being more toxic in alkaline conditions, as again the un-ionized molecule has a greater toxicity than the undissociated form (Edwards and Brown, 1967).

The presence of other chemicals can have an effect on the toxicity of a particular substance, although the additional chemicals may not be toxic by themselves. The hardness of the water, a measure of the calcium and magnesium content, in which the animals live often determines the amount of a toxic chemical they can withstand. Carpenter (1927, 1930) tested a number of fish species with solutions of heavy metal salts. She concluded that in soft water, death was due to asphyxiation by secreted mucus. Jones (1938a) tested the stickleback, Gasterosteus aculeatus L. and goldfish, Carassius auratus L. with solutions of zinc and lead in soft Aberystwyth tapwater, with and without the addition of 50 mg/l calcium as calcium nitrate. In soft water he found similar results to Carpenter, but with the hardened water obtained much longer survival times. The reason for this increased resistance in the presence of calcium may be chemical or physiological. Some metals, such as lead, will form very insoluble salts in hard water, due to combination with the carbonate, bicarbonate or sulphate ions. This will therefore, reduce the amount of metal in a soluble form, which may affect the toxicity of the metal. Lloyd (1965) studied the effect of water hardness on rainbow trout. He found that fish reared and tested in soft water were more sensitive to zinc poisoning than those reared in hard water and tested in soft. Fish kept in hard water had to be acclimatised to soft water for at least five days before they were as sensitive as soft-water reared rainbow trout. Lloyd suggested that the protective action of calcium is internal, and that hard-water reared rainbow trout have to lose calcium before they are as sensitive as soft-water reared rainbow trout. This may be due to calcium affecting the permeability of cell membranes.

The action of toxic substances to aquatic animals is usually direct, and can affect many parts of the body. In fish, the gills often show histopathological changes, with swelling and epithelium rupture. Cell regeneration may cause fusion of adjacent lamellae but after longer exposure the epithelium may break down, with subsequent blood loss. Water flow through the gills is restricted by fusion, and oxygen uptake becomes reduced. Later stages can progress to total loss of gill tissue, leaving exposed pillar cells (Brown _et al_., 1968). The kidney often shows swelling and may rupture, possibly from overload due to changes in permeability. Phenol was found to affect the gills, skin, liver, kidney, spleen, small intestines and ovary of rainbow trout after exposure for 7 days (Mitrovic _et al_., 1968). Cyanide acts as a respiratory poison, reacting with cytochrome oxidase, a respiratory enzyme, and produces a blocking action which prevents normal metabolism (Jones, in Klein, 1962).

The Water Pollution Research Laboratory at Stevenage has undertaken much work on the toxicity of chemicals, particularly to rainbow trout. Ball (1967a, 1967b) studied the relative susceptibility of six species of fish, including rainbow trout, to ammonia and zinc, while Herbert and

Merkens (1952) tested rainbow trout in potassium cyanide solution. Mixtures of chemicals were studied by Lloyd (1961) using zinc and copper, Herbert and Shurben (1964) with ammonia and zinc, and by Herbert and Vandyke (1964) for copper-ammonia and zinc-phenol combination. Brown (1968) details a method of calculation of the acute toxicity of mixtures of poisons to rainbow trout. The toxicity of fluctuating concentrations and mixtures of ammonia, phenol and zinc were studied by Brown et al. (1969) while Brown and Dalton (1970) looked at the effect of mixtures of copper, phenol, zinc and nickel. In all these papers the authors have tested fish under known conditions in an attempt at relating the mortality of fish to the concentration of the various chemicals.

In mixtures, it was found that the mortality could be predicted from a knowledge of the toxicity of the constituents of the mixture. Herbert et al. (1965) expressed the concentration of each constituent as a proportion of its threshold value. This threshold value was taken as the LC50, the concentration which would just kill 50% of the fish. It should be qualified by the length of time of the experiment, which Herbert et al. (1965) took as 48 hours, therefore giving a 48 hr LC50. The proportions of the threshold values were then added, to give a "sum of proportions". They found in many cases that, provided the sum of proportions was less than unity, the fish would survive in the mixture for 48 hours or longer, but die if the value exceeded unity. Using this method, they tested the toxicity of some Midland rivers, including the Cole and Tame. Analysis was performed on frequent water samples, and sum of proportions values calculated. When the mortality of the fish was related to these values, they found that mortality often occurred when the value exceeded unity. Brown et al. (1970) used four fish species for determining the toxicity of some polluted river waters, comparing the results with the predicted toxicity as determined by chemical analysis. They found that in many experiments more than 50% of the fish died in waters of a predicted toxicity of unity. The observed 48 hr LC50 was of the order of only 0.6 - 0.7 times the predicted value. The difference may be due to unmeasured toxic substances which contribute towards death. Experiments maintained over longer periods suggest that the proportion must be reduced to a value of 0.1 or less if a stable fishery is to maintain itself under polluted conditions. This unpredicted mortality of fish exposed over long periods could be caused by substances having a toxic effect which is not evident in short term experiments. It has been found that both cadmium and nickel exhibit this effect, remaining toxic at proportions of 0.05 or less of the 48 hr LC50 (Jackson and Brown, 1970; Ball, 1967c).

Sprague (1969, 1970, 1971) has reviewed the literature on the measurement of pollutant toxicity to fish. He covers the methods of assessing toxicity, the interpretation of the results, and their application to fishery management.

Invertebrate Toxicity

Much less work has been undertaken using invertebrates as test animals in toxicity experiments. Jones (1937) experimented with Polycelis nigra Muller and Gammarus pulex in Aberystwyth tapwater. He plotted survival time against the mortality, using salts of copper and zinc. At a concentration of 0.01N, approximately 0.3 mg/l zinc, the survival time of Gammarus was about 5 hours, while at 5×10^{-4}N, approximately 30 mg/l copper, survival time with copper was about one hour, and remained similar up to 0.15N. Aberystwyth tapwater is a very soft water, containing only about 1 mg/l calcium, and with a pH of 6.6 - 6.8. Jones (1938b) used Polycelis nigra, Gammarus pulex, Tubifex tubifex Muller, and frog tadpoles in solution of lead and copper nitrate. He found that copper nitrate was toxic to Gammarus at a concentration of only 0.13 mg/l copper, when the survival time was under four hours. Lead nitrate was less rapid in action, and Gammarus survived over 8 hours at 0.01N lead nitrate (1,035 mg/l lead). With mixtures of copper and lead nitrates he obtained a curve of survival time showing antagonism at about 500 mg/l lead. Survival times were, however, all under 4½ hours. Tubifex gave similar results, although again experiments usually only lasted for a few hours. Other work using different species of Gammarus has been undertaken by Arthur (1970), Arthur and Leonard (1970), and Emery (1970). Arthur used Gammarus pseudolimnaeus Bousfield and two snail species to determine the chronic effects of linear alkylate sulphonate detergent. He obtained a 96 hr LC50 of 7 mg/l, but found that for natural life processes to continue, a level of 0.2 - 0.4 mg/l was applicable. Arthur and Leonard tested the same species with copper, and obtained a 96 hr LC50 value of 0.02 mg/l copper for Gammarus in water of total hardness equivalent to approximately 45 mg/l calcium carbonate. In experiments where the complete life cycle from adult through to adult was tested, a threshold value allowing normal growth of between 0.0046 and 0.0080 mg/l copper was obtained in similar soft water. Emery experimented with Gammarus fasciatus Say and Asellus militaris Hay, and the acute toxicity of cresol. He found Asellus more resistant than Gammarus and adults more resistant than juveniles. Using Daphnia he tested the three isomers, and obtained thresholds of 12, 16 and 28 mg/l for the para-, ortho- and meta- isomers respectively. Emery also attempts to determine the biologically safe concentration by various formula using the results from short term experiments. He suggests that 0.525 - 0.70 mg/l cresol would be considered the upper limits of exposure for benthic amphiopod and isopod crustaceans.

Anderson (1944, 1946, 1950) has studied the effect of many inorganic chemicals to Daphnia magna Straus to obtain the toxicity of both cations and anions. Some of his experiments were of short duration, but later ones, with metallic chlorides, lasted for 64 hours. He gives a table of threshold concentrations (Anderson, 1950) for 50% immobilization of Daphnia magna, but states that some chemicals may be toxic at lower concentrations. He also states that "in general it may be said that Daphnia and other crustacea are more susceptible to toxic substances than fish are". Nais was used by Learner and Edwards (1963) in experiments with sodium chloride, chlorine and copper. They found that in both hard and soft water, Nais has a toxicity of threshold of under approximately 0.4 mg/l copper.

Degens et al. (1950) experimented with synthetic detergents, in determining the toxicity to tadpoles, sticklebacks and Daphnia. At their lowest concentration of 5 mg/l active material, mortality soon occurred, only tadpoles surviving over 100 hours in some types of detergents. Four species of fish were tested in an attempt to determine whether acclimation was possible. It was concluded that detergent concentrations in rivers were unlikely to be toxic, especially as many underwent biological decomposition. Roberts (1954) used Gammarus pulex in anionic detergent experiments, with either commercially produced or effluent derived material. In similar concentrations of active material, he found the effluent derived detergent less toxic than the commercial detergent at 10.0 and 7.5 mg/l, but of approximately equal toxicity at 5.0 and 2.5 mg/l over periods of 7 days. However, sewage effluent samples containing between 1.5 and 3.0 mg/l of detergent allowed Gammarus to survive for a month without mortality. He suggested that the toxicity might be modified by organic residuals or by silt in the river.

Schmitz et al. (1967), in assessing salinity tolerance, tested Gammarus pulex pulex, Gammarus tigrinus and Asellus aquaticus. Salts of sodium, magnesium, potassium and calcium were used, and the LC50 determined for periods of 24 and 48 hours. It was found that survival depended on the osmotic pressure of the total salts in solution, even when in different proportions to sea water.

3. RIVER SURVEYS

Description of the River System

The area which was studied was approximately the area covered by the Upper Tame Main Drainage Authority, this being the organisation responsible for sewage treatment of Birmingham and the Black Country. It lies within the western part of Warwickshire, and, together with parts of south-east Staffordshire and north-east Worcestershire, covers approximately 340 square miles (870 Km^2), serving 14 local authorities.

The main rivers are the Tame and its tributaries, the Rea, Cole and Blythe, which, with Ford Brook, Tipton Brook and the Bourne make up some 100 miles (Fig. 2).

The land height varies from about 200' to 850' above O.D., although most of the area lies between 300' and 500'. Small areas reach over 700' east of Walsall, and over 800' near Rubery. The Tame drops to between 250' and 200' in the north-east as it leaves the area. The average yearly rainfall is 28.7" (730mm).

The geology of the region can be classified mainly into two periods, the Coal Measures of the Carboniferous, and the Triassic portion of the New Red Sandstone (Fig. 3). The Coal Measures are found on the western side of a line from approximately Rubery to Brownhills, and east of a line from approximately Meriden to Tamworth. Within the western part, the northern section is mainly Lower and Middle Coal Measures, while the southern section and the portion to the east of the region are mainly Upper Coal Measures. The central part can be divided by a diagonal line from approximately Rubery to Sutton Coldfield, with Keuper and Bunter Sandstones to the north-west, and Keuper Marl to the south-east. Small outcrops of Silurian limestone occur near Dudley, Sedgley and Walsall. Igneous basalts from the Carboniferous period are found near Wednesbury

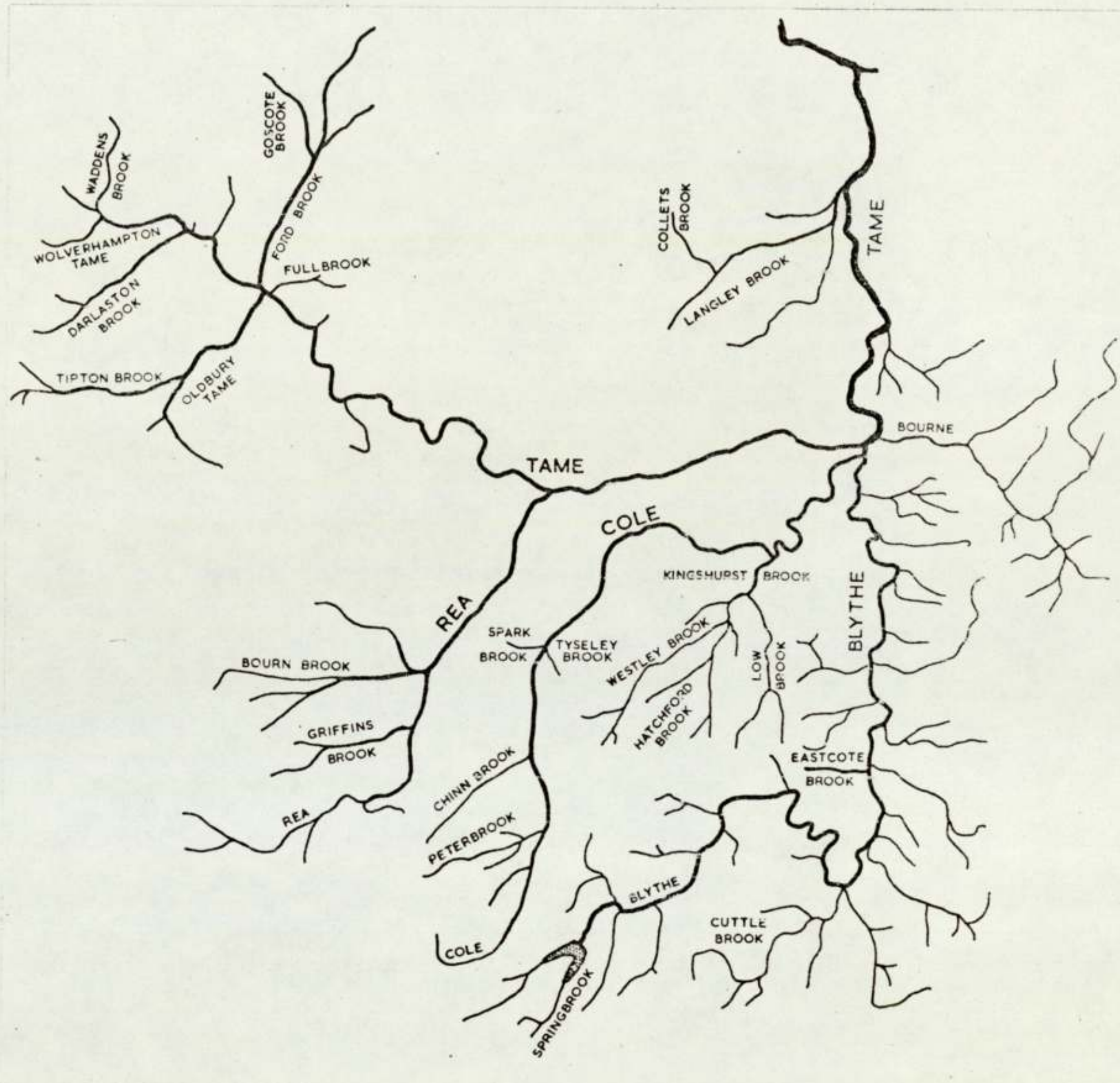
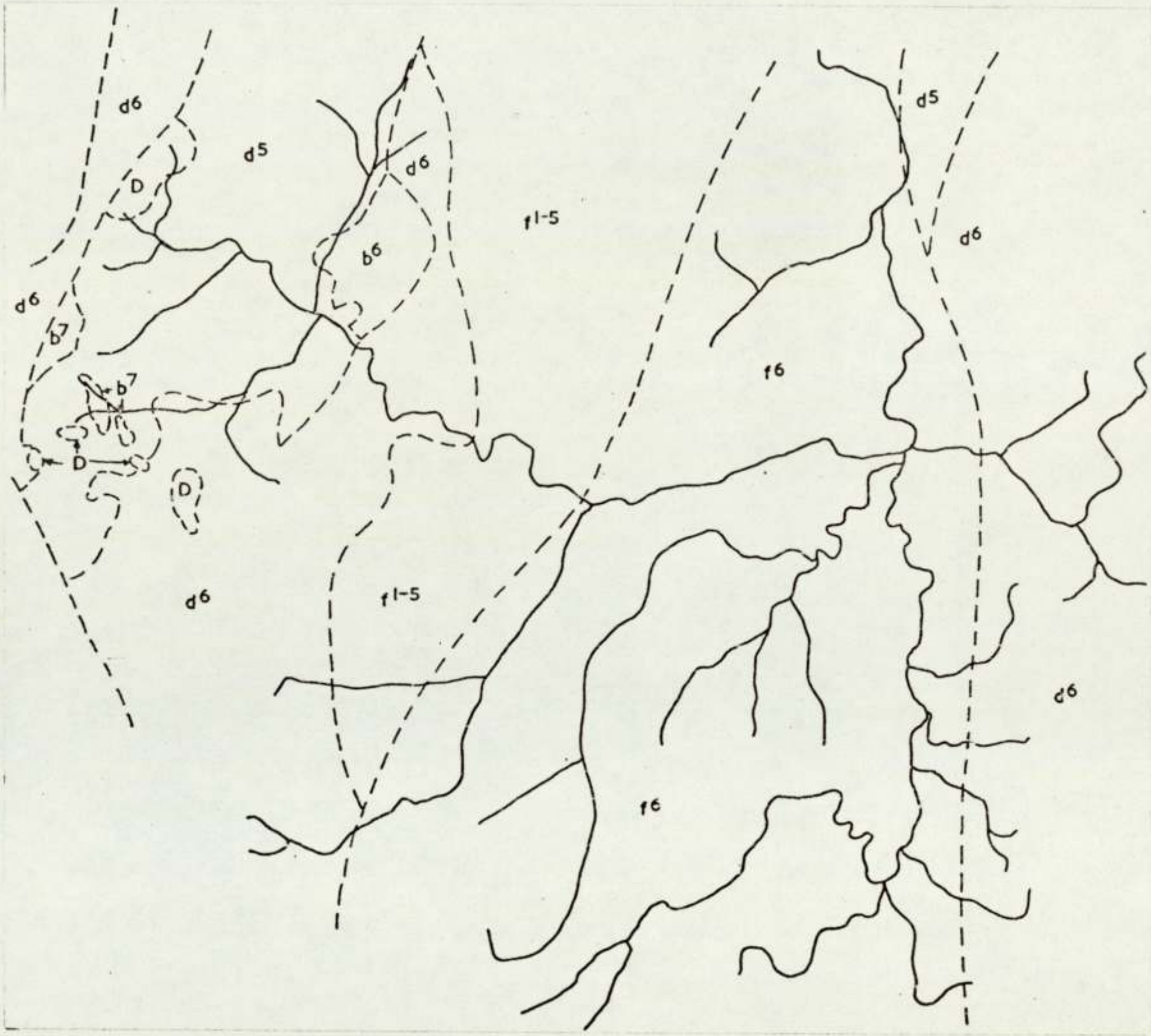


Fig. 2. Map of the River System



b^6	Wenlock Limestone	Silurian
b^7	Ludlow Limestone	
d^5	Upper Coal Measures	Carboniferous
d^6	Lower and Middle Coal Measures	
f^{1-5}	Keuper and Bunter Sandstones	Triassic or New Red Sandstone
f^6	Keuper Marl	
D	Carboniferous Basalts	

Fig. 3. Map of the Solid Geology of the Region

and Rowley Regis, the latter being quarried as 'Rowley Rag'. The rivers do not show any particular pattern related to the underlying geology, and the present dendritic drainage originates from the glacial period. The river valleys are filled with alluvium deposits, which is quarried in places for building construction.

The Tame originates on the Upper Coal Measures in the Black Country to the north-west of the area, and has two main branches. The Wolverhampton Tame begins as two small streams, rising on the east of Wolverhampton. The north-west arm contains effluent from a galvanising works and has also been seen covered by a thick layer of oil retained by a partially blocked bridge. Waddens Brook starts as a moderately clean ditch at Wednesfield, and flows south, receiving effluent from Watery Lane Sewage Works, and joins the Tame at Noose Lane. The Wolverhampton Tame then flows eastwards through Willenhall to Willenhall Sewage Works (Fig. 4).

Darlaston Brook, rising on the Silurian Limestone near Coseley as a moderately clean ditch flows north-east and receives an industrial effluent from a steel works (Fig. 5). This effluent was usually found to be over $20^{o}C$, even in winter. After passing through Lunt Road Sewage Works to Bilston, and receiving the effluent, it continues to Willenhall Sewage Works, where it is a grossly polluted stream, and joins the Wolverhampton Tame. The effluent from the sewage works discharges to the point of confluence of the two streams.

The Oldbury Tame, originating near Oldbury, is badly polluted before reaching Roway Lane Sewage Works (Fig. 6), which discharges to the river. Downstream it receives the Tividale Sewage Works effluent, and then a small side stream, which is badly polluted. After turning north it flows to Great Bridge, where it has an average summer flow of 8 mil gal/d ($36 \times 10^3 m^3/d$), half of this being sewage effluents.

Fig. 4. River Tame, Willenhall

Fig. 5. Tributary of Darlaston Brook, Bilston

Fig.6. River Tame, Oldbury

Fig.7. Goscote Brook, Goscote

The flow figures are taken from the Trent River Authority Triennial Report 1965-67, published in 1969, and containing 1969 flow figures. These are based on an average summer flow of 800 mil gal/d (3,640 x $10^3 m^3/d$) in the Trent at Trent Bridge, Nottingham, although Lester (1971) gives an average flow for 1969 of 1,824 mil gal/d (8,300 x $10^3 m^3/d$).

Tipton Brook begins as two small streams from Upper Gornal and Gorge Road Sewage Works, near Sedgley. That from Gorge Road consists almost entirely of works effluent. The stream above Upper Gornal is polluted before receiving the works effluent. At the point of effluent discharge, a very small clean side stream enters, containing overflow water from a nearby pool. After the confluence with the stream from Gorge Road, the water flows, partly piped beneath ground, to Foxyards Sewage Works, where it receives more effluent. The effluent from Tipton Road Sewage Works, Dudley, also discharges downstream of Foxyards Sewage Works, and the brook continues to Toll End Sewage Works at Tipton. Here it is grossly polluted before the sewage works discharge and has a flow of 6 mil gal/d (27 x $10^3 m^3/d$), before it joins the Oldbury Tame. The Tame then flows round the south-eastern edge of Wednesbury to Bescot.

The northern portion of the area is drained by Ford Brook, beginning near Brownhills. This has been polluted by phenol discharges near the source in the past, and also contains drainage water from abandoned mines. The sewage works at Walsall Wood discharges effluent to this portion of river. Above Barns Lane Sewage Works, a large pool, used for sailing, is fed by a small clean ditch. The pool overflow passes the sewage works, receiving the effluent, and joins Ford Brook at Rushall. Another tributary, Goscote Brook, rising near Pelsall is clean near the source, but soon receives storm water overflow from a nearby sewer. Downstream it passes through an area which has been used as a public industrial tip in the past, and probably contains waste material from a nearby copper refinery. From this point down it is heavily polluted by copper and nickel, with concentrations exceeding 10 mg/l at times (Fig. 7). Goscote Sewage Works discharges 2 mil gal/d ($9 \times 10^3 m^3$/d) to the brook before it joins Ford Brook at Rushall, just downstream from the Barns Lane branch. At Bescot the Ford Brook, with a flow of 6 mil gal/d ($27 \times 10^3 m^3$/d) joins the Wolverhampton Tame of 14 mil gal/d ($65 \times 10^3 m^3$/d). Some 50 yards (45m) downstream the Oldbury Tame, 15 mil gal/d ($70 \times 10^3 m^3$/d) joins the Wolverhampton Tame of 20 mil gal/d ($90 \times 10^3 m^3$/d). Storm water overflows from Bescot Sewage Works discharge to the Wolverhampton Tame before Ford Brook, but effluent is discharged at the point of confluence of the two branches of the Tame. Effluent from Brockhurst Sewage Works discharges to the Tame a short distance below the confluence.

Downstream from Brockhurst, a small tributary, the Fullbrook, enters. This drains the area towards Walsall Golf Course, although much of the watercourse has been piped underground. Before the main river, it is moderately clean but containing some household rubbish. At this point the Tame has a flow of about 39 mil gal/d ($180 \times 10^3 m^3$/d). Another $1\frac{1}{2}$ miles (2.4 Km) further downstream, Ray Hall Sewage Works discharges, with a flow of 6 mil gal/d ($27 \times 10^3 m^3$/d). The Tame flows south-eastwards through Hampstead and Perry Barr to Gravelly Hill where Hockley Brook enters. This contains surface drainage with some storm sewer overflows, and is mainly piped beneath ground level. Almost all of the industrial effluents previously discharged to the brook are now piped to treatment works. The Tame then continues to Saltley where the Rea joins.

The Rea rises on the Coal Measures in the south-west of the area, and flows roughly north-east on the western edge of the Keuper Marl. At Holly Hill, near the source, it runs down the side of a meadow as a shallow ditch containing clean water fauna. Callow Brook, running through Rubery Hill Hospital, shows signs of pollution before joining the Rea. It then continues through Longbridge and Northfield, with a flow of 2 mil gal/d ($9 \times 10^3 m^3/d$) to Stirchley. Merritts Brook rising near Frankley, and leading into Griffiths Brook through Bournville, joins the Rea at Stirchley.

Bourn Brook rises on the western edge of the area at Woodgate, where it is polluted close to the source by a riding school. A small sewage works at Woodgate previously discharged below the farm, but, since the survey has been closed. The brook flows east to Weoley Castle, where it receives a small tributary containing overflow from Bartley Reservoir. This is clean in the upper section and one stonefly, Isoperla grammatica (Poda) was found at this point. A branch from Bartley Green, badly polluted, joins nearby and maintains polluted conditions to Bourn Brook. At Edgbaston a polluted stream from Chad Valley joins before the Bourn Brook becomes confined by culverts and joins the Rea near Cannon Hill Park. From here to Saltley the Rea runs through brick and concrete culverts, where, with a flow of 7 mil gal/d ($32 \times 10^3 m^3/d$) it joins the Tame. From Saltley the Tame flows eastwards to Coleshill. Plants Brook, draining from Sutton Park enters the Tame at Castle Bromwich. Daily sewer overflows discharged to this brook from the Saltley-Minworth trunk sewer before the closure of Saltley Sewage Works. A total of 65 mil gal/d ($300 \times 10^3 m^3/d$) of effluents from Minworth and Coleshill Sewage Works discharged to the Tame before Hams Hall, giving the Tame a flow of 145 mil gal/d ($660 \times 10^3 m^3/d$). The present figure for effluent discharge is over 100 mil gal/d ($455 \times 10^3 m^3/d$) due to closure of Yardley and Saltley Sewage Works, and diversion of the flow to Minworth. Although the Minworth Sewage Works are situated upstream of Coleshill, the effluent is discharged downstream of the Coleshill effluent. Because of the higher level of the Tame compared with the effluent, it is necessary to convey the Minworth effluent along a 3 km channel to a point on the Tame where continuous discharge is possible at all states of the river. If this were not done, there would be a danger of flooding the works at Minworth, or of continuous pumping of the effluent up into the river Tame at Water Orton.

The Cole rises near Wythall, south of Birmingham, on the Keuper Marl. Close to the source it receives organic pollution from a farm and caravan site. Some repurification occurs, but Houndsfield Lane Sewage Works and some piggeries increase the organic load again and give a grossly polluted stream at Majors Green. Two small tributaries, Peterbrook and Chinn Brook, rising to the west, join the Cole near Majors Green and Billesley respectively. These are reasonably clean but the fauna suggests some organic pollution. Downstream conditions again improve slightly, and at Greet the Cole has a flow of 2 mil gal/d ($9 \times 10^3 m^3/d$).

At Tyseley, Spark Brook from the west and Tyseley Brook from the east join. Both of these are very badly polluted, Spark Brook receiving sewer overflow at times. The Cole then turns north-east to Stechford where the flow is 5 mil gal/d ($23 \times 10^3 m^3/d$) and east to Yardley Sewage Works. Daily storm water overflows and effluents totalling 10 mil gal/d ($45 \times 10^3 m^3/d$) maintained badly polluted conditions, but since the survey this works has closed, and the flow piped to Minworth.

The station at Cole Hall Lane sampled during the biological survey has now disappeared because of river straightening operations. At Kingshurst, the Cole is joined by Kingshurst Brook, a small stream of 2 mil gal/d ($9 \times 10^3 m^3/d$) derived from Low Brook, Hatchford Brook, Westley Brook and Lyndon Brook. These tributaries rise on the south side of the Cole and show slight to moderate signs of pollution. The Cole then passes through Coleshill, and flows north-east to join the Blythe. Originally the flow at Coleshill was 18 mil gal/d ($82 \times 10^3 m^3/d$) but this has dropped since the survey because of closure of Yardley Sewage Works.

The Blythe rises on the southern edge of the area, slightly to the east of the Cole, on the Keuper Marl. The Blythe and a tributary, Spring Brook, feed partly into Earlswood Lakes, and partly continue as the Blythe. Spring Brook is slightly polluted, probably from a nearby golf club-house. It also receives effluent from Spring Brook Sewage Works, but this is of good quality. Earlswood Lakes, suitable for sailing and angling, are used to maintain the water level in a nearby canal. After the lakes the Blythe is a small but clean stream. South of Solihull a tributary from the west containing drainage from a refuse tip enters. This is frequently polluted, and prosecutions regarding this drainage have been made in the past. Below this tributary the Blythe remains reasonably clean, with sticklebacks present, passing through Henwood Mill, east of Solihull, to Temple Balsall, south-east of Solihull. Here the Cuttle Brook enters, draining from Dorridge. This is a clean stream, containing the mayflies Ephemerella and Ecdyonurus. Norton Green Sewage Works effluent discharges to a canal feeder, which is also fed from the brook. At times a reverse flow in the feeder can cause effluent to enter the brook. The Blythe then turns north, flowing towards Hampton-in-Arden (Fig. 8). Eastcote Brook enters on the left, and consists almost entirely of effluent from Barston Sewage Works. The flow is about 2 mil gal/d ($9 \times 10^3 m^3/d$), while the Blythe before the junction is 3 mil gal/d ($14 \times 10^3 m^3/d$). The effluent is clean enough to support a varied invertebrate fauna, including Baetis, Gammarus and Asellus. After the confluence the river widens and becomes slow flowing and deep in many places. Good coarse and trout fishing is found between Hampton-in-Arden and Blythe Bridge, east of Coleshill, much of which is private and controlled by the Packington Estate. Between the Cuttle Brook and Coleshill, a number of small streams enter from the east, draining from the Coal Measures, some containing effluent from small rural sewage works. At Blythe Bridge the river is wide and deep, with a slow

Fig. 8. River Blythe, Hampton-in-Arden

Fig. 9. Langley Brook, Langley

flow, allowing supersaturation at periods of high algal photosynthesis. North-east of Coleshill, the Blythe has a flow of 8 mil gal/d ($36 \times 10^3 m^3$/d) before it receives the Cole, and after a short distance, discharges some 26 mil gal/d ($120 \times 10^3 m^3$/d) to the Tame, giving a flow in the latter of over 170 mil gal/d ($780 \times 10^3 m^3$/d). A short distance downstream of the Tame-Blythe confluence a small tributary, the Bourne, enters from the east. This rises on the Coal Measures around Arley and Fillongley and contains effluents from some small rural sewage works. Part of the flow is diverted into Shustoke Reservoir for treatment as drinking water, and only 2 mil gal/d ($9 \times 10^3 m^3$/d) discharged to the Tame.. This contains some saline drainage from coal mines which is piped to below the reservoir inlet.

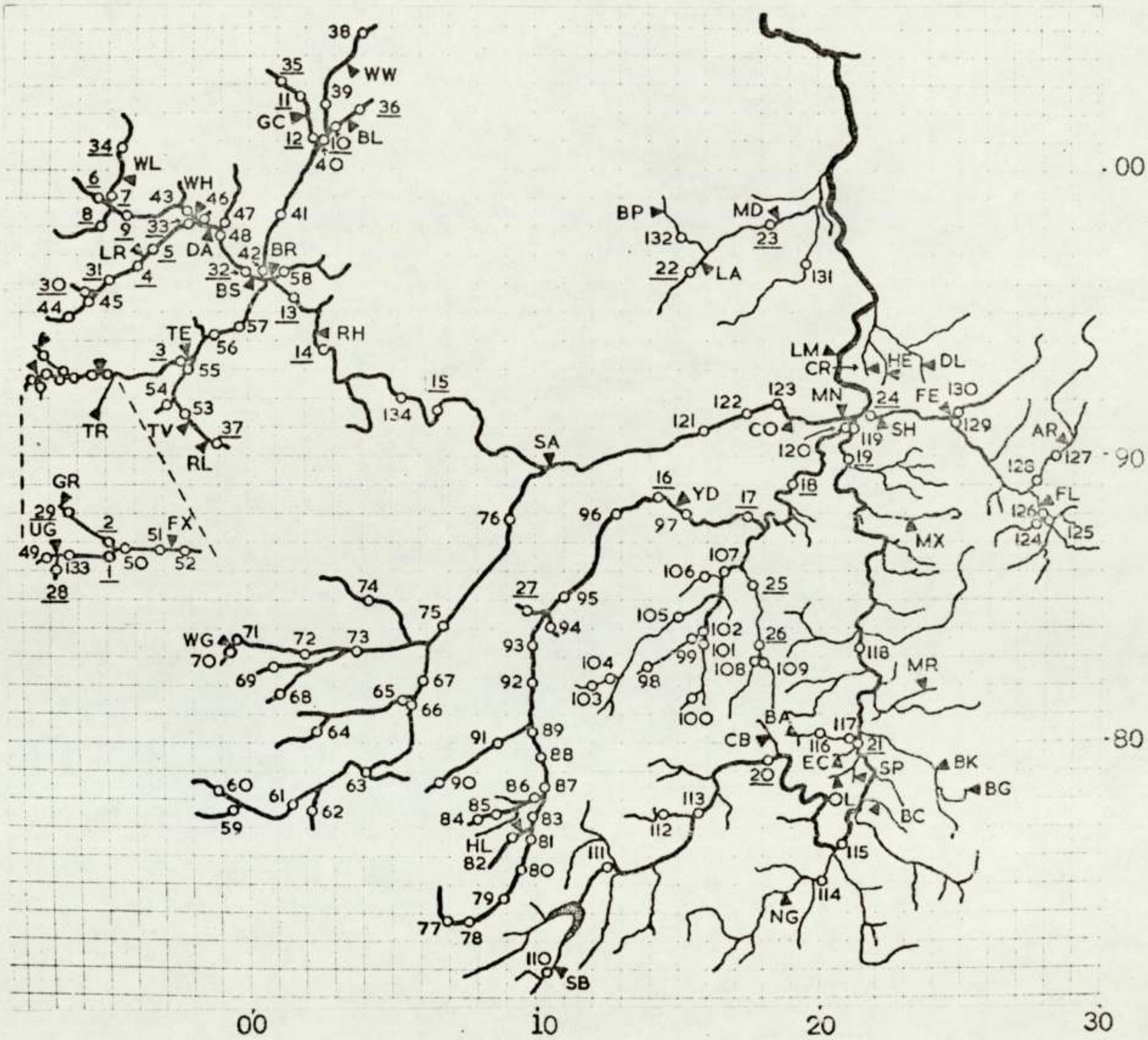
The Tame at Lea Marston has a flow of 175 mil gal/d ($800 \times 10^3 m^3$/d). At Dosthill, some 5 miles (8 Km) downstream, Langley Brook joins, with an estimated flow of 2 mil gal/d ($9 \times 10^3 m^3$/d). This drains the area east of Sutton Coldfield, and also contains effluent from Langley Mill and Middleton Sewage Works. Collets Brook, containing Bassetts Pole Sewage Work effluent, joins below Langley Mill. The fauna of Langley Brook (Fig. 9) is representative of a clean stream with little pollution. This brook was the source of Gammarus used throughout the laboratory experiments. Trout have been introduced into the lower part of Langley Brook, and apparently survive.

The Tame continues towards Tamworth receiving the Black Brook and Anker, and at Chetwynd Bridge, near Alrewas, Staffordshire, has a flow of 215 mil gal/d ($920 \times 10^3 m^3$/d). One mile further downstream, it joins the Trent, which at Trent Bridge, 39 miles lower had an average summer flow of 800 mil gal/d ($3,640 \times 10^3 m^3$/d) in 1969, upon which the above flow figures are based. (Trent River Authority, 1969).
The average flow of the Trent is much greater than this, and shows a large annual variation.

Methods of Survey - Biological

The river system has been surveyed by taking hand-net samples from about 130 stations within the area (Fig. 10). These were taken mostly from riffles but at some stations this was not possible because of the size or nature of the stream. Samples were collected during the summer of 1970, using a hand-net with 8 meshes/cm. This was placed on the riffles and the stones upstream disturbed, so that the flow washed any dislodged material into the net. The area sampled was approximately $0.1\,m^2$, but inevitably with a wide variation. Material collected was retained for later examination in the laboratory. In some areas the rivers were too deep for riffles, or with mud deposits. These places were sampled by sweeping the net through the top of the substratum. Mud and fine silt was washed from the net and any remaining material kept for further study. At stations where sampling appeared to give nothing living, further net samples were taken in an attempt to find living material. Material brought back to the laboratory was examined and the various species determined. The species or groups of species which have been used as indicators are Gammarus pulex, Asellus aquaticus L., Chironomidae and Oligochaeta. The two latter groups are composite groups which both include a number of species. Chironomidae consists of the various species forming the family Chironomidae; Chironomus riparius Meigen, the common red blood worm is included, together with the other red, green or white species. Oligochaeta has been used for the aquatic Oligochaeta, and includes the families Tubificidae, Enchytraeidae and Lumbriculidae.

The numbers of the individuals were counted in the laboratory and results grouped according to the following:-



Numbers represent Sampling Stations

Underlined numbers represent Chemical Sampling Stations

Letters represent Sewage Works Effluents

Fig. 10. Map of Sampling Stations

Rare	less than 5
Occasional	5 - 20
Common	20 - 100
Numerous	100 - 200
Very numerous	Over 200

The stations which were sampled, together with station number, National Grid Reference and a brief description of the sites are tabulated in Table 5.

The dimensions given are the approximate width and depth, in metres, of the water at the point of sampling. The sewage works effluents have been indicated on Figure 10 by triangles adjoining the receiving water course and are tabulated in Table 6.

Table 5. Sampling Stations.

Underlined numbers are stations where chemical samples were collected

No.	Station.	N.G.R.	Description.	
Wolverhampton Tame				
<u>6</u>	Noose Lane	SO950988	0.6 x 0.1	Sand. 'Rusty'. Oil traces.
<u>8</u>	Moseley Road.	SO948980	1.2 x 0.1	Stones, gravel, bricks. 'Rusty'.
<u>34</u>	Waddens Brook, Lichfield Road.	SJ955008	1.2 x 0.1	Stones, gravel.
<u>7</u>	Waddens Brook, Noose Lane.	SO951989	2.0 x 0.6	Mud with mud banks. Oil.
<u>9</u>	Summerford Road.	SO957984	2.5 x 0.6	Mud. Oil.
43	Willenhall Works.	SO978985	1.5 x 0.4	Stones, silt.
46	Pond overflow, Willenhall Works.	SO983982	0.6 x 0.1	Stones and gravel on clay.
47	Tributary Bentley Mill Lane.	SO991980	1.2 x 0.1	Sand, silt.
48	Bentley Mill Lane.	SO990978	2.0 x 0.8	Mud. Oil.
<u>32</u>	Bescot.	SO999964	2.5 x 0.5	Stones, gravel.
Darlaston Brook				
44	Meadow Lane, Bilston.	SO937948	1.0 x 0.1	Stones, gravel. Oil traces.
45	Ladymoor Road, Bilston.	SO944954	0.6 x 0.1	Stones, gravel.
<u>30</u>	Tributary Broad Lanes, Bilston.	SO945957	0.6 x 0.4	Mud. Oil. Warm.
<u>31</u>	Bankfield Road, Bilston.	SO951961	1.0 x 0.3	Mud, bricks, stones. Oil. Warm.
<u>4</u>	Above Lunt Road Works.	SO961966	1.2 x 0.2	Stones, gravel, bricks. Oil traces.

No.	Station.	N.G.R.	Description.	
5	Below Lunt Road Works.	SO966972	2.0 x 0.5	Mud, stones, bricks.
33	Willenhall Works.	SO980982	1.5 x 0.4	Mud. Oil traces.

Tipton Brook

No.	Station.	N.G.R.	Description.	
29	Turlshill Road, below Gorge Road Works.	SO928935	1.0 x 0.1	Stones, gravel, sand.
2	Jessons Bridge, below Gorge Road Works.	SO935928	1.0 x 0.1	Mud, sand. Oil trace.
49	Stream above Upper Gornal Works.	SO928927	0.8 x 0.1	Stones, gravel, bricks on clay. Oil trace.
28	Tributary above Upper Gornal Works.	SO926926	0.4 x 0.1	Stones, gravel on clay.
133	Below Upper Gornal Works.	SO928927	1.0 x 0.2	Stones, gravel on clay.
1	Jessons Bridge, below Upper Gornal Works.	SO935928	0.6 x 0.1	Stones, gravel, sand.
50	Below Jessons Bridge.	SO936928	1.0 x 0.1	Stones, gravel.
51	Above Foxyards Works.	SO946928	1.5 x 0.2	Stones, gravel.
52	Below Foxyards Works.	SO947929	2.0 x 0.3	Sand, mud.
3	Toll End Works.	SO977933	2.5 x 0.6	Stones, sand, mud. Oil traces. 'Rusty'.

Oldbury Tame

No.	Station.	N.G.R.	Description.	
37	Above Roway Lane Works.	SO989904	2.0 x 0.2	Stones, bricks. Oil. 'Rusty'.
53	Below Tividale Works.	SO978915	2.0 x 0.3	Stones, gravel, Sand. Oil.
54	Tributary below Tividale Works.	SO972918	1.0 x 0.1	Stones, mud.
55	Toll End Works.	SO979931	1.5 x 0.1	Clay, hard mud with some stones.

No.	Station.	N.G.R.	Description.	
56	Holloway Bank.	SO988942	3.0 x 1.0	Stones, mud. Oil.
57	Hydes Bridge.	SO997945	2.5 x 0.6	Stones, bricks on clay. Oil.

<u>Goscote Brook</u>

<u>35</u>	Wolverhampton Road.	SK011031	1.0 x 0.1	Stones, gravel.
<u>11</u>	Above Goscote Works.	SK019023	1.2 x 0.2	Mud, sand, bricks. 'Rusty'.
<u>12</u>	Below Goscote Works.	SK023010	2.0 x 0.4	Mud, sand, bricks.

<u>Ford Brook</u>

38	Above Walsall Wood Works.	SK040048	2.0 x 1.0	Hard clay, stones. Very 'Rusty'.
39	Below Walsall Wood Works.	SK027023	1.2 x 0.2	Stones, gravel.
<u>36</u>	Tributary above Barns Lane Works.	SK039021	0.6 x 0.2	Stones, gravel.
<u>10</u>	Tributary below Barns Lane Works.	SK030015	1.0 x 0.1	Stones, gravel, bricks.
40	Station Road, Rushall.	SK024009	2.0 x 1.0	Stones, mud.
41	Walsall Rail Goods Yard.	SP011984	2.5 x 0.5	Stones, sand, bricks.
42	Bescot.	SP005964	2.0 x 0.3	Bricks.
58	Fullbrook, Brockhurst.	SP012964	0.8 x 0.1	Stones, bricks.

<u>Tame</u>

<u>13</u>	Walsall - West Bromwich Road.	SP016955	4.0 x 1.2	Mud, stones.
<u>14</u>	Newton Road.	SP027937	6.0 x *	Mud, stones.
134	Hampstead.	SP054920	6.0 x *	Mud.
<u>15</u>	Perry Barr.	SP068913	6.0 x *	Mud.

No.	Station.	N.G.R.	Description.	
121	Parkhall Farm.	SP159909	12.0 x *	Stones, gravel banks in midstream.
122	Water Orton.	SP174915	9.0 x *	Stones, mud, gravel banks in midstream.
123	Curdworth.	SP185918	9.0 x *	Stones, mud, gravel banks in midstream.

* At these places, river is deep, but may have some gravel banks with riffles.

<u>Rea</u>

59	Callow Brook.	SO994776	1.0 x 0.1	Stones, gravel. Oil trace.
60	Holly Hill.	SO989783	0.5 x 0.1	Stones, sand.
61	Tessall Lane.	SP015778	2.0 x 0.2	Stones, mud. Oil.
62	Tributary Fairfax Road.	SP022776	1.2 x 0.1	Stones.
63	Wychall Road.	SP041790	2.0 x 0.2	Stones, gravel.
64	Merritts Brook, Whitehill Avenue.	SP024804	2.0 x 0.1	Stones.
65	Merritts Brook, Umberslade Road.	SP054815	4.0 x 0.1	Stones, gravel.
66	Cartland Road.	SP057814	6.0 x 0.1	Stones, gravel, bricks.
67	Dogpool Lane.	SP060822	6.0 x 0.2	Stones, silt, bricks.
68	Tributary Cromwell Lane.	SP011817	1.0 x 0.1	Stones on clay.
69	Tributary Mill Lane.	SP009827	1.0 x 0.1	Stones, sand.
70	Bourn Brook, above Woodgate Works.	SO994833	0.6 x 0.1	Stones, gravel.
71	Bourn Brook, below Woodgate Works.	SO995835	0.6 x 0.1	Stones, gravel.
72	Bourn Brook, Swinford Road.	SP020831	1.2 x 0.1	Stones, gravel.

No.	Station.	N.G.R.	Description.	
73	Bourn Brook, Harborne Lane.	SP038832	2.5 x 0.1	Stones, gravel.
74	Tributary Chad Valley Harborne Road.	SP042850	1.2 x 0.1	Stones, gravel.
75	Edgbaston Road.	SP068841	Culverted.	
76	Duddeston Mill Road.	SP091878	Culverted.	

Cole

No.	Station.	N.G.R.	Description.	
77	Above "Horse and Jockey".	SP069737	0.8 x 0.1	Stones, mud.
78	"Horse and Jockey".	SP077737	1.0 x 0.1	Stones, gravel, silt.
79	Tanners Green Lane.	SP089745	1.0 x 0.1	Stones, gravel.
80	Lowbrook Bridge.	SP095755	1.5 x 0.1	Stones, gravel, silt.
81	Houndsfield Lane.	SP098767	1.2 x 0.1	Stones, gravel, sand.
82	Tributary Houndsfield Lane.	SP092767	1.0 x 0.1	Stones, silt.
83	Trumans Heath Road.	SP099774	2.0 x 0.2	Stones, gravel, sand.
84	Peterbrook, Alcester Road.	SP080773	0.4 x 0.1	Stones, gravel, sand.
85	Peterbrook, Hollywood Road.	SP086775	1.0 x 0.1	Stones, gravel.
86	Peterbrook, Peterbrook Road.	SP101781	1.0 x 0.1	Stones, gravel,
87	Aqueduct Road.	SP103784	3.0 x 0.2	Mud, silt.
88	Slade Lane.	SP102795	3.0 x 0.3	Gravel, mud.
89	Highfield Road.	SP098804	2.5 x 0.2	Gravel, sand.
90	Chinn Brook, Bells Lane.	SP066786	1.4 x 0.1	Stones, sand.
91	Chinn Brook, Yardley Wood Road.	SP087800	2.5 x 0.2	Stones, gravel, mud.
92	Green Road.	SP099821	4.0 x 0.2	Stones, gravel.
93	Formans Road.	SP099834	9.0 x 0.1	Stones, gravel.
94	Tyseley Brook.	SP105840	1.0 x 0.3	Bricks, mud, oil.
<u>27</u>	Spark Brook.	SP097846	1.2 x 0.1	Stones, bricks, mud.

No.	Station	N.G.R.	Description	
95	Coventry Road.	SP110851	5.0 x 0.3	Stones, gravel, oil trace.
96	Stechford Bridge.	SP128880	8.0 x 0.1	Stones, gravel.
<u>16</u>	Cole Hall Lane.	SP143886	5.0 x 0.2	Stones, gravel, bricks.
97	Lea Ford Road.	SP152880	6.0 x 0.3	Stones, gravel, sand.
<u>17</u>	Bacons End.	SP174879	9.0 x 0.3	Stones, gravel, sand.
<u>18</u>	Coleshill.	SP199895	6.0 x 0.3	Stones, gravel.
120	Shustoke.	SP210911	6.0 x 0.3	Stones, gravel.

<u>Kingshurst Brook</u>

106	Lyndon Brook, Mackadown Lane.	SP159858	2.0 x 0.1	Stones, silt, oil traces.
103	Westley Brook, Fos Hollies Park.	SP120820	2.5 x 0.1	Culvert.
104	Westley Brook, Gospel Lane.	SP126822	0.6 x 0.1	Stones, gravel.
105	Westley Brook, Church Road.	SP150844	3.0 x 0.1	Stones, bricks in culvert.
98	Hatchford Brook, Olton Park.	SP139827	1.2 x 0.1	Concrete slab culvert.
99	Hatchford Brook, Wells Road.	SP156837	1.0 x 0.1	Stones, sand.
100	Hatchford Brook, Rover Automobile Factory.	SP154815	0.6 x 0.1	Stones, sand.
101	Hatchford Brook, Valley Road.	SP157836	1.2 x 0.3	Silt, mud.
102	Hatchford Brook, Coventry Road.	SP158838	2.5 x 0.1	Stones, gravel.
107	Hatchford Brook, Eastern Bridge.	SP166860	3.5 x 0.1	Stones, gravel, sand.
108	Low Brook, Coventry Road. (West Branch)	SP178829	0.6 x 0.1	Stones, sand, silt.

No.	Station.	N.G.R.	Description.	
109	Low Brook, Coventry Road. (East Branch)	SP178829	1.5 x 0.1	Stones, gravel, sand.
<u>26</u>	Low Brook, Coventry Road. (Below join)	SP178829	2.0 x 0.1	Stones, sand, mud.
<u>25</u>	Low Brook, Marston Green.	SP176855	2.0 x 0.1	Stones, sand, silt.

<u>Blythe</u>

110	Spring Brook.	SP104719	1.2 x 0.1	Stones, sand, mud.
111	Cheswick Green.	SP125756	1.2 x 0.1	Stones, gravel, silt.
112	Tributary Hay Lane.	SP145774	1.0 x 0.1	Gravel, silt, mud.
113	Widney Manor Road.	SP156774	4.0 x 0.1	Stones, gravel, bricks.
<u>20</u>	Henwood Mill.	SP181794	2.0 x 0.3	Stones, silt.
114	Cuttle Brook.	SP201751	1.5 x 0.2	Stones, gravel, silt.
115	Temple Balsall.	SP208764	4.0 x 0.2	Stones, gravel.
<u>21</u>	Hampton-in-Arden.	SP213800	6.0 x 0.2	Stones, gravel.
116	Eastcote Brook.	SP200803	1.0 x 0.2	Stones on clay.
117	Eastcote Brook before Blythe Confluence.	SP213800	1.5 x 0.2	Stones, gravel.
118	Stonebridge.	SP214833	10.0 x 0.2	Stones, gravel.
<u>19</u>	Blythe Bridge.	SP211898	10.0 x 1.0	Mud.
119	Shustoke.	SP211911	12.0 x 0.2	Stones, sand.

<u>Bourne</u>

124	Didgley Brook.	SP278877	0.6 x 0.1	Gravel, sand on clay.
125	Above Didgley Brook.	SP280877	1.0 x 0.1	Stones, gravel on clay.
126	Below Didgley Brook.	SP279879	0.8 x 0.2	Stones, gravel on clay.

No.	Station	N.G.R.	Description.	
127	Tributary below Arley Works.	SP283900	1.2 x 0.1	Silt, coal dust.
128	Tributary, Tippers Hill Lane.	SP276891	1.2 x 0.1	Stones, silt.
129	Furnace End	SP247913	2.5 x 0.2	Sand, gravel.
130	Tributary above Furnace End Works.	SP247914	1.2 x 0.1	Stones, gravel.
24	Whitacre.	SP216915	2.0 x 0.2	Stones, gravel.

Langley Brook

No.	Station	N.G.R.	Description.	
131	Tributary Bodymoor Heath.	SP195967	1.2 x 0.1	Stones, gravel, silt.
132	Colletts Brook.	SP151976	0.6 x 0.1	Stones, silt.
22	Above Langley Works.	SP154964	1.0 x 0.2	Stones, gravel, sand.
23	Middleton.	SP183981	1.2 x 0.2	Stones, gravel, sand.

Table 6. Sewage Treatment Works.

AR	Arley	LM	Lea Marston
BA	Barston	LR	Lunt Road
BC	Balsall Common	MD	Middleton
BG	Benton Green	MN	Minworth
BK	Berkswell	MR	Meriden
BL	Barns Lane	MX	Maxstoke
BP	Bassetts Pole	NG	Norton Green
BR	Brockhurst	OL	Oak Lane
BS	Bescot	RH	Ray Hall
CB	Catherine de Barnes	RL	Roway Lane
CO	Coleshill	SA	Saltley
CR	Coton Road	SB	Spring Brook
DA	Darlaston	SH	Shustoke
DL	Dog Lane	SP	Spinney
EC	Eastcote	TE	Toll End
FE	Furnace End	TR	Tipton Road
FL	Fillongley	TV	Tividale
FX	Foxyards	UG	Upper Gornal
GC	Goscote	WG	Woodgate
GR	Gorge Road	WH	Willenhall
HE	Hoggrill's End	WL	Watery Lane
HL	Houndsfield Lane	WW	Walsall Wood
LA	Langley	YD	Yardley

Table 7. Chemical Sampling Stations.

No.	Station.	N.G.R.	Main Stations Sept 68- Aug 70	Main Stations Nov 70- Apl 71	Additional Stations Nov 70 - Apl 71
1	Jessons Bridge, below Upper Gornal Works.	SO935928	X	X	
2	Jessons Bridge, below Gorge Road Works.	SO935928	X	X	
3	Tipton Brook, Toll End Works.	SO977933	X		
4	Darlaston Brook, above Lunt Road Works.	SO961966	X	X	
5	Darlaston Brook, below Lunt Road Works.	SO966972	X	X	
6	Tame, Noose Lane.	SO950988	X		
7	Waddens Brook, Noose Lane.	SO951989	X	X	
8	Tame, Moseley Road.	SO948980	X		
9	Tame, Summerford Road.	SO957984	X		
10	Ford Brook Tributary below Barns Lane Works.	SK030015	X	X	
11	Goscote Brook above Works.	SK019023	X	X	
12	Goscote Brook below Works.	SK023010	X	X	
13	Tame, Walsall - West Bromwich Road.	SP016955	X	X	
14	Tame, Newton Road.	SP027937	X		
15	Tame, Hampstead.	SP054920	X		
16	Cole, Cole Hall Lane.	SP143886	X	X	
17	Cole, Bacons End.	SP174879	X	X	
18	Cole, Coleshill.	SP199895	X	X	
19	Blythe, Blythe Bridge.	SP211898	X	X	
20	Blythe, Henwood Mill.	SP181794	X		

No.	Station.	N.G.R.	Main Stations Sept 68- Aug 70	Main Stations Nov 70- Apl 71	Additional Stations Nov 70 - Apl 71
21	Blythe, Hampton-in-Arden.	SP213800	X		
22	Langley Brook, above Works.	SP154964	X		
23	Langley Brook, Middleton.	SP183981	X		
24	Bourne, Whitacre.	SP216915	X		
25	Low Brook, Marston Green.	SP176855			X
26	Low Brook, Coventry Road.	SP178829			X
27	Spark Brook.	SP097846			X
28	Tributary above Upper Gornal Works.	SO926926			X
29	Turlshill Road, below Gorge Road Works.	SO928935			X
30	Tributary at Broad Lanes, Bilston.	SO945957			X
31	Darlaston Brook, Bankfield Road, Bilston.	SO951961			X
32	Tame, Bescot.	SO999964			X
33	Darlaston Brook, Willenhall Works.	SO980982			X
34	Waddens Brook, Lichfield Road.	SJ955008			X
35	Goscote Brook, Wolverhampton Road.	SK011031			X
36	Tributary above Barns Lane Works.	SK039021			X
37	Tame above Roway Lane Works.	SO989904	Jan 70 - Apl 71		

Methods of Survey - Chemical

Samples have been taken from 37 stations for chemical analysis. These stations are indicated by underlined numerals on Figure 10, and given in Table 7. Stations 1 to 24 inclusive were sampled monthly by the Upper Tame Main Drainage Authority, Works and Rivers Laboratory, as part of a regular monthly sampling programme. Samples were collected on either Monday or Tuesday, depending on area, and analysed in the Authority's laboratories. A portion was transferred to the Trade Effluent Laboratory for metal analysis. Results from this analysis have been used for a 24 month period, from September 1968 to August 1970.

Stations 25 to 36 inclusive were sites chosen after the biological survey had been undertaken. They were stations where clean or very dirty conditions existed, and where it was thought the chemical analysis would be useful in later work. Samples were collected on Thursdays on the following ten dates: November 12, 17; December 3, 17, 31; February 4, 25; March 25 and April 15, 29. Chemical analysis except for metals was carried out at the Minworth Laboratory, and additional samples transferred to the Trade Effluent Laboratory for metal analysis.

As the above two sets of chemical analysis did not overlap in time, selected stations from the main chemical survey were continued for a six-month period, November 1970 to April 1971 inclusive. These selected stations were as close to stations 25 to 36 as possible, and are indicated in Table 7. It was hoped that any changes which occurred in the rivers from one period to another would show in the continued analysis.

Station 37, Tame above Roway Lane Sewage Works (Fig. 6) was included in the monthly sampling programme from January 1970 to April 1971 inclusive. No sample was, however, collected in October, 1970, as the sampling date coincided with the period of industrial dispute. It is fortunate that the October 1970 period occurred after the two year period of the main sampling, and before the additional samples from stations 25 to 36 and the continuation of selected main stations were collected. Although the main stations were sampled in September, 1970, the results have not been included in order to keep the main analysis to a 24 month period, and as the additional samples were not started until November, 1970. It is not thought, from looking at the analysis results, that the September 1970 figures would be significantly different from the means of either period, and can safely be omitted.

Samples were collected by using a dip-can, care being taken not to disturb the bottom while sampling.

Methods of Chemical Analysis

The chemical analysis has been done by other laboratories within the Upper Tame Main Drainage Authority.

Standard methods have been used for the majority of the chemical analysis (H.M.S.O., 1956), with slight modifications to fit into the laboratory requirements. Any variations from the standard method are detailed under the appropriate section below.

Ammoniacal and Oxidised Nitrogen. These have both been measured on automatic analysis equipment. This is similar to the "Technicon" apparatus, but has been assembled within the Authority's workshops. The concentrations of the reagents have been selected to suit the normal range of sewages and effluents, and are not at the optimum for river samples. Samples are allowed to settle before sub-sampling to avoid blockages by suspended solids. It has been found that no significant difference results from this method. Ammonia is measured by an indole blue condensation with phenol and acetone. Nitrate is reduced to nitrite by hydrazine and copper. The total nitrite then undergoes diazotisation with a primary amine and phenol in acid media. The two coloured solutions pass to two in-stream colorimeters where optical densities are measured at appropriate wavelengths, and the outputs plotted on chart recorders. Standard solutions are used to plot calibration graphs, from which the ammoniacal and oxidised nitrogen concentrations of the sample are obtained.

Permanganate Value (P.V.) of shaken sample. The thiosulphate solution used in the titration was N/16, not N/80, to allow a greater range to be measured. The Minworth Laboratory did not determine permanganate values after 4th February, 1971, so some of the later additional samples taken in February, March and April 1971 were not measured.

Biochemical Oxygen Demand, 5-day, (B.O.D) of shaken sample. The volume after dilution with synthetic dilution water was 500ml. The bottles used for immediate analysis and for incubation of the sample were 175ml, not 250ml as suggested in the standard method. The dilution factor used for the shaken sample depended on the expected B.O.D.

pH. This was measured by a Pye pH meter, type 79 or 23A.

Temperature. A 50°C thermometer was used to measure the temperature immediately after sampling.

Dissolved Oxygen. This was determined by the Winkler method, using the Alsterberg, or sodium azide modifications. 175ml bottles were filled by gentle pouring from the sample can and preserved immediately.

Metal analysis. 200ml of shaken sample was acidified with concentrated nitric acid in a covered beaker and evaporated to dryness on a hot-plate. The residue was dissolved in a small quantity of hydrochloric acid, transferred to a graduated flask, and diluted to 50ml (Jenkins, et al., 1965). Copper, zinc and chromium were determined by atomic absorption on either Hilger and Watts or Perkin-Elmer equipment and compared against standards. Iron and nickel were measured by standard colorimetric methods. Dimethylglyoxime reagent was used for nickel, and thioglycollic acid for iron, producing coloured solutions. The optical densities of these were measured on an EEL Spectra colorimeter, calibrated with standard solutions.

Water Hardness. A number of water samples from various stations were measured for water hardness, using B.D.H. "Nalfloc" Water Testing Reagents. The results are given in Table 10.

Survey Results - Biological

The distributions of Baetis rhodani, Gammarus pulex, Asellus aquaticus, Chironomus riparius, Chironomidae (excluding C. riparius) and Oligochaeta are given in Table 8, with a list of the fauna found at each station given in Appendix 1. These results have been used to construct distribution maps for the occurrence of Gammarus (Fig. 11), Asellus (Fig. 12), Chironomidae including C. riparius (Fig. 13) and Oligochaeta (Fig. 14). Sticklebacks, (Gasterosteus aculeatus L.) were observed at a number of stations, but the absence of a record does not imply that they were absent from that station.

Table 8. Distribution of selected species

a = absent
r = rare
o = occasional
c = common
n = numerous
vn = very numerous

	Station	Baetis rhodani	Gammarus pulex	Asellus aquaticus	C. riparius	Chironomidae	Oligochaeta
	Wolverhampton Tame						
6	Noose Lane	a	a	a	a	a	a
8	Moseley Road	a	a	a	a	a	c
34	Waddens Brook, Lichfield Road	a	o	o	a	a	c
7	Waddens Brook, Noose Lane	a	a	a	a	a	c
9	Summerford Road	a	a	a	a	a	o

	Station	Baetis rhodani	Gammarus pulex	Asellus aquaticus	C. riparius	Chironomidae	Oligochaeta
43	Willenhall Works	a	a	a	a	a	o
46	Pond overflow, Willenhall Works	a	a	c	a	a	a
47	Tributary, Bentley Mill Lane	a	a	a	a	a	r
48	Bentley Mill Lane	a	a	a	a	r	r
32	Bescot	a	a	a	a	a	a

Darlaston Brook

44	Meadow Lane, Bilston	a	a	a	a	r	o
45	Ladymoor Road, Bilston	a	a	o	a	a	o
30	Tributary, Broad Lanes, Bilston	a	a	a	a	a	a
31	Bankfield Road, Bilston	a	a	a	a	a	a
4	Above Lunt Road Works	a	a	a	a	a	o
5	Below Lunt Road Works	a	a	a	a	a	a
33	Willenhall Works	a	a	a	a	a	a

Tipton Brook

29	Turlshill Road, below Gorge Road Works	a	a	a	o	c	c
2	Jessons Bridge, below Gorge Road Works	a	a	a	r	r	n
49	Stream above Upper Gornal Works	a	a	a	a	a	r
28	Tributary above Upper Gornal Works	a	o	a	a	r	o
133	Below Upper Gornal Works	a	a	a	a	a	o
1	Jessons Bridge, below Upper Gornal Works	a	a	o	o	r	n
50	Below Jessons Bridge	a	a	o	r	o	n

	Station	Baetis rhodani	Gammarus pulex	Asellus aquaticus	C. riparius	Chironomidae	Oligochaeta
51	Above Foxyards Works	a	a	a	a	r	n
52	Below Foxyards Works	a	a	a	a	a	c
3	Toll End Works	a	a	a	a	a	a
Oldbury Tame							
37	Above Roway Lane Works	a	a	a	a	a	a
53	Below Tividale Works	a	a	a	a	a	n
54	Tributary below Tividale Works	a	a	a	a	a	o
55	Toll End Works	a	a	a	a	a	r
56	Holloway Bank	a	a	a	a	a	n
57	Hydes Bridge	a	a	a	a	a	r
Goscote Brook							
35	Wolverhampton Road	a	o	c	a	c	o
11	Above Goscote Works	a	a	a	a	a	a
12	Below Goscote Works	a	a	a	a	a	a
Ford Brook							
38	Above Walsall Wood Works	a	a	a	a	a	a
39	Below Walsall Wood Works	a	a	a	r	o	a
36	Tributary above Barns Lane Works	a	r	a	a	a	o
10	Tributary below Barns Lane Works	a	a	a	a	r	n
40	Station Road, Rushall	a	a	a	r	a	n
41	Walsall Rail Goods Yard	a	a	a	r	r	c
42	Bescot	a	a	a	a	a	o

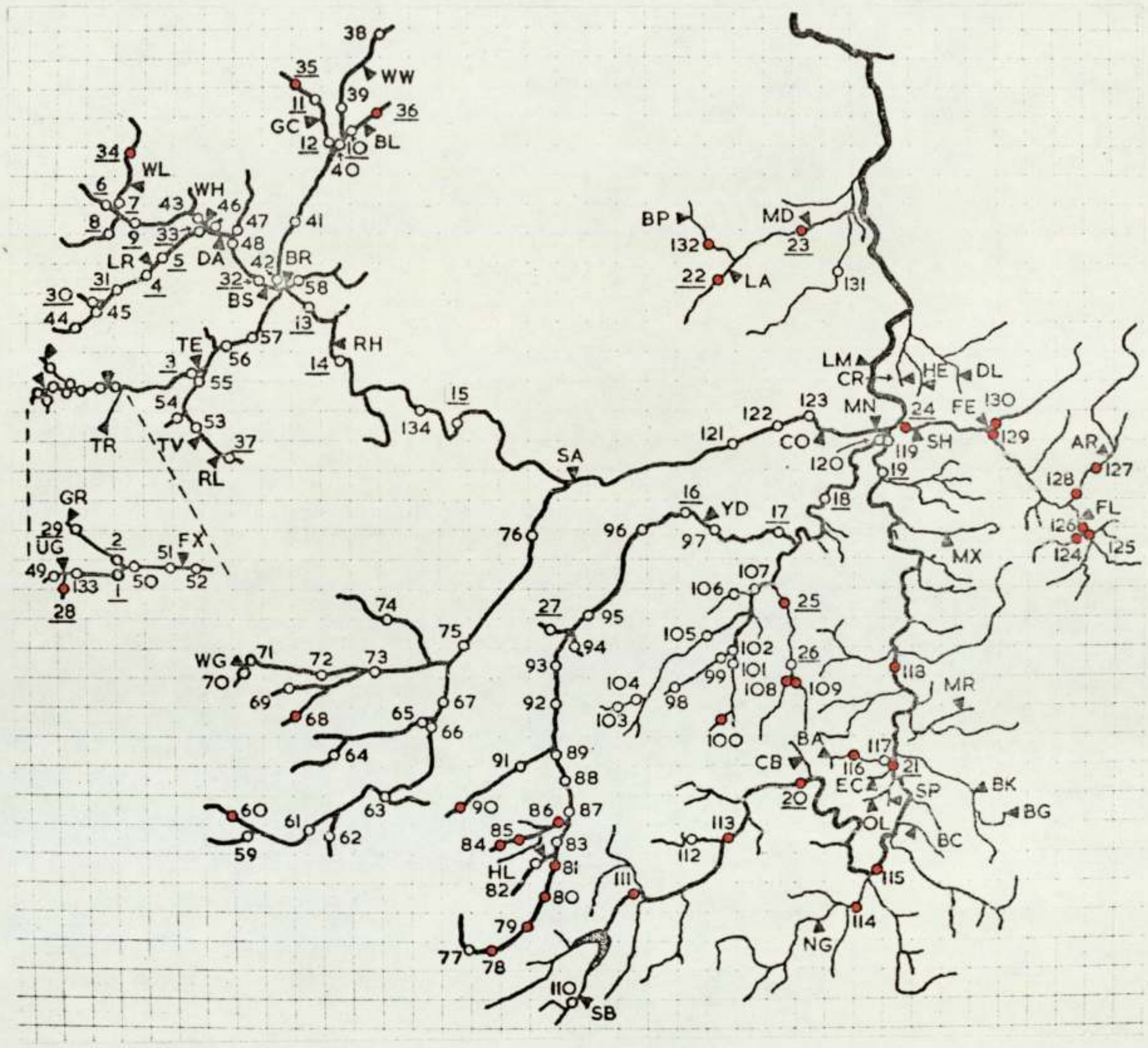
	Station	*Baetis rhodani*	*Gammarus pulex*	*Asellus aquaticus*	*C. riparius*	Chironomidae	Oligochaeta
58	Fullbrook, Brockhurst	a	a	o	o	c	r
Tame							
13	Walsall - West Bromwich Road	a	a	a	a	a	o
14	Newton Road	a	a	a	a	a	c
134	Hampstead	a	a	a	a	a	o
121	Parkhall Farm	a	a	a	a	r	o
122	Water Orton	a	a	r	a	a	n
123	Curdworth	a	a	a	a	a	c
Rea							
59	Callow Brook	a	a	a	a	c	o
60	Holly Hill	c	c	a	a	o	r
61	Tessall Lane	a	a	a	a	r	c
62	Tributary, Fairfax Road	a	a	a	r	c	c
63	Wychall Road	a	a	n	a	o	c
64	Merritts Brook, Whitehill Avenue	r	a	a	a	o	c
65	Merritts Brook, Umberslade Road	o	a	c	a	c	c
66	Cartland Road	a	a	c	r	n	o
67	Dogpool Lane	a	a	c	a	n	o
68	Tributary, Cromwell Lane	o	o	a	a	o	o
69	Tributary, Mill Lane	a	a	a	a	c	n
70	Bourn Brook, above Woodgate Works	a	a	a	a	a	n
71	Bourn Brook, below Woodgate Works	a	a	a	a	a	c

	Station	Baetis rhodani	Gammarus pulex	Asellus aquaticus	C. riparius	Chironomidae	Oligochaeta
72	Bourn Brook, Swinford Road	c	a	a	a	o	a
73	Bourn Brook, Harborne Lane	a	a	o	a	a	c
74	Tributary, Chad Valley Harborne Road	a	a	a	a	o	r
75	Edgbaston Road	a	a	a	a	n	a
76	Duddeston Mill Road	a	a	a	a	o	a
Cole							
77	Above "Horse and Jockey"	a	a	a	a	o	o
78	"Horse and Jockey"	a	r	r	vn	c	c
79	Tanners Green Lane	o	o	a	o	c	o
80	Lowbrook Bridge	o	o	r	a	o	o
81	Houndsfield Lane	r	r	r	r	c	o
82	Tributary, Houndsfield Lane	c	a	a	n	o	o
83	Trumans Heath Road	a	a	a	vn	r	a
84	Peterbrook, Alcester Road	a	n	a	a	o	c
85	Peterbrook, Hollywood Road	r	r	r	a	c	o
86	Peterbrook, Peterbrook Road	c	r	a	a	r	r
87	Aqueduct Road	a	a	a	n	c	r
88	Slade Lane	a	a	a	c	n	c
89	Highfield Road	a	a	r	c	n	vn
90	Chinn Brook, Bells Lane	o	c	a	a	c	c
91	Chinn Brook, Yardley Wood Road	r	a	a	a	o	o

	Station	Baetis rhodani	Gammarus pulex	Asellus aquaticus	C. riparius	Chironomidae	Oligochaeta
92	Green Road	r	a	r	a	o	c
93	Formans Road	a	a	n	a	o	o
94	Tyseley Brook	a	a	a	a	a	o
27	Spark Brook	a	a	a	a	a	a
95	Coventry Road	a	a	a	a	c	c
96	Stechford Bridge	a	a	a	a	vn	vn
16	Cole Hall Lane	a	a	r	a	c	n
97	Lea Ford Road	a	a	a	a	o	r
17	Bacons End	a	a	a	a	o	c
18	Coleshill	a	a	a	r	c	c
120	Shustoke	a	a	a	a	o	c
	Kingshurst Brook						
106	Lyndon Brook, Mackadown Lane	a	a	a	c	c	c
103	Westley Brook, Fox Hollies Road	a	a	a	r	c	r
104	Westley Brook, Gospel Lane	o	a	a	a	o	o
105	Westley Brook, Church Road	a	a	a	a	c	a
98	Hatchford Brook, Olton Park	a	a	a	a	c	a
99	Hatchford Brook, Wells Road	a	a	o	a	r	c
100	Hatchford Brook, Rover Automobile Factory	a	o	r	a	o	c
101	Hatchford Brook, Valley Road	a	a	r	a	c	c
102	Hatchford Brook, Coventry Road	a	a	o	a	o	o

	Station	*Baetis rhodani*	*Gammarus pulex*	*Asellus aquaticus*	*C. riparius*	Chironomidae	Oligochaeta
107	Hatchford Brook, Eastern Bridge	c	a	r	a	o	c
108	Low Brook, Coventry Road (West Branch)	a	r	a	a	r	a
109	Low Brook, Coventry Road (East Branch)	o	c	a	a	a	a
25	Low Brook, Marston Green	c	o	r	a	o	o
Blythe							
110	Spring Brook	a	a	r	c	o	a
111	Cheswick Green	o	o	a	a	o	o
112	Tributary, Hay Lane	a	a	a	a	c	c
113	Widney Manor Road	a	r	a	a	o	o
20	Henwood Mill	r	o	o	a	o	r
114	Cuttle Brook	r	o	a	a	o	o
115	Temple Balsall	c	c	a	a	o	o
21	Hampton-in-Arden	r	c	a	a	o	r
116	Eastcote Brook	o	o	c	a	c	c
117	Eastcote Brook, before Blythe Confluence	c	a	r	a	o	n
118	Stonebridge	r	c	a	a	o	c
119	Shustoke	o	a	o	a	o	r
Bourne							
124	Didgley Brook	c	c	a	a	a	a
125	Above Didgley Brook	o	c	a	a	r	r
126	Below Didgley Brook	o	c	a	a	a	a
127	Tributary below Arley Works	a	o	a	a	o	r

	Station	*Baetis rhodani*	*Gammarus pulex*	*Asellus aquaticus*	*C. riparius*	Chironomidae	Oligochaeta
128	Tributary, Tippers Hill Lane	r	c	r	a	r	r
129	Furnace End	o	c	a	a	o	o
130	Tributary above Furnace End Works	c	c	a	a	o	r
24	Whitacre	a	r	a	a	c	c
	Langley Brook						
131	Tributary, Bodymoor Heath	a	a	a	a	o	c
132	Colletts Brook	a	c	r	a	a	a
22	Above Langley Works	o	n	r	a	r	r
23	Middleton	c	c	a	a	o	o



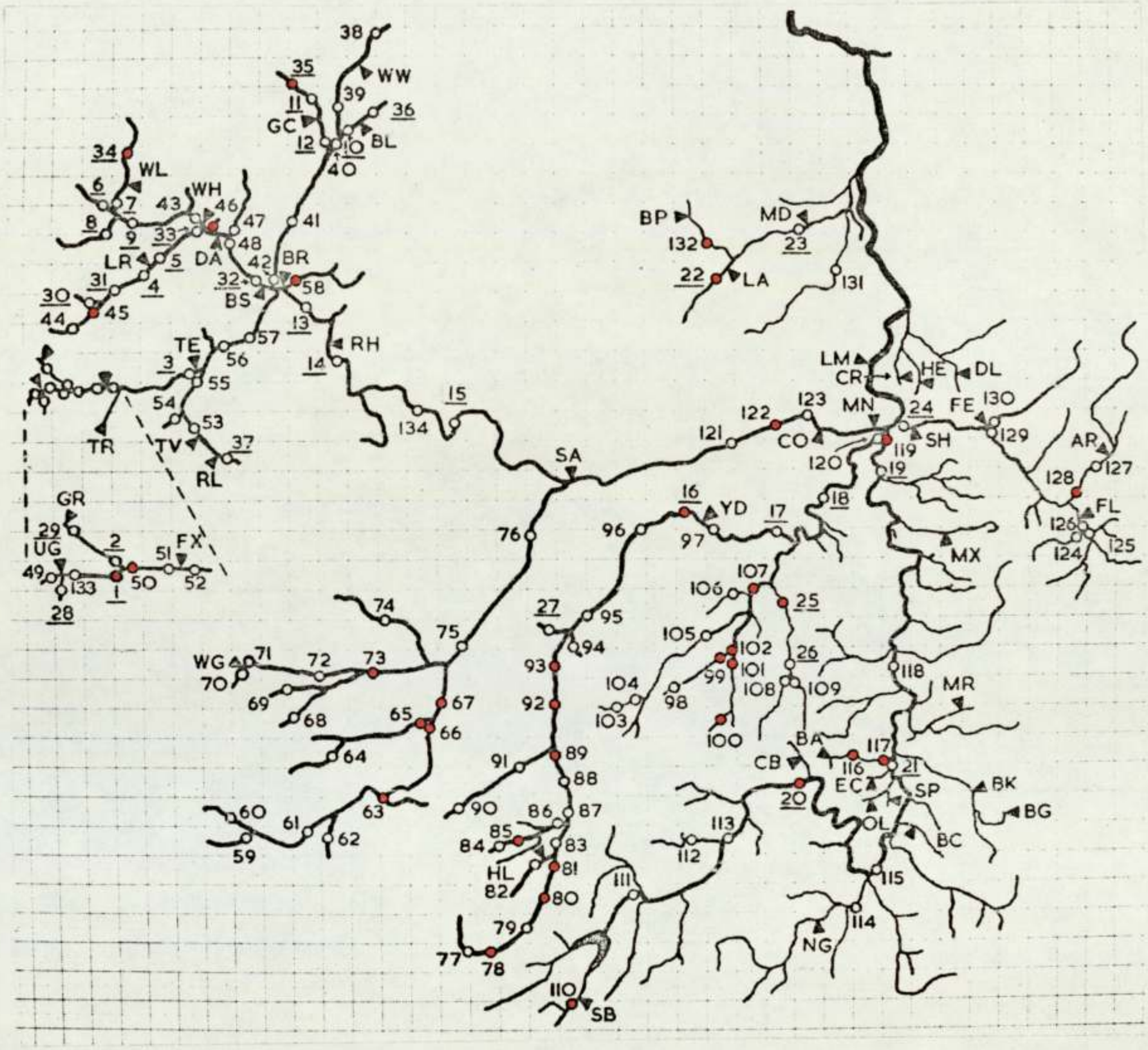
● Gammarus present

o Gammarus absent

Numbers represent Sampling Stations

Letters represent Sewage Works Effluents

Fig. 11. Distribution of <u>Gammarus pulex</u>



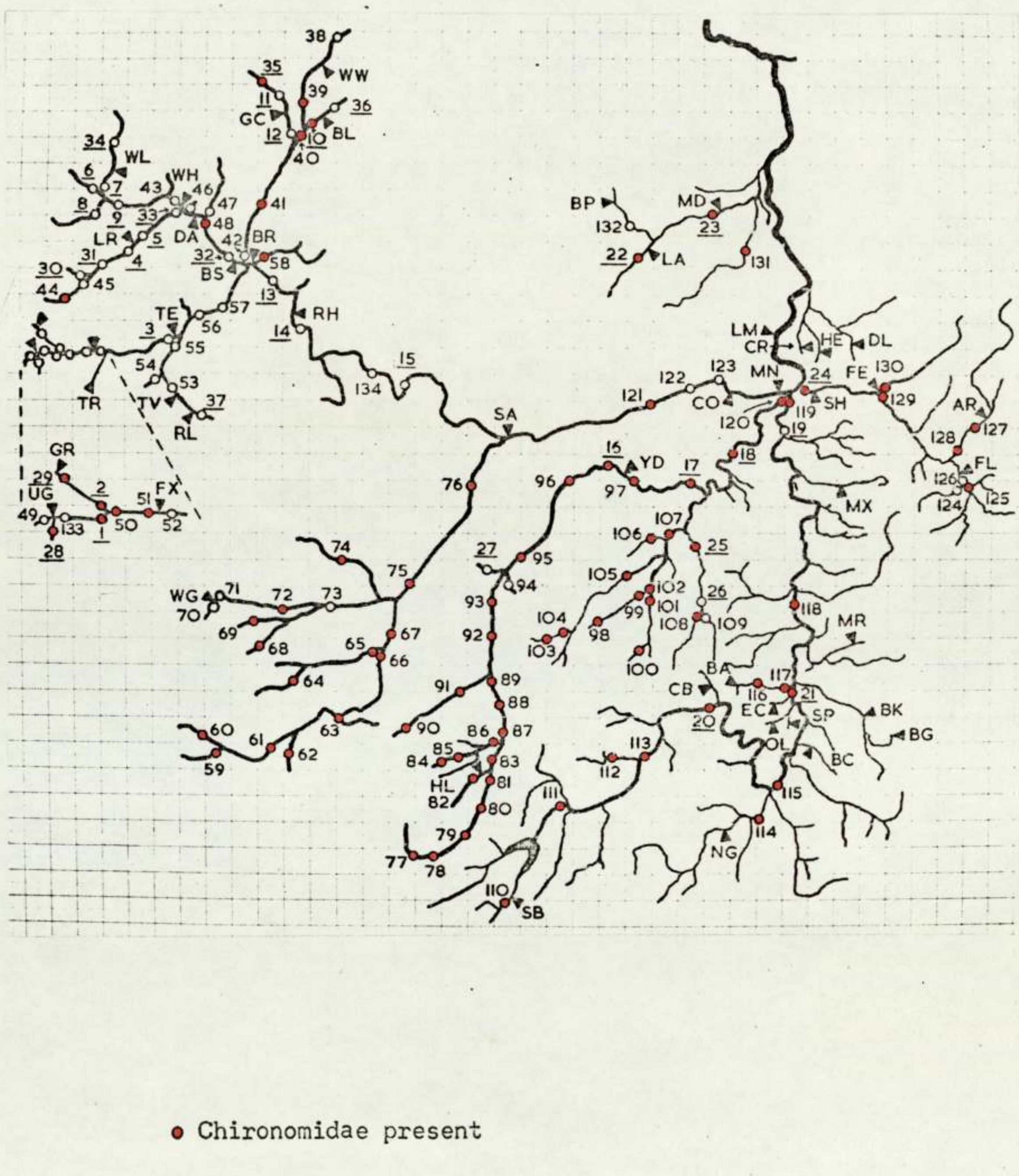
• Asellus present

o Asellus absent

Numbers represent Sampling Stations

Letters represent Sewage Works Effluents

Fig. 12. Distribution of <u>Asellus aquaticus</u>



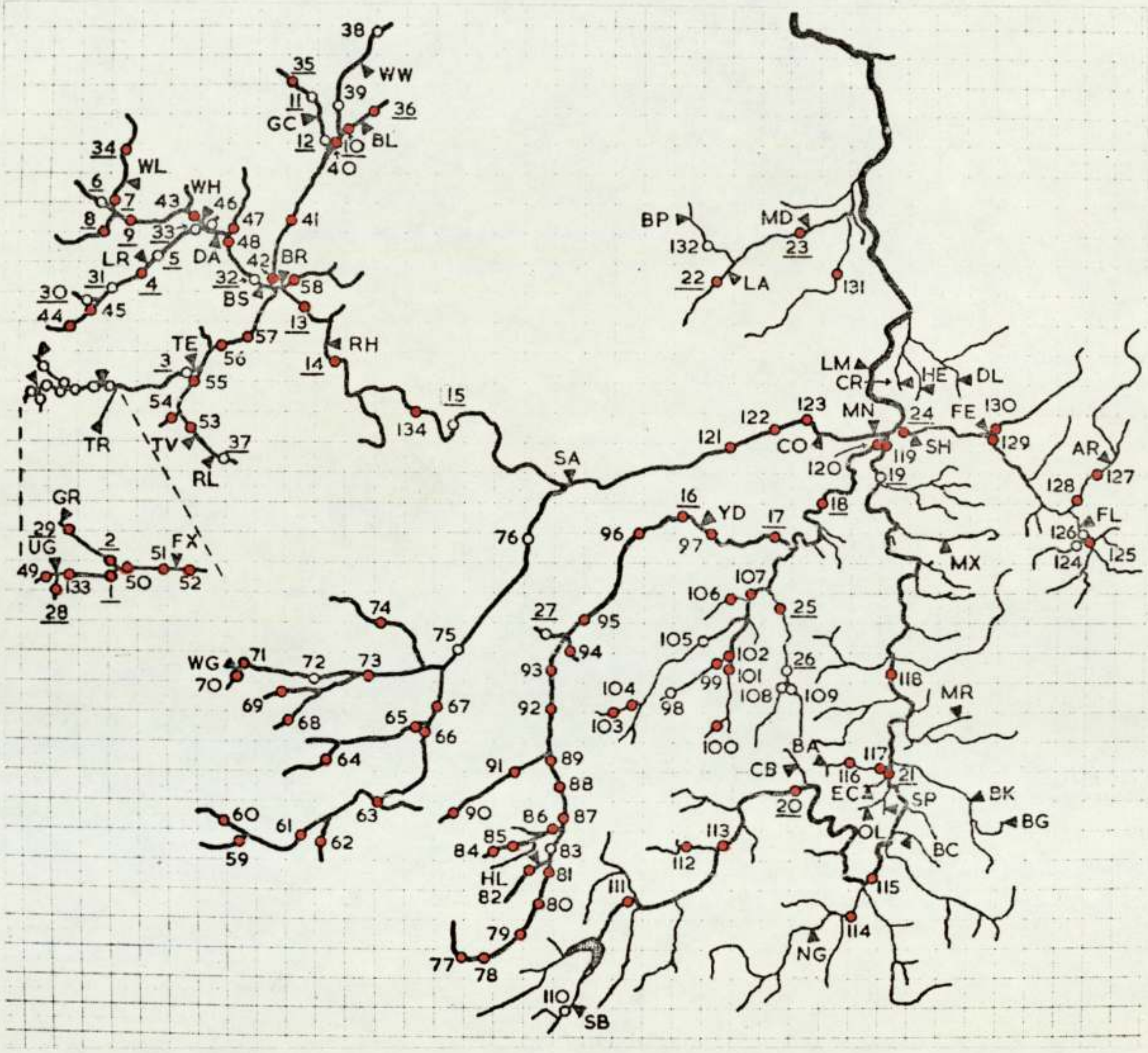
• Chironomidae present

o Chironomidae absent

Numbers represent Sampling Stations

Letters represent Sewage Works Effluents

Fig. 13. Distribution of Chironomidae, including <u>Chironomus riparius</u>



● Oligochaeta present

o Oligochaeta absent

Numbers represent Sampling Stations

Letters represent Sewage Works Effluents

Fig. 14. Distribution of Oligochaeta

Survey Results - Chemical

The complete results of the monthly chemical analysis are given in Appendix 2, with the mean, minimum and maximum values summarised in Table 9. The results of the continuation of the survey on the main stations, 1-24, do not appear to differ greatly from the results of the two year period.

The dissolved oxygen concentration at Station 16, Cole at Cole Hall Lane, shows an increase over the previous two years, with an especially high value of 17.7 mg/l in April 1971. It should be noted, however, that a dissolved oxygen concentration of 18.1 mg/l was recorded at Station 19, Blythe at Blythe Bridge, in April 1971. It is likely that these high concentrations, giving supersaturated conditions, were caused by an increase in algal photosynthesis. The zinc concentration at Station 4, Darlaston Brook above Lunt Road Works, for the period November 1970 to April 1971 increased fivefold over the concentration for the previous two year period. Occasionally the mean has become biased by an individual sample, as occurred with nickel at Station 4 for August 1969. Here a concentration of 28.50 mg/l has increased the mean nickel concentration from 0.12 mg/l to 1.31 mg/l for the two year period.

The results of the measurements of water hardness are given in Table 10. In all cases the hardness is expressed as an equivalent concentration of calcium carbonate, $CaCO_3$, in mg/l. There is a possibility that a few of the results may be high due to complexing between the metals present in solution and the EDTA solution used in the titration. 75% of the results lie within the range 250-500 mg/l, with an overall mean of approximately 375 mg/l. The waters in the Cole, Blythe and tributaries did not exceed 400 mg/l, although Langley Brook above the works effluent had a mean of 570 mg/l. Samples from

Table 9. Chemical Analysis. Mean, minimum and maximum concentrations (mg/l) from River Survey

	Station	Date		Ammon. Nitrogen Mean	Min	Max
1	Jessons Bridge, below	Sep 68 - Aug 70	1a	4.4	0.7	10.0
	Upper Gornal Works	Nov 70 - Apl 71	1b	3.4	2.0	5.0
2	Jessons Bridge, below	Sep 68 - Aug 70	2a	2.6	0.0	8.9
	Gorge Road Works	Nov 70 - Apl 71	2b	4.2	0.5	7.5
3	Tipton Brook, Toll End	Sep 68 - Aug 70	3	4.5	0.9	10.0
4	Darlaston Brook, above	Sep 68 - Aug 70	4a	0.9	0.0	4.5
	Lunt Road Works	Nov 70 - Apl 71	4b	2.9	0.5	8.0
5	Darlaston Brook, below	Sep 68 - Aug 70	5a	16.2	10.4	22.7
	Lunt Road Works	Nov 70 - Apl 71	5b	17.3	13.5	23.0
6	Wolver. Tame, Noose Lane	Sep 68 - Aug 70	6	1.5	0.0	10.0
7	Waddens Brook, Noose Lane	Sep 68 - Aug 70	7a	6.1	1.4	20.7
		Nov 70 - Apl 71	7b	3.3	1.5	5.0
8	Tame, Moseley Road	Sep 68 - Aug 70	8	3.7	0.7	9.5
9	Tame, Summerford Road	Sep 68 - Aug 70	9	3.8	1.4	9.8
10	Tributary below Barns	Sep 68 - Aug 70	10a	4.4	0.6	8.5
	Lane Works	Nov 70 - Apl 71	10b	6.0	3.0	9.5
11	Goscote Brook, above	Sep 68 - Aug 70	11a	1.3	0.0	3.1
	Goscote Works	Nov 70 - Apl 71	11b	1.9	0.5	3.5
12	Goscote Brook, below	Sep 68 - Aug 70	12a	5.4	2.5	11.9
	Goscote Works	Nov 70 - Apl 71	12b	6.3	4.0	13.0
13	Tame, Walsall - West	Sep 68 - Aug 70	13a	5.9	2.0	10.2
	Bromwich Road	Nov 70 - Apl 71	13b	7.0	4.5	11.0
14	Tame, Newton Road	Sep 68 - Aug 70	14	6.0	2.0	9.5
15	Tame, Perry Barr	Sep 68 - Aug 70	15	7.2	3.0	11.5

	Station	Date		Ammon. Nitrogen Mean	Min	Max
16	Cole, Cole Hall Lane	Sep 68 - Aug 70	16a	1.7	0.0	4.5
		Nov 70 - Apl 71	16b	1.1	0.5	2.0
17	Cole, Bacons End	Sep 68 - Aug 70	17a	7.1	2.5	17.0
		Nov 70 - Apl 71	17b	7.6	5.0	10.5
18	Cole, Coleshill	Sep 68 - Aug 70	18a	4.9	1.5	10.5
		Nov 70 - Apl 71	18b	5.1	3.0	8.5
19	Blythe, Blythe Bridge	Sep 68 - Aug 70	19a	0.6	0.0	6.0
		Nov 70 - Apl 71	19b	0.4	0.0	0.6
20	Blythe, Henwood Mill	Sep 68 - Aug 70	20	1.1	0.0	5.0
21	Blythe, Hampton-in-Arden	Sep 68 - Aug 70	21	1.4	0.0	5.0
22	Langley Bk., above Langley	Sep 68 - Aug 70	22	1.3	0.0	6.0
23	Langley Brook, Middleton	Sep 68 - Aug 70	23	0.4	0.0	2.5
24	Bourne, Whitacre	Sep 68 - Aug 70	24	0.8	0.0	5.5
25	Low Brook, Marston Green	Nov 70 - Apl 71	25	0.8	0.5	3.7
26	Low Brook, Elmdon	Nov 70 - Apl 71	26	0.5	0.5	0.5
27	Spark Brook	Nov 70 - Apl 71	27	1.1	0.5	3.1
28	Trib. above Upper Gornal	Nov 70 - Apl 71	28	0.5	0.5	0.5
29	Turlshill Road	Nov 70 - Apl 71	29	3.6	0.5	11.2
30	Broad Lanes, Bilston	Nov 70 - Apl 71	30	1.8	0.5	4.0
31	Bankfield Road, Bilston	Nov 70 - Apl 71	31	2.4	0.5	8.5
32	Tame, Bescot	Nov 70 - Apl 71	32	6.7	5.1	8.5
33	Darlaston Bk., Willenhall	Nov 70 - Apl 71	33	11.4	9.0	14.2
34	Waddens Bk., Lichfield Rd	Nov 70 - Apl 71	34	0.7	0.5	3.1
35	Goscote Bk., Wolver. Road	Nov 70 - Apl 71	35	0.6	0.5	1.6
36	Trib. above Barns Lane	Nov 70 - Apl 71	36	0.6	0.5	1.6
37	Tame above Roway Lane	Jan 70 - Apl 71	37	3.3	0.0	7.3

	Oxid. Nitrogen			PV			BOD			pH		
	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
1a	14.2	7.0	37.0	10.7	3.0	27.0	16.8	5.2	43.6	7.5	6.9	8.2
1b	10.4	6.5	14.2	7.4	4.7	15.5	8.7	5.5	12.0	7.5	7.2	7.7
2a	23.3	12.3	41.0	13.7	3.0	62.0	15.9	2.1	100.0	7.5	7.0	8.0
2b	17.3	7.8	23.6	9.1	4.5	15.2	10.3	7.2	16.8	7.6	7.2	7.8
3	8.5	4.5	16.0	18.9	6.5	54.0	33.3	4.0	83.0	6.9	6.4	7.3
4a	3.8	0.0	6.5	3.9	1.0	7.0	11.1	2.0	30.2	7.2	7.0	7.6
4b	5.6	3.4	8.5	5.9	2.2	11.0	14.8	6.5	25.7	7.3	7.1	7.6
5a	3.3	0.0	8.0	18.4	9.0	31.0	43.3	15.6	102.0	7.4	7.0	7.7
5b	7.2	4.6	10.0	22.1	19.2	30.6	59.6	44.0	102.4	7.5	7.2	8.1
6	6.2	0.6	14.2	9.2	3.0	26.5	20.8	2.8	69.2	7.1	4.9	9.1
7a	18.7	11.0	30.0	11.1	4.4	23.6	12.3	3.0	57.2	7.4	6.9	7.7
7b	20.5	12.6	28.8	10.2	8.9	12.0	9.9	6.0	14.4	7.5	7.4	7.7
8	5.0	1.6	9.5	5.0	1.0	21.2	7.6	0.3	56.2	7.2	6.8	7.7
9	14.6	3.2	24.0	10.0	5.4	17.2	13.9	3.2	34.4	7.3	6.9	7.8
10a	10.4	4.0	19.5	9.7	4.0	19.5	12.4	2.6	20.0	7.4	6.4	7.8
10b	11.9	8.5	21.4	10.0	6.6	14.5	13.9	8.0	18.1	7.5	7.4	7.6
11a	1.4	0.0	5.5	3.9	1.0	18.0	3.1	0.0	15.6	6.8	6.4	7.5
11b	1.6	1.0	2.5	2.8	1.0	8.7	6.3	1.9	27.0	6.9	6.7	7.5
12a	11.3	4.0	17.5	14.7	8.7	59.0	25.3	0.0	110.0	7.1	6.9	7.5
12b	12.7	4.2	20.6	14.1	11.8	18.0	27.1	21.6	34.8	7.1	6.9	7.3
13a	8.6	6.4	11.4	14.8	9.0	27.5	28.1	10.0	104.0	7.3	6.9	7.7
13b	10.4	7.5	13.6	15.5	11.6	20.5	27.9	20.8	40.2	7.3	7.2	7.4
14	7.9	2.0	11.0	13.2	7.5	26.5	23.0	9.6	65.5	7.3	6.9	7.8
15	6.4	3.5	8.6	13.2	6.1	28.5	27.2	6.4	134.4	7.4	6.9	7.8

	Oxid. Nitrogen			PV			BOD			pH		
	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
16a	4.2	0.5	8.5	8.7	3.0	32.2	9.8	1.5	42.0	7.6	7.1	8.5
16b	5.2	4.1	7.0	4.1	2.6	5.3	4.1	1.6	4.9	7.7	7.5	8.7
17a	7.3	1.5	11.5	16.6	8.7	35.4	23.3	11.2	57.5	7.3	7.0	7.6
17b	9.8	8.2	13.0	10.6	9.0	14.5	18.1	13.2	30.8	7.4	7.1	7.9
18a	6.1	1.5	9.0	10.5	5.0	26.0	11.7	4.8	43.2	7.4	6.9	7.9
18b	7.3	6.4	9.2	8.8	5.4	12.4	7.5	3.8	13.9	7.6	7.4	7.9
19a	6.6	4.0	10.0	4.1	2.0	6.4	2.6	0.4	12.2	7.8	7.3	8.9
19b	7.4	6.0	8.0	3.9	2.4	5.5	2.5	1.4	3.3	7.9	7.5	8.4
20	4.4	2.5	10.0	4.5	2.0	8.0	2.7	1.0	13.4	7.7	7.0	9.2
21	8.6	4.5	13.0	5.4	2.4	8.9	4.7	0.8	24.0	7.6	7.2	9.5
22	9.1	1.5	15.0	3.8	2.0	8.0	3.7	0.4	17.1	7.7	7.2	8.2
23	10.4	7.0	16.0	4.1	2.1	13.6	2.4	0.7	7.9	7.9	7.2	9.1
24	8.1	4.5	12.5	3.2	1.4	8.3	3.4	0.4	13.3	7.9	7.4	8.8
25	5.3	2.7	8.0	7.0	2.5	16.0	6.9	0.5	19.5	7.7	7.4	8.1
26	5.4	3.0	9.0	7.7	2.0	19.0	6.0	1.0	21.5	7.7	7.4	8.0
27	7.2	3.7	13.3	6.3	1.5	13.0	11.0	4.0	35.5	7.7	7.3	7.6
28	9.1	6.8	11.8	3.9	1.5	7.5	6.9	1.2	22.5	7.7	7.5	8.0
29	22.4	0.5	35.5	9.5	2.0	15.5	24.4	4.5	51.0	7.5	7.3	7.6
30	8.8	0.5	14.0	8.4	2.0	15.0	13.4	5.0	23.0	7.5	7.4	7.8
31	6.9	3.3	9.8	5.4	1.5	12.0	18.5	1.0	67.5	7.6	7.4	7.9
32	5.3	4.0	6.8	8.7	2.0	15.0	28.0	14.0	39.0	7.1	6.9	7.3
33	5.9	3.6	7.5	14.6	10.5	18.0	32.1	1.0	52.5	7.2	7.1	7.4
34	7.9	3.3	12.0	5.6	1.0	14.0	6.9	1.5	15.5	7.5	7.3	8.0
35	3.7	1.2	6.0	6.1	1.5	14.5	6.3	1.0	20.5	7.3	7.0	7.6
36	2.4	0.5	4.6	6.0	1.5	12.5	6.4	0.5	21.5	7.3	7.1	7.7
37	4.2	1.0	8.0	20.2	4.2	128.0	10.9	2.8	28.0	6.1	1.4	8.8

	Temperature °C			Dissolved Oxygen			Iron		
	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
1a	11.5	5.0	19.8	7.56	4.00	10.00	2.41	0.00	26.00
1b	8.4	6.7	12.0	8.81	8.20	10.00	1.83	0.46	6.69
2a	11.2	4.5	18.0	8.28	2.54	11.08	2.77	0.37	13.75
2b	8.7	7.1	12.0	8.92	6.64	10.00	1.76	0.81	3.61
3	12.0	5.0	18.4	4.88	1.06	9.20	41.12	2.30	107.20
4a	15.9	9.8	21.0	7.11	5.80	8.78	3.56	0.06	28.00
4b	15.2	13.5	17.0	6.69	4.82	7.92	5.18	1.07	10.27
5a	13.9	7.4	20.5	3.76	1.22	6.28	3.92	1.74	6.80
5b	12.3	10.5	14.2	5.10	3.10	6.70	6.08	2.87	6.69
6	16.3	6.1	24.5	6.28	0.47	9.08	25.77	2.62	126.00
7a	12.9	6.0	21.0	5.41	0.70	10.45	4.04	0.62	36.10
7b	10.6	9.0	13.2	6.97	4.40	7.80	3.63	2.19	5.19
8	12.0	5.6	20.0	4.23	1.34	7.59	11.22	1.97	23.70
9	12.9	5.6	22.0	4.61	1.84	7.82	6.01	0.88	23.00
10a	12.0	3.0	22.0	6.48	2.44	10.15	1.31	0.35	3.05
10b	8.7	7.0	11.5	6.74	4.68	8.80	2.50	0.66	4.11
11a	11.3	5.3	18.0	2.72	0.00	5.30	15.59	1.60	46.90
11b	9.1	11.6	7.8	3.08	1.98	4.03	12.10	7.25	15.81
12a	12.3	5.2	19.8	5.03	0.00	7.62	5.52	3.00	29.80
12b	9.6	8.0	12.0	5.22	1.70	7.00	5.10	3.35	6.12
13a	12.5	5.2	20.5	4.21	0.80	8.20	10.33	3.75	32.75
13b	9.4	8.4	12.5	5.65	4.32	6.78	11.32	6.24	16.74
14	12.5	4.8	21.0	3.94	0.94	7.40	10.13	4.86	23.10
15	12.6	4.8	21.5	3.51	0.78	7.00	8.83	4.32	26.25

	Temperature °C			Dissolved Oxygen			Iron		
	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
16a	13.8	5.2	27.0	7.58	1.24	12.75	2.45	0.53	30.00
16b	9.1	6.8	15.0	12.26	9.32	17.70	1.26	0.86	2.09
17a	13.8	6.8	23.8	4.32	0.32	7.52	5.65	0.87	26.40
17b	10.1	8.3	14.0	6.86	5.20	8.12	1.40	0.87	2.03
18a	12.8	5.5	24.4	6.06	2.62	12.70	2.41	0.62	10.29
18b	9.5	7.0	14.8	7.80	6.30	10.00	1.63	0.84	2.25
19a	12.2	3.8	23.3	10.14	4.30	12.83	0.90	0.27	3.56
19b	7.4	5.7	13.0	12.65	9.82	18.10	0.95	0.37	2.12
20	11.0	2.7	21.7	9.39	6.38	13.52	0.97	0.22	2.31
21	11.8	4.5	22.0	9.59	4.38	12.65	0.80	0.46	3.00
22	10.1	4.5	17.9	8.99	5.76	13.90	1.96	0.09	10.50
23	10.3	4.2	17.7	10.12	6.78	13.00	0.97	0.30	5.02
24	11.2	4.0	21.6	9.73	5.80	12.04	1.42	0.23	4.27
25	7.2	2.2	9.1	11.5	8.8	14.9	0.55	0.22	1.37
26	7.1	2.0	9.0	10.6	8.5	12.1	0.61	0.30	1.39
27	8.4	4.1	11.0	7.0	6.0	8.1	0.66	0.28	1.52
28	8.1	4.4	10.0	11.0	6.9	12.1	0.63	0.34	1.00
29	9.5	6.0	11.7	9.0	7.5	10.6	0.90	0.12	2.40
30	21.0	18.3	22.2	5.7	4.6	6.8	1.73	0.69	4.25
31	16.9	13.0	19.4	6.0	5.0	6.9	2.88	1.19	5.01
32	10.6	7.1	13.0	3.2	1.6	4.8	4.65	3.06	6.36
33	11.9	8.6	14.5	4.4	3.3	5.8	4.06	2.22	8.75
34	9.0	5.6	12.0	10.4	9.2	11.9	0.47	0.37	0.66
35	7.7	1.0	11.8	7.1	5.8	9.3	0.61	0.25	0.94
36	8.6	2.0	12.0	8.6	4.7	17.2	0.56	0.19	0.99
37	12.7	7.0	17.5	4.54	0.72	9.02	92.89	11.12	640.00

	Chromium			Copper			Nickel			Zinc		
	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
1a	0.04	0.00	0.13	0.13	0.05	0.31	0.09	0.00	0.90	0.18	0.08	0.66
1b	0.02	0.00	0.03	0.10	0.03	0.24	0.06	0.03	0.11	0.16	0.06	0.47
2a	0.03	0.00	0.10	0.13	0.01	0.48	0.06	0.00	0.21	0.20	0.06	0.73
2b	0.02	0.00	0.05	0.07	0.04	0.09	0.06	0.05	0.06	0.13	0.06	0.26
3	0.62	0.04	1.70	0.27	0.06	1.01	0.89	0.00	2.61	1.25	0.32	7.75
4a	0.08	0.00	0.50	0.33	0.03	0.92	1.31	0.00	28.50	0.73	0.26	1.80
4b	0.21	0.01	1.00	0.37	0.20	0.58	0.40	0.06	1.36	3.63	1.33	5.70
5a	0.12	0.00	0.36	0.21	0.11	0.35	0.53	0.09	4.75	1.40	0.46	3.10
5b	0.36	0.11	1.42	0.20	0.16	0.25	0.34	0.12	0.81	2.21	1.25	3.75
6	0.45	0.10	4.81	0.41	0.07	1.55	0.53	0.00	2.67	8.75	0.67	68.00
7a	0.03	0.00	0.16	0.14	0.05	0.98	0.07	0.00	0.31	0.41	0.12	1.91
7b	0.04	0.01	0.06	0.11	0.07	0.12	0.11	0.08	0.14	0.63	0.18	0.80
8	0.05	0.00	0.16	0.09	0.01	0.32	0.15	0.00	0.70	2.57	1.07	6.65
9	0.10	0.00	0.81	0.14	0.06	0.42	0.15	0.00	0.77	1.33	0.44	8.10
10a	0.04	0.00	0.19	0.15	0.08	0.37	0.09	0.00	0.27	0.43	0.19	0.88
10b	0.03	0.02	0.05	0.16	0.07	0.21	0.09	0.06	0.16	0.60	0.37	0.62
11a	0.04	0.00	0.15	6.60	1.82	11.75	7.33	3.60	12.90	0.60	0.30	2.08
11b	0.01	0.00	0.04	4.89	2.95	6.25	6.03	3.40	11.62	0.68	0.36	0.71
12a	0.08	0.00	0.26	2.36	0.82	15.00	2.66	1.36	4.62	0.60	0.29	2.27
12b	0.04	0.01	0.09	2.12	1.42	2.80	2.20	1.50	2.97	0.53	0.46	0.70
13a	0.19	0.06	0.38	0.35	0.13	0.75	0.75	0.26	3.90	1.00	0.46	2.30
13b	0.15	0.02	0.38	0.79	0.26	3.12	0.53	0.36	0.75	1.17	0.67	1.50
14	0.17	0.05	0.43	0.34	0.09	0.85	0.59	0.29	1.26	1.14	0.38	3.17
15	0.12	0.00	0.49	0.26	0.10	0.87	0.44	0.25	1.52	0.78	0.32	2.50

	Chromium			Copper			Nickel			Zinc		
	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
16a	0.05	0.00	0.22	0.07	0.00	0.25	0.12	0.00	0.65	0.31	0.14	1.13
16b	0.02	0.00	0.04	0.04	0.01	0.09	0.27	0.03	0.88	0.16	0.09	0.26
17a	0.24	0.07	0.46	0.36	0.14	1.07	0.60	0.13	1.32	0.55	0.30	1.57
17b	0.19	0.12	0.33	0.26	0.15	0.34	0.63	0.34	1.04	0.36	0.33	0.41
18a	0.13	0.04	0.33	0.20	0.11	0.41	0.37	0.00	0.68	0.31	0.19	0.67
18b	0.12	0.07	0.20	0.15	0.12	0.21	0.36	0.17	0.66	0.26	0.22	0.31
19a	0.02	0.00	0.13	0.05	0.00	0.29	0.05	0.00	0.45	0.10	0.03	0.72
19b	0.03	0.00	0.06	0.03	0.00	0.06	0.05	0.02	0.06	0.06	0.04	0.07
20	0.01	0.00	0.04	0.05	0.00	0.33	0.04	0.00	0.16	0.10	0.01	0.80
21	0.02	0.00	0.09	0.07	0.00	0.41	0.06	0.00	0.57	0.12	0.03	0.96
22	0.02	0.00	0.08	0.07	0.00	0.40	0.05	0.00	0.14	0.13	0.02	0.60
23	0.02	0.00	0.10	0.06	0.00	0.33	0.04	0.00	0.16	0.09	0.00	0.63
24	0.02	0.00	0.07	0.06	0.02	0.35	0.05	0.00	0.23	0.10	0.00	0.72
25	0.02	0.00	0.04	0.06	0.00	0.27	0.03	0.01	0.04	0.08	0.04	0.16
26	0.02	0.00	0.04	0.02	0.00	0.06	0.03	0.01	0.08	0.05	0.02	0.08
27	0.02	0.00	0.05	0.03	0.00	0.07	0.04	0.02	0.06	0.36	0.22	0.63
28	0.03	0.00	0.07	0.02	0.00	0.03	0.04	0.02	0.06	0.09	0.03	0.37
29	0.14	0.00	1.20	0.17	0.03	1.07	0.04	0.02	0.06	0.19	0.09	0.86
30	0.03	0.00	0.06	0.16	0.03	0.39	0.06	0.02	0.12	4.86	1.55	8.32
31	0.03	0.00	0.08	0.09	0.03	0.17	0.06	0.04	0.09	6.30	1.85	30.50
32	0.15	0.07	0.28	0.19	0.09	0.67	0.28	0.18	0.37	1.26	0.93	1.80
33	0.12	0.05	0.21	0.19	0.11	0.38	0.25	0.16	0.45	2.22	1.20	3.32
34	0.03	0.00	0.08	0.03	0.00	0.06	0.05	0.02	0.11	0.12	0.09	0.22
35	0.03	0.00	0.12	0.04	0.01	0.10	0.05	0.02	0.09	0.16	0.09	0.25
36	0.02	0.00	0.09	0.02	0.00	0.06	0.04	0.02	0.07	0.10	0.04	0.25
37	0.30	0.01	1.92	1.11	0.08	13.90	0.94	0.06	10.80	4.23	0.49	33.00

Table 10. Results of Water Hardness Measurements

Equivalent concentration (mg/l) of calcium carbonate, $CaCO_3$

		Oct 68	Oct 69	Apl 71
Wolverhampton Tame				
6	Noose Lane	409		340
8	Moseley Road	177	707	518
34	Waddens Brook, Lichfield Road			380
7	Waddens Brook, Noose Lane	605		392
9	Summerford Road	567		
32	Bescot			527
Darlaston Brook				
30	Tributary, Broad Lanes, Bilston			496
31	Bankfield Road, Bilston			503
4	Above Lunt Road Works	434		663
5	Below Lunt Road Works	278	398	454
33	Willenhall Works			475
Tipton Brook				
29	Turlshill Road, below Gorge Road Works			340
2	Jessons Bridge, below Gorge Road Works	263		320
28	Tributary above Upper Gornal Works			335
1	Jessons Bridge, below Upper Gornal Works	251		310
51	Above Foxyards Works			328
52	Below Foxyards Works		157	230
3	Toll End Works	246	424	522
Oldbury Tame				
37	Above Roway Lane Works			415
Goscote Brook				
35	Wolverhampton Road			409
11	Above Goscote Works	378		660
12	Below Goscote Works	242	351	352

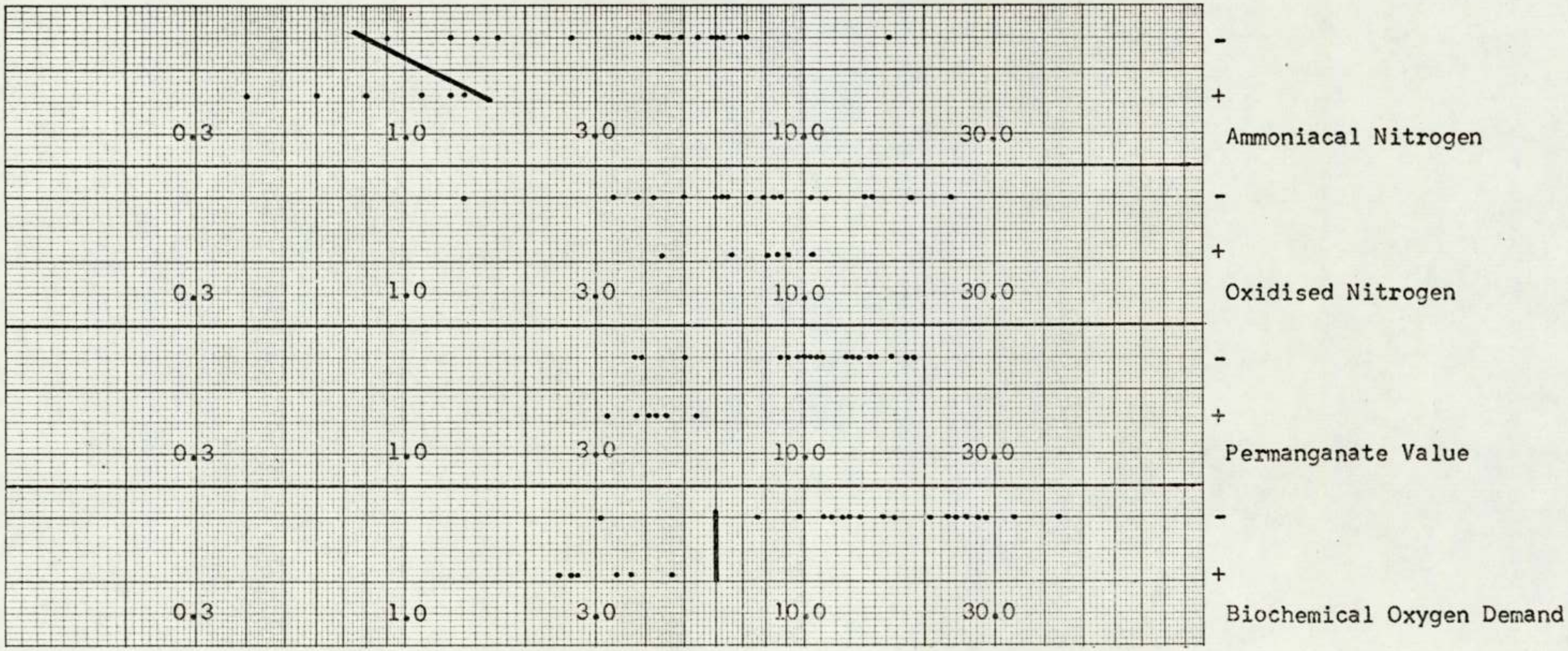
		Oct 68	Oct 69	Apl 71
Ford Brook				
39	Below Walsall Wood Works	278	322	
36	Tributary above Barns Lane Works			348
10	Tributary below Barns Lane Works	308	314	329
Tame				
13	Walsall - West Bromwich Road	337		468
14	Newton Road	315	460	494
15	Perry Barr	306	448	450
Cole				
27	Spark Brook			302
16	Cole Hall Lane	275	290	325
17	Bacons End	220		256
18	Coleshill	254	242	303
Kingshurst Brook				
26	Low Brook, Elmdon (below join)			368
25	Low Brook, Marston Green			370
Blythe				
20	Henwood Mill	292	258	265
21	Hampton-in-Arden	258		342
116	Eastcote Brook			206
19	Blythe Bridge	271	279	316
Bourne				
24	Whitacre	396		403
Langley Brook				
22	Above Langley Works	522	576	612
23	Middleton	383	383	433

the western part of the area were usually harder than those from the eastern side, due to the initial harder quality of the water supply, and the greater proportion of effluent present.

Synthesis of Biological and Chemical Data

The means of the monthly chemical data for the main two year period have been plotted on a line diagram (Fig. 15), distinction being made for the presence or absence of Gammarus at each station. This has been used to obtain the apparent threshold concentrations for the various factors, as the concentration between presence and absence. It should be emphasized that these thresholds are unlikely to be of value when taken individually, but are us-able when taken in conjunction with other factors.

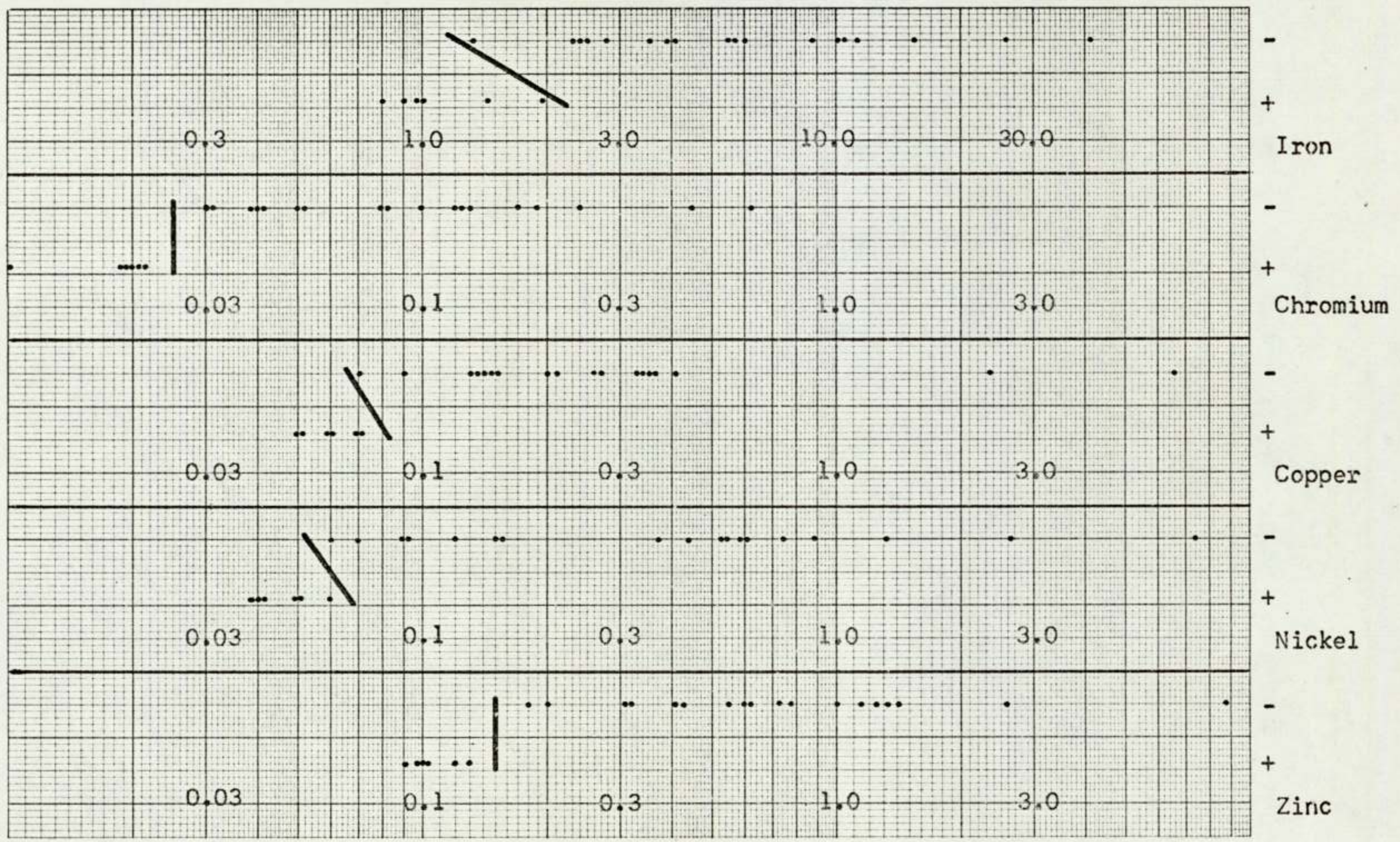
It would appear that oxidised nitrogen, permanganate value, pH and temperature, over the ranges measured, are of little use in predicting the occurrence of Gammarus. The slightly lower pH values obtained were associated with the absence of Gammarus, but this could be caused by industrial discharges lowering the natural pH of the water, as well as rendering it toxic. These discharges frequently increase the temperature of the water at the same time, thereby making the cooler waters appear more favourable to Gammarus. During the summer, however, the river temperature can rise to over 20°C, with Gammarus present, which is higher than any mean value obtained for a station with Gammarus absent. Ammoniacal nitrogen shows a poor demarcation between the absence and presence of Gammarus, but a concentration of 1.0 mg/l can be assigned as the apparent threshold. The Biochemical Oxygen Demand (BOD) and Dissolved Oxygen (DO) show clearer divisions, with a BOD of 6.0 mg/l and a DO of 8.5 mg/l as the threshold values. A BOD of 3.1 mg/l, with Gammarus absent, occurs at Station 11, Goscote Brook above Goscote Works. Here the high concentrations of copper



- Gammarus absent   + Gammarus present

Concentrations are given in mg/l.   Solid lines represent 'threshold' values

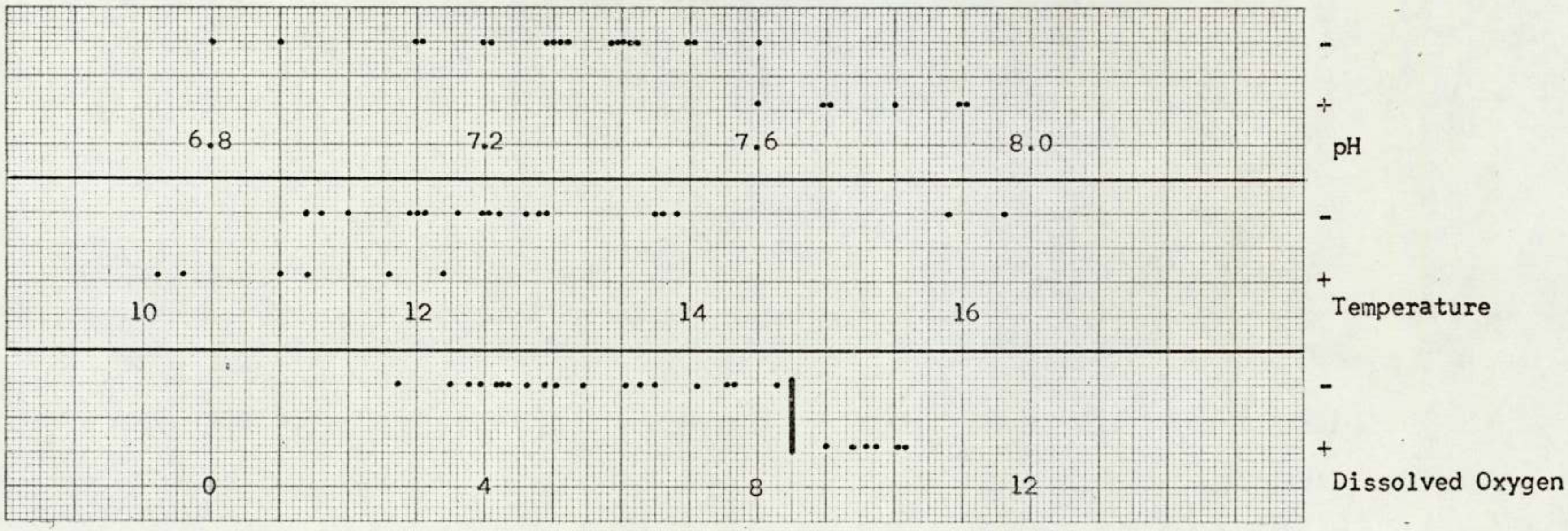
Fig. 15a. Mean values of Ammoniacal Nitrogen, Oxidised Nitrogen, Permanganate Value and Biochemical Oxygen Demand from Chemical Survey, September 1968 - August 1970, related to occurrence of Gammarus.



- Gammarus absent + Gammarus present

Concentrations are given in mg/l. Solid lines represent 'threshold' values

Fig. 15b. Mean values of Iron, Chromium, Copper, Nickel and Zinc from Chemical Survey, September 1968 - August 1970, related to occurrence of Gammarus



\- Gammarus absent   + Gammarus present

Temperature is given in ^{o}C.   Dissolved Oxygen is given in mg/l

Solid line represents 'threshold' value

Fig. 15c. Mean values of pH, Temperature and Dissolved Oxygen from Chemical Survey, September 1968 - August 1970, related to occurrence of Gammarus and nickel most probably cause suppression of oxidation in the BOD test, leading to a low mean BOD value. Iron does not give a very clear distinction, but a value of 1.5 mg/l could represent the threshold. The other four metals, chromium, copper, nickel and zinc however, all show distinct demarcations between presence and absence of Gammarus. These same four metals were the ones which Butcher (Clay, 1946, in discussion) suggested were the cause of the biological sterility of the Tame. Threshold values obtained from the field data are chromium, 0.025 mg/l; copper, 0.075 mg/l; nickel, 0.06 mg/l; and zinc, 0.15 mg/l. These thresholds are lower than would be obtained for single substances when tested under laboratory conditions, and the individual thresholds should not be used separately.

Using a method similar to that of Herbert <u>et al</u> (1965) for the prediction of the toxicity of mixtures, a Toxicity Index (T.I) has been calculated for each station. This is obtained by expressing the mean at each station as a proportion of the threshold obtained from the chemical results. In Herbert's method, the predicted toxicity of the mixture is obtained from the thresholds of the individual components of the mixture, when each component is tested separately. The threshold of any individual substance in the presence of other toxic substances will obviously be lower, and assuming equi-toxicity, will be 0.25 of the value when separate if three other substances are present.

In the present method, however, the thresholds are obtained for each component when in the presence of the other components of the mixture. The individual thresholds may be multiplied by four to obtain values similar to those used by Herbert, or the resulting Sum of Proportions divided by four to obtain the Toxicity Index. (Table 11). The value of T.I. obtained may be correlated with the occurrence of

Table 11. Concentrations, proportions of threshold values, toxicity index and occurrence of Gammarus at main stations sampled for the two year period, September 1968 - August 1970

	Metal	Chromium		Copper		Nickel		Zinc			Toxicity	Gammarus
	Threshold (mg/l)	0.025		0.075		0.06		0.15		Sum	Index	absent: -
	Station	Conc	Prop	Conc	Prop	Conc	Prop	Conc	Prop			present: +
1	Below Upper Gornal Works	0.04	1.6	0.13	1.7	0.09	1.5	0.18	1.2	6.0	1.5	-
2	Below Gorge Road Works	0.03	1.2	0.13	1.7	0.06	1.0	0.20	1.3	5.2	1.3	-
3	Tipton Brook, Toll End	0.62	24.8	0.27	3.6	0.89	14.8	1.25	8.3	51.5	12.9	-
4	Above Lunt Road Works	0.08	3.2	0.33	4.4	1.31	21.8	0.73	4.9	34.3	8.6	-
5	Below Lunt Road Works	0.12	4.8	0.21	2.8	0.53	8.8	1.40	9.3	25.7	6.4	-
6	Tame, Noose Lane	0.45	18.0	0.41	5.5	0.53	8.8	8.75	58.3	90.6	22.6	-
7	Waddens Brook, Noose Lane	0.03	1.2	0.14	1.9	0.07	1.2	0.41	2.7	7.0	1.7	-
8	Tame, Moseley Road	0.05	2.0	0.09	1.2	0.15	2.5	2.57	17.1	22.8	5.7	-
9	Tame, Summerford Road	0.10	4.0	0.14	1.9	0.15	2.5	1.33	8.9	17.3	4.3	-
10	Below Barns Lane Works	0.04	1.6	0.15	2.0	0.09	1.5	0.43	2.8	7.9	2.0	-

	Metal	Chromium		Copper		Nickel		Zinc			Toxicity	Gammarus
	Threshold (mg/l)	0.025		0.075		0.06		0.15		Sum	Index	absent: -
	Station	Conc	Prop	Conc	Prop	Conc	Prop	Conc	Prop			present: +
11	Goscote Brook, above works	0.04	1.6	6.60	88.0	7.33	122.2	0.60	4.0	215.8	53.9	-
12	Goscote Brook, below works	0.08	3.2	2.36	31.5	2.66	44.3	0.60	4.0	83.0	20.7	-
13	Tame, Walsall-West Brom.Rd	0.19	7.6	0.35	4.7	0.75	12.5	1.00	6.7	31.5	7.9	-
14	Tame, Newton Road	0.17	6.8	0.34	4.5	0.59	9.8	1.14	7.6	28.7	7.2	-
15	Tame, Perry Barr	0.12	4.8	0.26	3.5	0.44	7.3	0.78	5.2	20.8	5.2	-
16	Cole, Cole Hall Lane	0.05	2.0	0.07	0.9	0.12	2.0	0.31	2.1	7.0	1.7	-
17	Cole, Bacons End	0.24	9.6	0.36	4.8	0.60	10.0	0.55	3.7	28.1	7.0	-
18	Cole, Coleshill	0.13	5.2	0.20	2.7	0.37	6.2	0.31	2.1	16.2	4.0	-
19	Blythe, Blythe Bridge	0.02	0.8	0.05	0.7	0.05	0.8	0.10	0.7	3.0	0.7	+
20	Blythe, Henwood Mill	0.01	0.4	0.05	0.7	0.04	0.7	0.10	0.7	2.5	0.6	+
21	Blythe, Hampton-in-Arden	0.02	0.8	0.07	0.9	0.06	1.0	0.12	0.8	3.5	0.9	+
22	Langley Brook, above works	0.02	0.8	0.07	0.9	0.05	0.8	0.13	0.9	3.4	0.8	+
23	Langley Brook, Middleton	0.02	0.8	0.06	0.8	0.04	0.7	0.09	0.6	2.9	0.7	+
24	Bourne Brook, Whitacre	0.02	0.8	0.06	0.8	0.05	0.8	0.10	0.7	3.1	0.8	+

Gammarus at each station. A T.I. exceeding 1 should be found at stations without Gammarus, whereas those with Gammarus present should have a T.I. of less than 1.

It can be seen from Table 11 that this does occur, but this is as would be expected since the concentrations used to derive the thresholds are those also used for the Toxicity Index, and good correlation may therefore be expected. The same method of analysis has been applied to the main stations where sampling was continued (Table 12) and to the additional stations, 25 to 37 (Table 13). The continued sampling of the main stations represent additional data for the same stations, and cannot justifiably be treated as separate points. As only six samples were taken to calculate the mean, they can differ from the mean value of the 24 month period. This is seen with Station 1, Jessons Bridge below Upper Gornal Works, and Station 2, Jessons Bridge below Gorge Road Works, where T.I. values of 1.0 and 0.9 respectively were found, but with Gammarus absent. Calculation of the T.I. for the complete 30 month period would give both values exceeding 1.0.

It would have been preferable to have taken regular samples from a greater number of stations with Gammarus present, and which were spacially isolated. These requirements could have been fulfilled if more headstreams with Gammarus present existed. Table 13 gives the T.I. of six additional stations where Gammarus existed. These represent five separate communities, Stations 25 and 26 coming from the same tributary. The remaining stations of Table 13, which are without Gammarus, are in some cases, from stations where no fauna whatsoever existed. All six stations with Gammarus present have a T.I. of less than 1, thus giving strong support to the method of prediction of the toxicity of polluted water to Gammarus. The BOD values of these same six stations are all above the value of 6.0 mg/l

Table 12. Concentrations, proportions of threshold values, toxicity index and occurrence of Gammarus at main stations sampled for the six month period, November 1970 - April 1971

	Metal	Chromium		Copper		Nickel		Zinc			Toxicity	Gammarus
	Threshold (mg/l)	0.025		0.075		0.06		0.15		Sum	Index	absent: -
	Station	Conc	Prop	Conc	Prop	Conc	Prop	Conc	Prop			present: +
1	Below Upper Gornal Works	0.02	0.8	0.10	1.3	0.06	1.0	0.16	1.1	4.2	1.0	-
2	Below Gorge Road Works	0.02	0.8	0.07	0.9	0.06	1.0	0.13	0.9	3.6	0.9	-
4	Above Lunt Road Works	0.21	8.4	0.37	4.9	0.40	6.7	3.63	24.2	44.2	11.0	-
5	Below Lunt Road Works	0.36	14.4	0.20	2.7	0.34	5.7	2.21	14.7	37.5	9.4	-
7	Waddens Brook, Noose Lane	0.04	1.6	0.11	1.5	0.11	1.8	0.63	4.2	9.1	2.3	-
10	Below Barns Lane Works	0.03	1.2	0.16	2.1	0.09	1.5	0.60	4.0	8.8	2.2	-
11	Goscote Brook, above works	0.01	0.4	4.89	65.2	6.03	100.5	0.68	4.5	170.6	42.6	-
12	Goscote Brook, below works	0.04	1.6	2.12	28.2	2.20	36.7	0.53	3.5	70.0	17.5	-
13	Tame, Walsall-West Brom.Rd	0.15	6.0	0.79	10.5	0.53	8.8	1.17	7.8	33.1	8.3	-
16	Cole, Cole Hall Lane	0.02	0.8	0.04	0.5	0.27	4.5	0.16	1.1	6.9	1.7	-
17	Cole, Bacons End	0.19	7.6	0.26	3.5	0.63	10.5	0.36	2.4	24.0	6.0	-
18	Cole, Coleshill	0.12	4.8	0.15	2.0	0.36	6.0	0.26	1.7	14.5	3.6	-
19	Blythe, Blythe Bridge	0.03	1.2	0.03	0.4	0.05	0.8	0.06	0.4	2.8	0.7	+

Table 13. Concentrations, proportions of threshold values, toxicity index and occurrence of Gammarus at additional stations sampled for the six month period, November 1970 - April 1971

	Metal	Chromium		Copper		Nickel		Zinc			Toxicity	Gammarus
	Threshold (mg/l)	0.025		0.075		0.06		0.15		Sum	Index	absent: -
	Station	Conc	Prop	Conc	Prop	Conc	Prop	Conc	Prop			present: +
25	Low Brook, Marston Green	0.02	0.8	0.06	0.8	0.03	0.5	0.08	0.5	2.6	0.7	+
26	Low Brook, Elmdon	0.02	0.8	0.02	0.3	0.03	0.5	0.05	0.3	1.9	0.5	+
27	Spark Brook	0.02	0.8	0.03	0.4	0.04	0.7	0.36	2.4	4.3	1.1	-
28	Trib. above Upper Gornal	0.03	1.2	0.02	0.3	0.04	0.7	0.09	0.6	2.8	0.7	+
29	Tipton Bk., Turlshill Road	0.14	5.6	0.17	2.3	0.04	0.7	0.19	1.3	9.9	2.5	-
30	Broad Lanes, Bilston	0.03	1.2	0.16	2.1	0.06	1.0	4.86	32.4	36.7	9.2	-
31	Bankfield Road, Bilston	0.03	1.2	0.09	1.2	0.06	1.0	6.30	42.0	45.4	11.3	-
32	Tame, Bescot	0.15	6.0	0.19	2.5	0.28	4.7	1.26	8.4	21.6	5.4	-
33	Darlaston Bk., Willenhall	0.12	4.8	0.19	2.5	0.25	4.2	2.22	14.8	26.3	6.6	-
34	Waddens Bk., Lichfield Rd	0.03	1.2	0.03	0.4	0.05	0.8	0.12	0.8	3.2	0.8	+
35	Goscote Bk., Wolverhamp. Rd	0.03	1.2	0.04	0.5	0.05	0.8	0.16	1.1	3.6	0.9	+
36	Above Barns Lane Works	0.02	0.8	0.02	0.3	0.04	0.7	0.10	0.7	2.5	0.6	+
37	Above Roway Lane Works (Jan 70 - Apl 71)	0.30	12.0	1.11	14.8	0.94	15.7	4.23	28.2	70.7	17.7	-

previously ascribed as the threshold. They are, however, below 7.0 mg/l and this figure would fit the original data equally well.

Table 14. Thresholds obtained from the Chemical Survey results for the occurrence of Gammarus

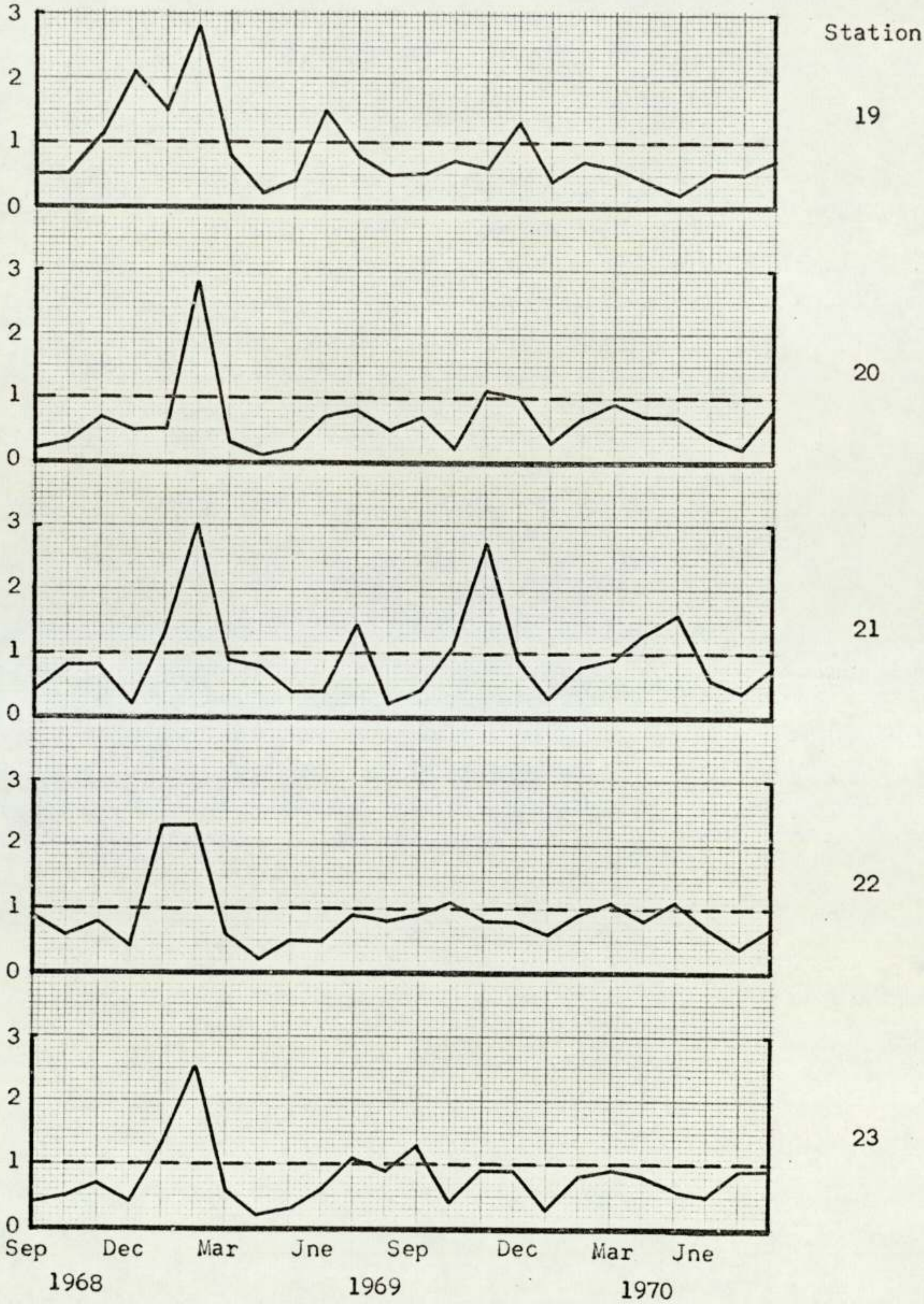
Chemical Factor	Threshold Concentration (mg/l)
Ammoniacal Nitrogen	1.0
Oxidised Nitrogen	Not definable
Permanganate Value	Not definable
Biochemical Oxygen Demand	7.0
pH	Not definable
Temperature	Not definable
Dissolved Oxygen	8.5
Iron	1.5
Chromium	0.025
Copper	0.075
Nickel	0.06
Zinc	0.15

In order to gain more information from the Toxicity Index, those stations in the main chemical survey with a T.I. of less than 2.0 have been analysed on the individual monthly samples. These represent six stations with Gammarus present, and four without Gammarus. Table 58 gives the complete analysis, with a summary in Table 15. The results of this analysis have been plotted in Fig. 16. It may be seen that, at stations with Gammarus present, the monthly T.I. only occasionally exceeds 1.0, whereas at the other four stations, values of 1.0 or greater frequently occur. The

Table 15. Monthly Toxicity Index of selected stations for the main two year period

	Station	Mean T.I.	Gammarus
19	Blythe at Blythe Bridge	0.7	present
20	Blythe at Henwood Mill	0.6	present
21	Blythe at Hampton-in-Arden	0.9	present
22	Langley Brook above Langley Works	0.8	present
23	Langley Brook at Middleton	0.7	present
24	Bourne Brook	0.8	present
1	Jessons Bridge below Upper Gornal Works	1.5	absent
2	Jessons Bridge below Gorge Road Works	1.3	absent
7	Waddens Brook at Noose Lane	1.7	absent
16	Cole at Cole Hall Lane	1.7	absent

Date	Stations									
	19	20	21	22	23	24	1	2	7	16
Sep 68	0.5	0.2	0.4	0.9	0.4	0.3	0.9	0.9	1.6	2.6
Oct 68	0.5	0.3	0.8	0.6	0.5	0.7	1.6	1.8	1.1	1.7
Nov 68	1.1	0.7	0.8	0.8	0.7	0.7	1.1	0.9	2.0	2.5
Dec 68	2.1	0.5	0.2	0.4	0.4	2.3	2.8	2.5	2.0	6.5
Jan 69	1.5	0.5	1.3	2.3	1.3	1.4	2.1	1.7	3.4	2.5
Feb 69	2.8	2.8	3.0	2.3	2.5	3.0	1.8	1.9	1.8	1.6
Mar 69	0.8	0.3	0.9	0.6	0.6	0.5	0.8	0.8	1.6	1.6
Apl 69	0.2	0.1	0.8	0.2	0.2	0.2	1.1	1.1	1.1	2.3
May 69	0.4	0.2	0.4	0.5	0.3	0.4	0.7	3.2	8.0	1.2
Jne 69	1.5	0.7	0.4	0.5	0.6	0.3	1.0	0.9	1.1	0.8
Jly 69	0.8	0.8	1.4	0.9	1.1	0.6	1.3	1.0	1.3	0.8
Aug 69	0.5	0.5	0.2	0.8	0.9	0.6	1.8	0.4	0.9	1.3
Sep 69	0.5	0.7	0.4	0.9	1.3	0.9	1.1	1.0	0.7	1.4
Oct 69	0.7	0.2	1.1	1.1	0.4	0.8	1.2	1.4	0.9	1.9
Nov 69	0.6	1.1	2.7	0.8	0.9	0.7	6.3	1.8	3.0	1.3
Dec 69	1.3	1.0	0.9	0.8	0.9	0.7	1.7	1.8	2.0	2.9
Jan 70	0.4	0.3	0.3	0.6	0.3	0.4	0.5	0.3	0.8	2.2
Feb 70	0.7	0.7	0.8	0.9	0.8	1.1	0.7	1.4	1.5	1.7
Mar 70	0.6	0.9	0.9	1.1	0.9	0.8	0.9	1.2	1.1	1.0
Apl 70	0.4	0.7	1.3	0.8	0.8	0.8	1.2	1.2	1.6	1.3
May 70	0.2	0.7	1.6	1.1	0.6	0.7	1.1	0.6	1.0	0.9
Jne 70	0.5	0.4	0.6	0.7	0.5	0.4	1.1	2.6	1.4	1.1
Jly 70	0.5	0.2	0.4	0.4	0.9	0.7	2.2	1.5	0.8	0.7
Aug 70	0.7	0.8	0.8	0.7	0.9	0.8	0.8	1.2	1.0	1.3



19 Blythe at Blythe Bridge

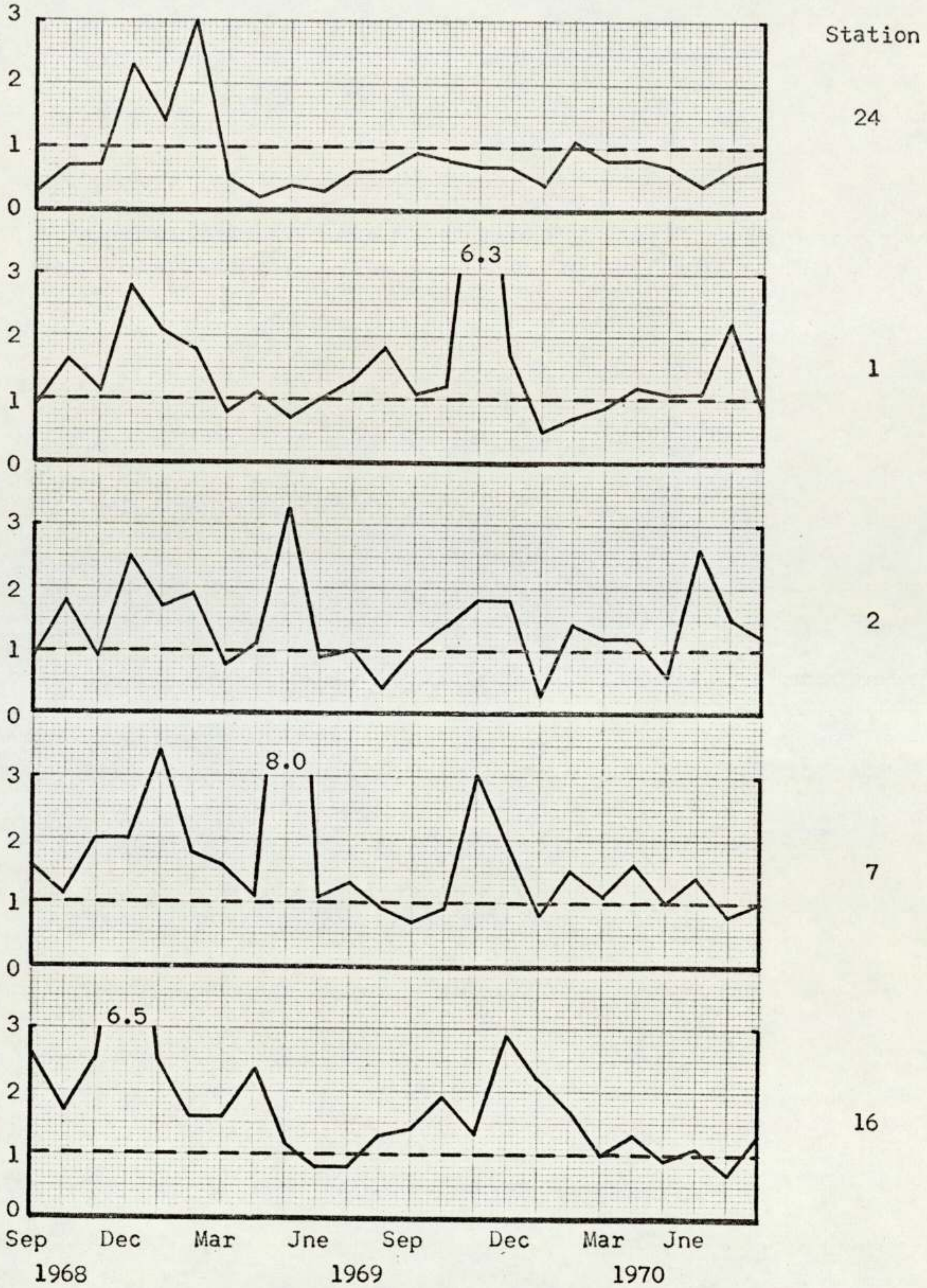
20 Blythe at Henwood Mill

21 Blythe at Hampton-in-Arden

22 Langley Brook above Langley Works

23 Langley Brook at Middleton

Fig. 16a. Monthly Toxicity Index of selected stations



24 Bourne at Whitacre
1 Jessons Bridge below Upper Gornal Works
2 Jessons Bridge below Gorge Road Works
7 Waddens Brook at Noose Lane
16 Cole at Cole Hall Lane

Fig. 16b. Monthly Toxicity Index of selected stations diagrams show that in February, 1969, a disproportionately high T.I. was obtained at all six stations with Gammarus present. This has been caused by high concentrations of copper and zinc in the metal analysis. The four stations without Gammarus do not show a similar occurrence. Of these four, Stations 1, 2 and 7 are sampled one day before the remaining Station 16, which is sampled on the second day along with the remaining six stations. The anomalous stations are distributed over three water-courses, and high concentrations of both copper and zinc are most unlikely to occur simultaneously at these six stations. The metal analysis of both days sampling are performed together, and, since the results for Station 16 appear normal, no satisfactory explanation for the high T.I. values of February 1969 can be suggested.

It is probable that, provided the Toxicity Index remains below 1.0 for approximately 70% or greater of the time, and no individual value is so high as to cause complete mortality, Gammarus should be able to exist under natural conditions.

4. LABORATORY EXPERIMENTS

Materials and Methods

Experimental Apparatus

Toxicity experiments were performed in controlled temperature rooms, each approximately 2m (6') x 1m (3'), maintained at 10°C. Temperature variations were usually less than ± 1.5°C, although at times during the summer, the temperature went beyond this range while working within the rooms. A thermal lag within the water in the dishes reduced the effects of these variations.

The toxicity tests were carried out in glass crystallising dishes, 150mm diameter, 75mm deep, with a nominal capacity of 1,200 ml, housed on shelves within the rooms. Compressed air was supplied to each dish through a diffuser, regulated by a Bunsen screw clip, to maintain the oxygen concentration as near saturation as possible. (Fig. 17). To avoid spray, each dish was covered by a perspex sheet approximately 150mm square.

In the long term experiment, perspex troughs with recirculation of the solution were used. (Fig. 18). These were approximately 700mm long, 150mm wide and 100mm deep, and were divided into seven equal units by perspex and nylon netting screens. An outlet at one end was connected by plastic tubing to an air lift to circulate the test solution, which was further aerated by a diffuser at the inlet end. During the tests Gammarus were placed only in the five middle units. The troughs were filled with 8 litres of test solution, which was replaced at approximately weekly intervals. As these tests were for longer periods than those carried out in the dishes, food was provided by placing two or three previously dried willow leaves in each unit.

Preparation of Dilution Water

The water used during the toxicity tests consisted of a mixture

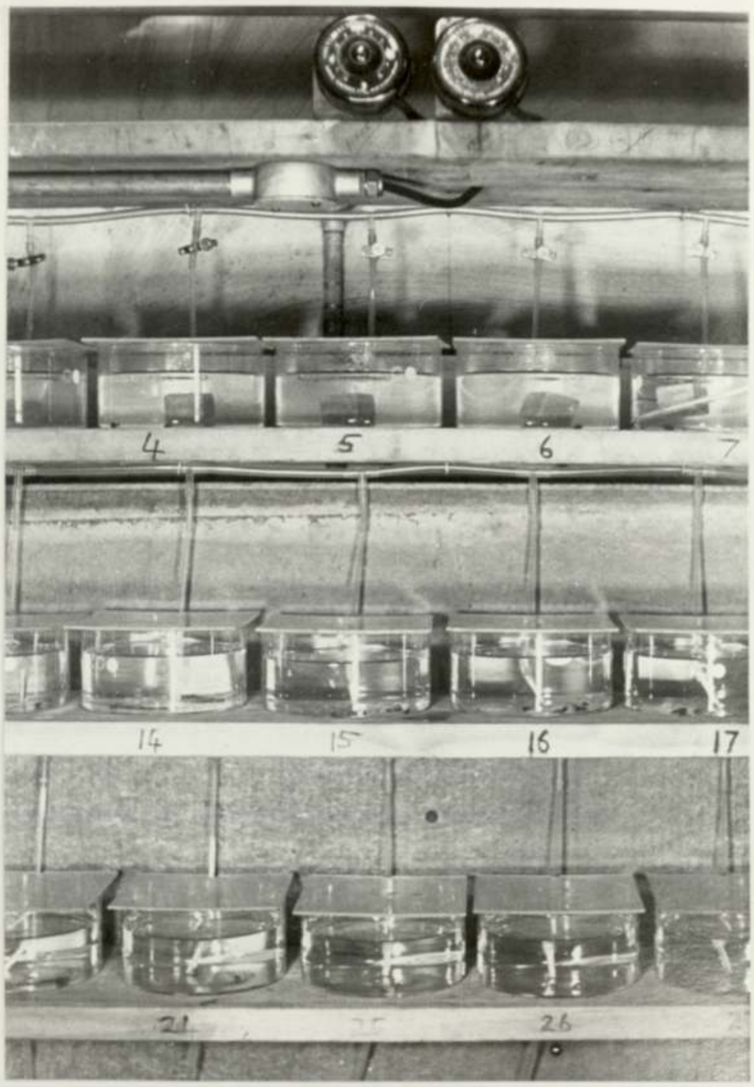
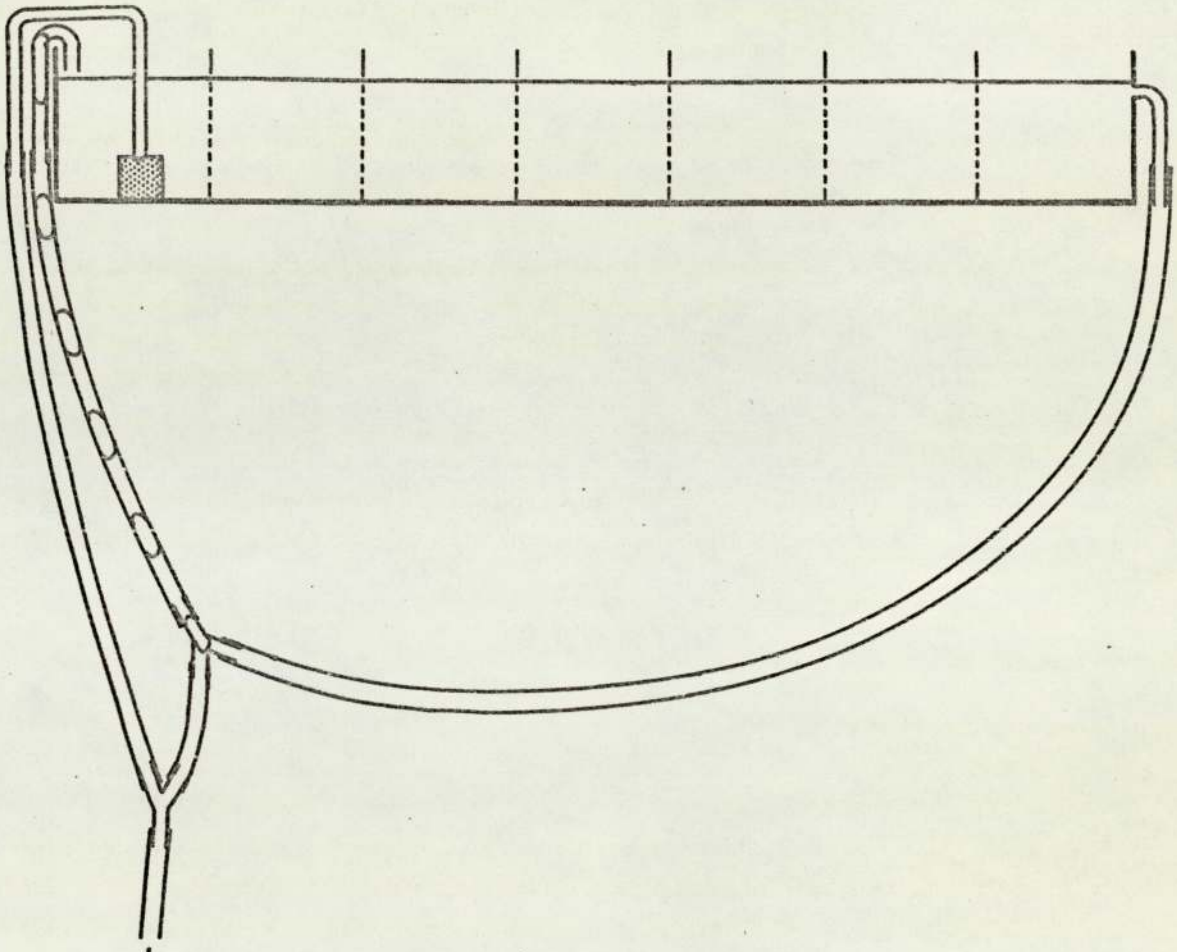


Fig. 17. Portion of experimental, temperature controlled room



Air supply

Fig. 18. Diagram of perspex trough as used for the long term experiment.

of Birmingham tapwater and Shustoke reservoir water. Birmingham tapwater is very soft, with a total hardness equivalent to approximately 30 mg/l calcium carbonate. This was aerated at least overnight before mixing to dispel any residual chlorine which may have been present. Reservoir water was obtained from the small reservoir of the City of Birmingham Water Department at Shustoke (N.G.R. SP. 235915). This is abstracted from the Bourne and stored in reservoirs, before treatment at Whitacre Waterworks for public supply. During the summer period, to control algal growth, copper sulphate is added to the flow from the small reservoir to the larger reservoir. The water was therefore collected above this point, at approximately 6-8 week intervals as required. On two occasions it was necessary to collect from the treatment plant because of winter conditions, but at these times copper sulphate was not being added. The total hardness varied from approximately 250 to 400 mg/l equivalent of calcium carbonate.

Before use in the tests, the water was aerated in a large plastic tank, which allowed most of the suspended solids to precipitate. Occasionally the reservoir water was too soft for use alone, and it was therefore artificially hardened to about 400 mg/l by the addition of chemicals. (Alabaster and Abram, 1965). The chemicals used were sodium bicarbonate, sodium chloride, sodium nitrate, sodium sulphate, calcium chloride and magnesium sulphate. The dilution water was prepared by mixing suitable quantities of hard and soft water to give the required total hardness.

Preparation of Chemical Stock Solutions

All the chemicals used for the tests were obtained as 'Analar' grade. Stock solution were prepared, usually with 1,000 mg/l of the required element or compound, using distilled water, as shown in Table 16.

Table 16. Chemicals used and concentrations of stock solutions prepared for toxicity tests

Element or compound	Chemical	Concentration (mg/l) of element	Weight of chemical(g)/litre
Copper	$CuSO_4.5H_2O$	1,000	3.93
Zinc	$ZnSO_4.7H_2O$	1,000	4.40
Nickel	$NiSO_4.7H_2O$	1,000	4.79
Chromium	$K_2Cr_2O_7$	1,000	2.83
Lead	$Pb(NO_3)_2$	1,000	1.60
Cadmium	$3CdSO_4.8H_2O$	1,000	2.28
Ammonia	NH_4Cl	50,000 as N	191
Cyanide	KCN	1,000 as CN	2.50
Phenol	C_6H_5OH	1,000	1.00

Using graduated pipettes, the required amount of toxic material was added to each experimental dish. To reduce errors some 1,000 mg/l solutions were diluted in graduated flasks for use in very weak concentrations, while the ammonium chloride solution was made up at 50,000 mg/l nitrogen. By these means the amounts of standard solution to be added to each dish was kept between 0.5 and 25.0 ml. For the test with nickel, at a hardness of 100 mg/l, a 10,000 mg/l nickel solution was prepared using 100 hardness dilution water. It was necessary to use 100 hardness dilution water in place of distilled water in order that the hardness in the test solutions was not changed by the addition of the nickel solution.

Collection and Selection of Gammarus

The Gammarus used in the experiments were collected from Langley Brook. (N.G.R. SP. 155966) (Fig. 9). They were brought back to the laboratory and kept for at least four days in earthenware sinks at 10°C, in water of approximately the hardness in which they would be tested. Dried willow or elm leaves were placed in the sinks as a source of food during the acclimation period. For the experiments to determine the effects of hardness, a number of Gammarus were placed in 250mm diameter glass troughs with the appropriate hardness water for acclimation.

Prior to the experiments being started, a number of Gammarus were removed from the sink with a hand-net and transferred to a 250mm diameter glass trough, partly filled with water. The contents were then tipped into a 200mm diameter sieve, mesh size 5.7mm. This allowed the Gammarus to pass, but retained any leaves, stalks and stones. The process was repeated using a 130mm square sieve, mesh size approximately 1.8mm. This held back the larger Gammarus, but allowed the smaller ones, together with sand and silt to pass. Still containing the larger Gammarus, the small sieve was placed inside the larger one, and the two placed in a glass trough. Water was added until it covered approximately half the depth of the small sieve, when any remaining small Gammarus could escape. The two sieves were transferred to another trough, and water added to cover the small sieve by approximately 15-20mm. The Gammarus could then swim over the sides of the small sieve, and pass through the larger mesh. Any inactive or dead large Gammarus remained in the small sieve. By this method a supply of active large Gammarus, free of silt, sand, stones, leaves, dead or small Gammarus was obtained. A length of rigid plastic tubing, 10mm bore, was used to transfer individuals to small plastic dishes, before placing in the experimental dishes. Care was taken to prevent specimens which were captured early being placed in dishes which would be at one end of the experimental concentration range. No attempt was made to determine the sex of individual Gammarus, although at times pairs in a precopula position were placed in the dishes, having withstood the sieving treatment. Either 10, 12 or 15 Gammarus were placed in each dish, but the number was always constant for one experiment.

Experimental Design and Methods

The experiments were designed to assess the toxicity to Gammarus of some of the substances which are found in the streams of the Birmingham area. They were carried out over both short and medium time periods. The short experiments, of 48 hours duration, were useful as a preliminary screening test on the various chemicals. From these, longer experiments may then be undertaken to determine the lethal threshold concentrations. It should be remembered, however, that the apparent non-toxic effect of a chemical over a short time does not mean that it will be non-toxic over a longer period. Jackson and Brown (1970) give results of experiments, using rainbow trout, with cadmium and nickel. They found that the toxicity of both metals greatly increased when experiments were allowed to continue well beyond the 48 hour period.

It has been discovered by many workers on toxicity that the response of animals to a poison is dependent upon the concentration of the poison and the period of exposure. The mortality of the experimental animals can be expressed either as the number dead since the start of the experiment, or by the rate of dying. In toxicity tests it is often more convenient to use the cumulative number of animals which have reacted, express this as a percentage, and relate it to the experimental test conditions. It is found that equal increases in percentage mortality are normally obtained when the time elapsed or concentration of poison is increased by geometric proportions, rather than arithetic proportions. Times of observations and concentrations of poisons used in toxicity tests are frequently based on a logarithmic scale. (Bliss, 1935, 1937).

In the laboratory experiments on toxicity, the concentrations used were derived from an approximately equi-spaced logarithmic series. This gives a series of concentrations which may be used at each point, or selected points chosen to give a wider range of concentrations.

Table 17. Concentration series used in toxicity experiments.

1.0	2.2	4.7	10.0
1.2	2.7	5.6	
1.5	3.3	6.8	
1.8	3.9	8.2	

Each concentration may be multiplied by a factor of 10^n, where n is a positive or negative integer.

For the tests, 800ml volumes of the prepared dilution water were measured into each of the required number of dishes. In early experiments, 1,000ml was used, but it was found that the water level in the dish may have allowed Gammarus to escape through the point of entry of the air supply. The volumes were measured by the use of a 1,000ml graduated cylinder, each to an accuracy of ± 10ml, representing an error of approximately ± 1%.

Graduated pipettes of 1, 2, 5, 10 and 25ml were used to measure the required volume of toxic stock solution into the experimental dishes, usually using two or three dishes as replicates at each concentration.

A wide range of concentrations was used initially to determine the toxic range to use in later experiments. The range of volumes to be pipetted was kept between 0.5ml and 25.0ml, using the smallest pipette suitable. The maximum error by the addition of 25ml of toxic stock solution to the previously measured 800ml of dilution water amounts to approximately 3%. With errors in pipetting of approximately 1%, the total errors incurred in the preparations of the required toxic concentration were approximately 5%.

For the 48 hour test with nickel, from 180 mg/l to 1,200 mg/l nickel, the test solutions were prepared by dilution. The required amount of 10,000 mg/l nickel stock solution, made up in 100 hardness dilution water, was measured into a 1,000ml graduated cyclinder. This was then diluted to 800ml by 100 hardness dilution water and transferred to an experimental dish.

In the long term experiment with nickel at 200 hardness, in the perspex troughs, the 100 mg/l solution was prepared by the addition of the requisite amount of nickel sulphate crystals to the 8,000ml of 200 hardness dilution water. The lower concentrations were prepared by pipetting 1,000 mg/l stock solution to give the required concentration.

When testing the toxicity of ammonium chloride, it was found necessary to add the standard solution to the experimental dishes some time before the start of the experiment to allow the pH to stabilize. The amount of undissociated ammonia is dependent upon the pH of the solution, and it is preferable for this to remain constant throughout the experiment. The pH of each experimental dish was measured with a Pye Universal pH meter, type 11075, at 0, 24 and 48 hours from the time the Gammarus were introduced.

For determining the effects of water hardness, different ranges of concentrations had to be used at each hardness to obtain similar ranges of mortality.

In the experiments with reduced dissolved oxygen concentrations, nitrogen was used to partially deoxygenate the water. Initially streams of nitrogen and air were mixed and piped to ten diffusers aerating one shelf of ten dishes. It was found, however, by carrying out Winkler tests, that the oxygen concentration remained high, and was dependent upon the volume of nitrogen/air mixture passed through the diffuser. Removing the air supply, and using only nitrogen, lower dissolved oxygen levels were obtained, but still dependent upon the rate of nitrogen flow. Attempts to regulate ten diffusers to each give an equal flow of nitrogen were unsatisfactory, and the diffusers and screw clips were removed. A length of glass capillary tubing, 38mm long, with a bore of approximately 0.3mm, was used to supply each dish with nitrogen, (Fig. 16., No.6) flow being controlled by one screw clip at the end of each shelf. Provided that the supply piping is large enough, each dish has the same depth of water, and the capillary tubing is resting on the inside base of the dish, equal amounts of nitrogen will pass through each capillary tubing. The dissolved oxygen concentration could be regulated by adjusting the nitrogen flow, atmospheric diffusion being sufficient to maintain the oxygen level. Preliminary tests for dissolved oxygen concentration were made by carefully using a syphon tube to fill a 175ml Winkler bottle. It was found that if some water was syphoned to waste initially, and the syphon tube was placed well into the Winkler bottle to eliminate aeration, a satisfactory test could be performed. Samples were preserved immediately after sampling, and the dissolved oxygen concentration determined by standard methods. During toxicity tests, the water was deoxygenated for 3-4 hours before the Gammarus were introduced. At the end of the 48 hour period, samples were taken from all dishes for dissolved oxygen determinations.

Preliminary screening tests were undertaken to determine the range of concentrations to be used for the laboratory experiments, but these were often of limited number and approximate nature, and were not otherwise used. A summary of the laboratory experiments, with the time period, water hardness and chemicals tested is given in Table 18.

Table 18. Range of Laboratory Experiments

Time(hours)	48	48+	48+	48+	48+	48	48+	48
Water hardness	100	100	100, 200, 400	200	300	100 Mix-tures	300 Mix-tures	300 Red-uced Oxygen
Chemical tested								
Copper	x	x	x		x	x }	x }	x
Zinc	x	x	x		x	x }	x }	x
Chromium (Cr^{6+})	x	x	x		x		x }	
Nickel	x			x	x			
Lead	x							
Cadmium	x							
Ammonia	x							
Phenol	x							
Cyanide	x							

The method of analysis of the experimental results is included later in a separate section on statistical analysis, in order to facilitate cross reference.

Experimental Observations

The experiments were initially allowed to continue for 48 hours before being examined, and the number of Gammarus in each dish recorded. The end-point was taken as death, as indicated by the lack of response when gently stimulated by a needle. It was noticed that in some solutions, a colour change occurred in the body before death. A darkening of the gut, or of the eggs in the female brood-pouch was seen with copper, while in zinc solutions the body tended to become a greyish-white colour. This differs from the orange colour at death which frequently occurs due to lack of oxygen.

In experiments which lasted for over 48 hours, more frequent observations were made, especially at the beginning of the experiment. It was found, however, that in some experiments a period of time elapsed before mortality occurred unless very toxic solutions were used. Jones (1937) obtained similar results with Gammarus, where the reaction time remained approximately 1 hour for a wide range of copper concentrations. In the present experiments, the period between observations varied from 4-5 hours at the beginning to 3-4 days later, but were, as far as was possible, arranged as equi-spaced intervals on a logarithmic scale.

The experimental observations of tests for 48 hours in 100 mg/l hardness water are given in Appendix 3, with a summary and the subsequent analysis included in the appropriate section below. For most other experiments, which usually lasted for over 48 hours, the results and preliminary analysis are also given in Appendix 3, and a summary of the times of observation and calculated lethal concentrations is included with the analysis to obtain the thresholds.

Determination of Median Lethal Concentration

Review of Methods: The mortality of animals under toxic conditions at a given concentration and time has been found to exhibit a log-normal distribution curve. If the cumulative percentage mortality at a given time is plotted against toxic concentration, a skewed sigmoid curve usually results. This skew occurs because of the geometric nature of a biological response. The curve may be transformed to a symmetrical shape by plotting the concentration on a logarithmic scale. The symmetrical sigmoid which then results represents the variation of individuals within a supposedly uniform population. By transforming the cumulative percentage mortality from an arithmetic scale to a probability or probit scale, a straight line is usually obtained (Bliss, 1935).

The accuracy of the estimated concentration, when results are plotted on a cumulative percentage-logarithm concentration graph, is at a maximum when the mortality is 50%. At this point the curve shows the maximum slope, giving the least change in concentration for a unit change in percentage mortality. The concentration which will just kill 50% of the individuals has, therefore, a greater accuracy than at other percentages. This concentration has been named the "Median Lethal Concentration", and is denoted by the symbol LC50. It should be qualified by the length of time of the experiment, such as 48 hr LC50. This value is somewhat similar to the LD50, the Median Lethal Dose, first proposed by Trevan (1927) for pharmacological purposes. In this the symbols were all written on the same line, and this has been followed by the major pharmacological writers. (Bliss, 1952; Finney, 1964; Gaddum, 1953). Other writers have, however, sometimes used the symbol with the percentage figure as a small subscript, which is historically incorrect. It is therefore proposed to use the form as originally given by Trevan.

When the logarithm-probit transformation to a straight line is used, the concentration for other than 50% mortality may be found, with a calculable error. (Bliss, 1937). These other percentages are useful in an attempt at obtaining 'safe' concentration levels.

Various methods have been described for obtaining the LC50 from the experimental results, ranging from simplified graphical methods to elaborate calculations. Litchfield and Wilcoxon (1949) describe a graphical method, using logarithm-probit graph paper, which allows results to be plotted directly. From this, and together with the use of nomographs, the LC50 and slope, with errors, can be obtained in a short time. Bliss (1935) gives the procedure for the calculation of the LC50. Tables of probits and weighting coefficients are included to allow a weighted regression line to be calculated. Finney (1952) in his book "Probit Analysis" has tables of probits, weighting coefficients, working probits, and a number of worked examples. In his calculations he makes allowance for the mortality which occurs in the experimental controls.

Adopted Method: The method of Finney, as given in Appendix 1 of "Probit Analysis", has been used as the basis for the method of analysis of the results obtained in the laboratory experiments, and is described below. To facilitate the calculations, a programme for use on an Olivetti Programma 101 electronic desk computer was written, enabling the LC50 and other required values to be easily obtained.

Table 19. Details of column headings used in analysis of experimental results

1	2	3	4	5
Concentration mg/l	Number of individuals tested	Number of individuals dead	Observed percentage dead	Corrected percentage dead
v	n	r	p^1	p

6	7	8	9	10
Expected percentage dead	Expected probit	Weighting coefficient	Logarithm concentration	Working probit
e	Y	w	x	y

Statistical Procedure:

1. Enter range of experimental concentrations, v, from control to highest, in column 1.
2. Enter number of animals tested at each concentration, n, in column 2.
3. Enter corresponding number dead, r, in column 3.
4. Calculate observed percentage dead, p^1, to nearest % unless n greater than 200, and enter into column 4.
5. Calculate corrected percentage dead, p, allowing for the control mortality, c, from

$$p = \frac{p^1 - c}{100 - c} \times 100$$

   to nearest % and enter into column 5.
6. Construct a graph, using logarithm-probability paper, plotting concentration, v, against corrected percentage dead, p, and fit a provisional line to the points. Points nearer to 50% carry a greater weight than those at higher or lower percentage mortalities.

7. From the provisional line, read off the expected percentage dead, e, and enter into column 6.
8. From Finney, Appendix Table I, read off the expected probit, Y, to one decimal place and enter into column 7.
9. From Table II, read off the weighting coefficient, w, for each value of Y, under the appropriate value of control mortality, c, to three decimal places, and enter into column 8.
10. Enter logarithm of concentration into column 9.
11. From Table IV, read off working probit, y, for each value of p (not p^1) and Y, and enter into column 10.
12. For values of 0% or 100% mortality, determine expected percentage dead from provisional line, enter into column 6, and determine expected probit Y as before. The minimum or maximum working probits for 0% or 100% respectively may be obtained from Table III or IV. Only the last 0% or first 100% may be so used.
13. Using the values n, w, x, and y, the following may be calculated for the "best-fit" of y upon x, for the general equation y = a + bx.

'S' has been used to represent "the sum of".

$$\bar{x} = \frac{Snwx}{Snw}$$

$$\bar{y} = \frac{Snwy}{Snw}$$

$$Sxx = Snwx^2 - \frac{(Snwx)^2}{Snw}$$

$$Syy = Snwy^2 - \frac{(Snwy)^2}{Snw}$$

$$Sxy = Snwxy - \frac{(Snwx)(Snwy)}{Snw}$$

$$b \text{ (slope)} = \frac{Sxy}{Sxx}$$

$$a \text{ (intercept)} = \bar{y} - b\bar{x}$$

$$= \frac{Snwy - bSnwx}{Snw}$$

$$chi^2 = Syy - \frac{(Sxy)^2}{Sxx}$$

N = number of concentrations used in calculation of straight line

$$\text{Variance of 'a', } V(a) = \frac{chi^2}{(N-2)\ (Snw)}$$

$$\text{Standard Error of 'a', S.E.(a)} = \sqrt{V(a)}$$

$$\text{Variance of 'b', } V(b) = \frac{chi^2}{(N-2)\ (Sxx)}$$

$$\text{Standard Error of 'b', S.E.(b)} = \sqrt{V(b)}$$

14. Using the general equation, $y = a + bx$, the logarithm of the LC50, m, may be calculated when $Y = 5.0$.

$$m = \frac{Y - a}{b}$$

$$\text{Log LC50} = \frac{5.0 - a}{b}$$

15. The Standard Error of 'm' can be calculated;

$$\text{Variance of 'm', } V(m) = \frac{1}{b^2}\left[\frac{1}{Snw} + \frac{(m - x)^2}{Sxx}\right]$$

$$\text{Standard Error of 'm'} = \sqrt{V(m)}$$

16. Repeat 14 and 15, using other values of Y;

percentage mortality	probit Y
10	3.718
20	4.158
50	5.000
80	5.842
90	6.282

17. Plot at least three of the calculated values on the graph, which should be co-linear. If a significant value of chi^2 is obtained from step 13, this plotted line may be used as a provisional line for a second cycle of calculations, from step 7 onwards.

18. Calculate fiducial limits;

    Fiducial limits = Antilog (m ± t.SE (m))

    where 't' is taken from a table of 'Student's' integral, from the column for P = 0.05 at the value of (N-2) degrees of freedom.

In the analysis of experiments where mortality was recorded at a number of times, the full analysis has not been applied. Only lethal concentrations at each time were calculated for replotting to obtain lethal thresholds.

Determination of Median Lethal Time

As an alternative to the above method of analysis, the Median Lethal Time may be determined. In experiments where mortality is obtained over various times, at given concentration, the results are plotted on a logarithm time-probit percentage graph. From this the time required to kill 50% of the individuals at a given concentration can be found. This is the Median Lethal Time, denoted by the symbol LT50. It should not be confused with TLm or TL50, which are other symbols sometimes used in place of LC50. (Sprague, 1969).

This method is favoured by many workers, who claim that more information may be obtained from experiments. (Sprague, 1969). Survival times for each individual are recorded by continuous observation, or the experiment examined at very frequent intervals, especially near the beginning. The percentage mortality is calculated at each time interval, and the results plotted against time of exposure. Using linear scales for time and percentage, a skewed sigmoid is frequently obtained, which may be straightened by transforming to time and probit percentage mortality. Litchfield (1949) describes a graphic method, using logarithm-probit paper and nomographs which is similar to the method used for Median Lethal Concentration.

Arithmetic methods have also been used in the determination of the Median Lethal Time. Doudoroff et al (1966) used the response time of the median fish, but this ignores the data obtained from the other individuals. Herbert (1952) calculated the geometric mean, as the antilogarithm of the mean of the logarithm of the individual survival times. The harmonic mean, which is the reciprocal of the arithmetic mean of the reciprocals of the individual response times, was described by Abram (1964). Bliss (1937) gives details of the method of calculation of the time-mortality curve, including graphic analysis to determine any departure from normality.

In time-mortality experiments, it is impossible for the percentage mortality at any given time to be less than at a previous time. In dosage-mortality experiments, however, the mortality in a given concentration can be less than that in a lower concentration. This is due to the variation in the susceptibility of individuals to a toxic substance. (Bliss, 1937). If a large number of animals are tested at each concentration, the probability of this occurring is greatly reduced.

Determination of Lethal Thresholds

The median lethal concentrations or median lethal times obtained by the above methods can be used for the determination of threshold values. This is the concentration which will just kill 50% of the animals after a prolonged period of exposure, and has been described as the "incipient LC50". (Sprague, 1969). Threshold values for other percentages may be found from lines plotted from the appropriate lethal concentrations or times.

The graph for obtaining the threshold may be constructed from lethal concentration against fixed times, or from lethal times against fixed concentrations. The times and concentrations are plotted on logarithm scales, as this permits a wider range to be more easily accommodated and takes into account the nature of the biological response. Provided that sufficient times and concentrations have been used, either method should give essentially the same curve. The threshold value is taken as the concentration where the line becomes asymptotic to the time axis, where reduction in the concentration will not give any further increase in survival time. (Fig. 19b). A curve of this type was obtained by Lloyd (1960) for the toxicity of zinc to rainbow trout in hard water.

Some chemicals do not produce lines becoming asymptotic, but continue as a straight line or curve, at an angle to the time axis. (Fig. 19a). Jackson and Brown (1970) give a graph for the toxicity of acrylonitrile to rainbow trout, where the asymptotic point had not been reached after a period of 100 days. In many cases, substances which produce such lines are those which do not occur in natural aquatic habitats, and to which the animals cannot develop any tolerance.

This may be caused by the inability of the animal to eliminate or break down these substances from the body, which then build up to toxic proportions. The time required to reach this toxic level may be longer than the normal life span of the animal.

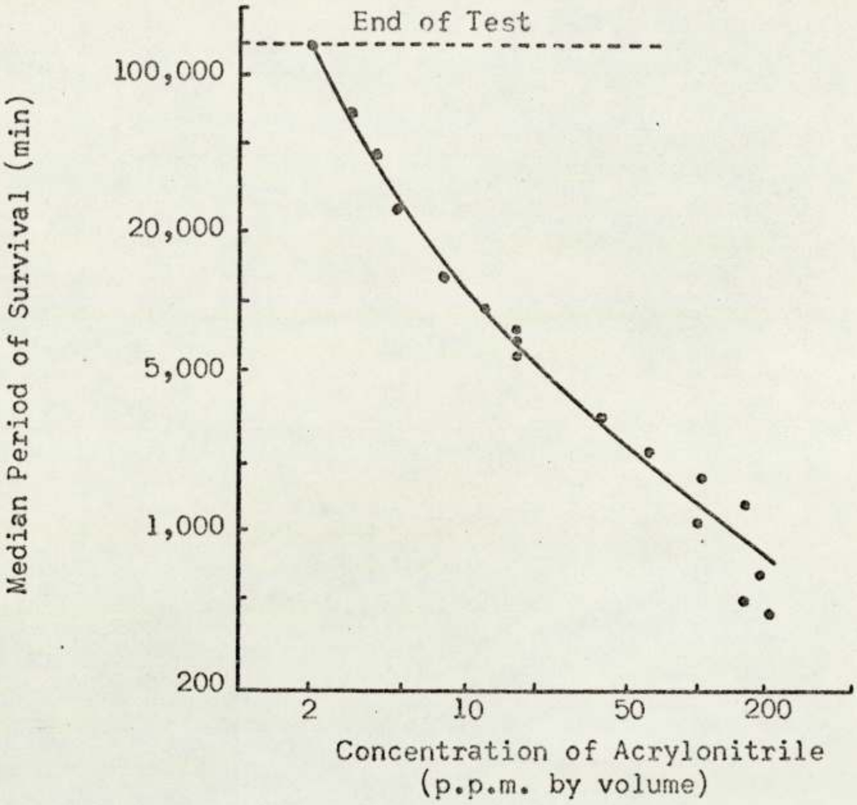


Fig. 19a. Toxicity of Acrylonitrile to Rainbow Trout

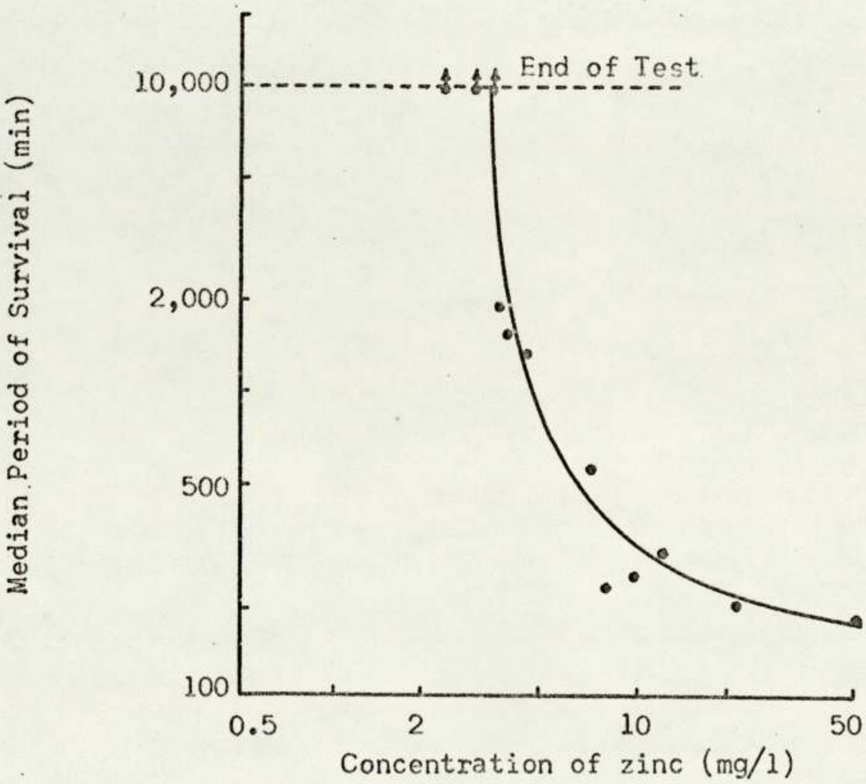


Fig. 19b. Toxicity of zinc to Rainbow Trout, water hardness, 320 as $CaCO_3$.pH, 7.6 - 7.8

In the laboratory experiments on Gammarus, where lethal concentrations were extrapolated from concentration - mortality curves, the thresholds were obtained from time - lethal concentration graphs.

Toxicity of Mixtures

Herbert et al. (1965) used the thresholds obtained from experiments on single substances to calculate the expected mortality of mixtures of these substances. They found that the toxicity of the mixture could be represented by the sum of the proportions of the individual toxic substances. The contribution of each toxic substance was calculated as the proportion of its threshold value, which in their case was taken as the 48hrLC50 concentration. If the concentration of two toxic substances, P and Q, in solution are Ps and Qs, and their respective thresholds are Pt and Qt, then the sum of the proportions may be represented by

$$\text{Sum of Proportions} = \frac{Ps}{Pt} + \frac{Qs}{Qt}$$

This formula may be extended to cover any number of substances. It was found that if the sum of proportions was equal to 1 or less, then the fish usually survived, but that mortality occurred when the value exceeded 1.

There is the possibility that two or more substances together in solution may affect each other. This obviously results when a chemical reaction takes place, but may also occur at a physiological level. Apart from any direct chemical precipitation, the presence of calcium salts in solution can influence the toxicity of metal salts in solution. (Carpenter, 1927; Jones, 1938a; Lloyd, 1965).

When two toxic substances are combined, the mixture can act as if each substance were exerting its own separate toxic action. The total effect is the addition of the individual actions, a condition widely described as 'additive'. Two other possibilities then exist, with either a greater or lesser toxic action than that of the additive condition. When the toxic action is less, it is commonly described as 'antagonistic', while a toxicity greater than 'additive' is referred to as 'synergistic'. This method has been used by Jones (1964) and many other workers. To simplify the explanation it is proposed that the formula A + B = T shall be used, where A and B represent the toxicities of two substances A and B, and T represents the total toxicity of the mixture. The additive case would therefore be 1 + 1 = 2, the antagonistic case 1 + 1 = < 2 and the synergistic case, 1 + 1 = > 2. However, as discussed by Sprague (1970), this method has certain disadvantages. The cases where each of two toxic substances act as if the other were not present (1 + 1 = 1) and where the combined effect is greater than each one separately but still less than the additive condition (1 + 1 = > 1 but < 2) would both be classified as antagonistic by Jones's method. By the definition of antagonism as an opposing or counteracting effect, neither of these can be regarded as antagonism in its strictest sense. Sprague also suggests that because of past mis-use, the term synergism should also be avoided. He has divided the joint action of two substances into five groups:-

more - than - additive	1 + 1 = > 2
additive	1 + 1 = 2
less - than - additive	1 + 1 = > 1 but < 2
no interaction	1 + 1 = 1
antagonism	1 + 1 = < 1

In the discussion of results this latter method has been adopted, as although it is more complicated, it is at the same time more precise.

In the laboratory experiments on the toxicity of mixtures of copper, zinc and chromium, the expected joint toxicities have been calculated from the sum of proportions. The individual thresholds used were those obtained from the 48 hour experiments, or extrapolated from threshold curves. The sum of proportions values obtained by these methods have been plotted against the experimental mortality. If the toxicity of the mixtures were strictly additive, then 50% mortality would occur at a sum of proportions equal to 1.0. A mortality greater than 50% would indicate more - than - additive conditions while less than 50% less - than - additive, no interaction or antagonistic conditions. The sum of proportions values have been plotted on logarithmic scales, since they are factors of concentration. When mortality is plotted on a probit scale, a straight line should result for the additive condition.

Prediction of Toxicity

By using the calculated sum of proportions value, the toxicity of mixtures can be predicted. It only gives, however, the mortality which should occur over the same period upon which the initial toxicities are based, and does not predict the rate of mortality. The toxicities used in obtaining the sum of proportions value must be under the same experimental conditions, as water hardness, dissolved oxygen concentration, temperature and pH can all modify individual toxicities.

In order to determine the effects of varied hardness, experiments on the toxicity of copper, zinc and chromium at three different hardnesses have been performed. The results of these may be used in conjunction with the water hardness measurements to determine the toxicity of the metals under field conditions. The results of the experiments with copper and zinc at reduced dissolved oxygen concentrations have been plotted to give a factor related to the saturated condition. This has been used to predict the toxicity of the toxic metal mixtures at reduced dissolved oxygen levels, as occurs under natural stream conditions.

By these means the toxicity of the substances which have been found in the field can be calculated and correlated with the occurrence of Gammarus in the streams of the area.

Experimental Results

The results of the laboratory experiments have been analysed wherever possible by the methods described in the statistical procedure. (Page 106). Where this has not been possible, details of the alternative method have been given. This has usually involved plotting the results in a suitable form to enable the required information to be extrapolated. Table 20 gives a list of the abbreviations which have been used in the statistical analysis.

Experiments for 48 hours at a water hardness equivalent to 100 mg/l calcium carbonate to measure the toxicities of Copper, Zinc, Chromium, Nickel, Lead, Cadmium, Ammonia, Phenol and Cyanide.

The observations of these experiments are included in Appendix 3, where the mortality in individual dishes is given. The overall mortality at each concentration is given below under the appropriate section, and has been used to calculate the best straight line to fit the corrected experimental mortalities. From this line, the theoretical concentrations necessary to kill different percentages of the test animals have been determined. At each percentage, the 95% fiducial limits of the concentration have been calculated, enabling the fiducial lines to be plotted with the calculated straight line.

In some of the early experiments, only a limited number of experimental dishes were available. This necessitated repeating the experiment a number of times to obtain a satisfactory number of animals over a suitable concentration range. In these cases, the individual experiments have been added to give the total result.

Copper: Six separate experiments were performed, giving a total of at least 100 animals tested at each concentration. (Table 60). It is thought that the number of animals tested will have largely cancelled out any difference between experiments. Table 21 summarises the mortalities and gives the statistical analysis, with the results shown graphically in Fig. 20. The range of concentrations tested, 0.22 mg/l to 1.0 mg/l, could have been increased at the higher end with advantage. However, the 50% point has been covered, and a calculated 48hrLC50 value of 0.58 mg/l obtained. The chi^2 value of 7.63 is below the 5% level of 14.07, indicating no significant difference from the calculated straight line. The 95% fiducial limits have been calculated for the 10%, 20% and 50% points, and plotted with the calculated straight line in Fig. 20. The fiducial limits for the 48hrLC50 value of 0.58 mg/l were calculated as 0.52 mg/l and 0.65 mg/l.

Zinc: The range of concentrations of from 1.8 mg/l to 6.8 mg/l has covered the mortality range, although only 20 animals were tested at 6.8 mg/l, as opposed to 50 at each of the other concentrations. (Table 61). If an equal number had been used, the value of 100% may well have been reduced to nearer the extrapolated expected value of 98%. The effects of this difference have been minimised by the use of weighted coefficients in the regression. Table 22 shows a very low chi^2 value of 2.05, compared with a 5% value of 12.59. The 95% fiducial limits have been calculated for all the 10%, 20%, 50%, 80% and 90% points, and are plotted with the straight line in Fig. 21. All the observed mortalities have been enclosed within the 95% fiducial lines. A 48hrLC50 value of 3.2 (3.0 - 3.4) mg/l has been calculated.

Chromium (hexavalent): The range of concentrations of from 0.39 mg/l to

Table 20. Abbreviations used in analysis of experimental results.

v	Concentration of chemical in experimental dish
n	Number of animals tested at each concentration
r	Number of animals dead at each concentration
p^1	Observed percentage mortality
p	Corrected percentage mortality, allowing for control mortality
e	Expected percentage mortality, obtained from provisional straight line
Y	Probit of expected percentage mortality
w	Weighting coefficient
x	Logarithm of concentration 'v'
y	Working probit
N	Number of concentrations used in the calculations
chi^2	Value of chi^2 obtained from calculations
a	Intercept of calculated straight line
SE(a)	Standard error of 'a'
b	Slope of calculated straight line
SE(b)	Standard error of 'b'
D.F.	Degrees of Freedom of calculated line
p	Probability. Taken as 0.05 or 95%
t	Value of student's 't' at given D.F. and p
$*chi^2$	Maximum value of chi^2 at given D.F. and p
Mortality %	Theoretical mortalities of 10, 20, 50, 80, and 90%
Probit	Probit of given mortality %
m	Logarithm of concentration necessary to give mortality %
SE(m)	Standard error of 'm'

Antilog m	Antilogarithm of 'm' : concentration necessary to produce given mortality %
t.SE(m)	Product of 't' and 'SE(m)', used to add to and subtract from 'm' to give logarithms of 95% confidence limits
Antilog	Antilogarithms of m ± t.SE(m) to give concentrations of 95% confidence limits of calculated straight line at given mortality %
48 hour LC50	Concentration of chemical necessary to kill 50% of the experimental animals in 48 hours, together with 95% confidence limit concentrations

Experiments for 48 hours at a water hardness of 100 mg/l

Table 21. Copper: 10 Gammarus/1,000ml solution/dish. 100 hardness

Mortality after 48 hours

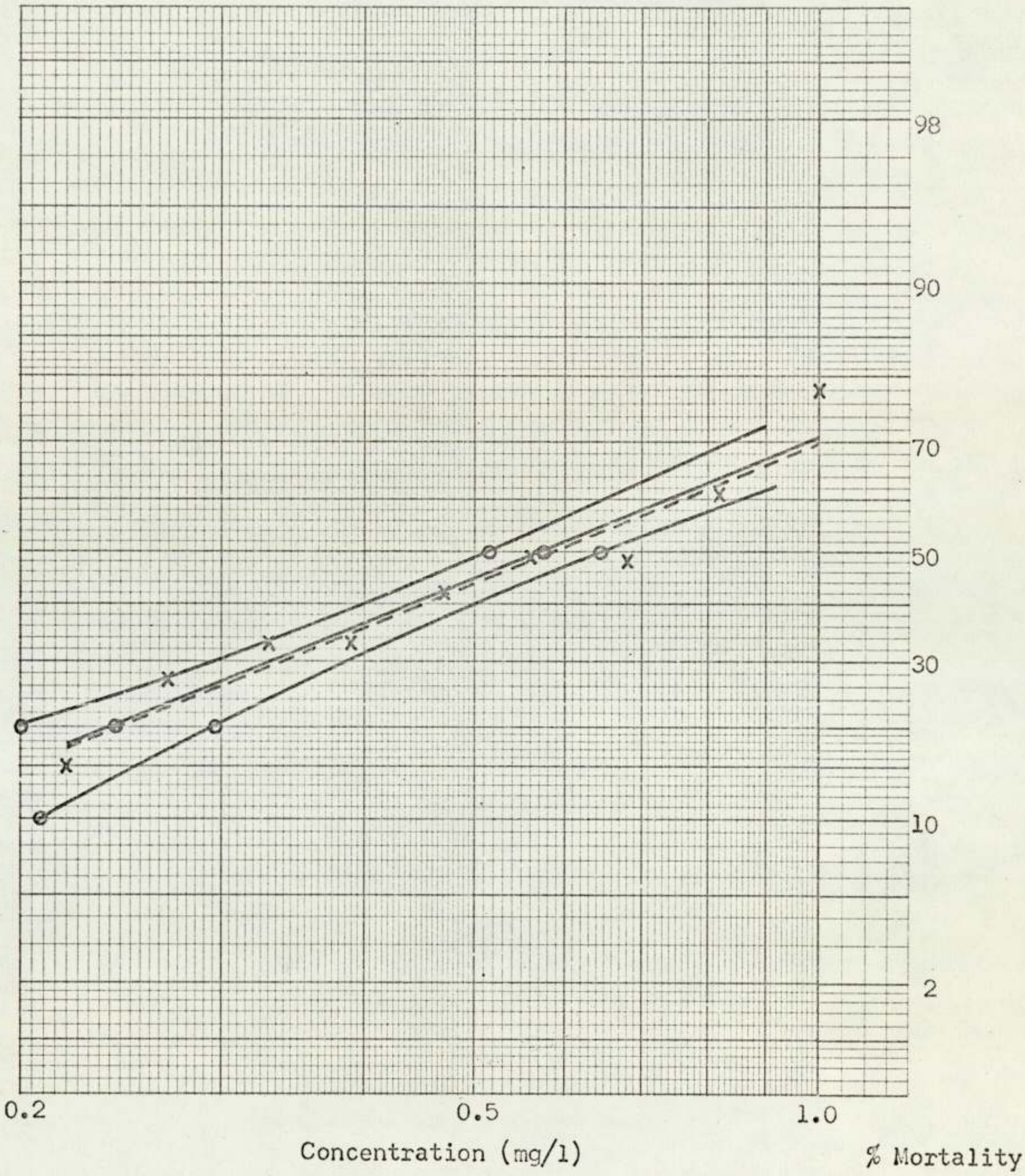
v	n	r	p^1	p	e	Y	w	x	y
Cont	140	3	2	-	-	-	-	-	-
0.22	100	17	17	15	17	4.0	0.389	-0.658	3.96
0.27	100	28	28	27	23	4.3	0.490	-0.569	4.39
0.33	100	34	34	33	29	4.4	0.519	-0.481	4.57
0.39	100	34	34	33	35	4.6	0.567	-0.409	4.56
0.47	110	47	43	42	41	4.8	0.598	-0.328	4.80
0.56	100	50	50	49	49	5.0	0.612	-0.244	4.97
0.68	100	49	49	48	56	5.2	0.606	-0.167	4.95
0.82	100	62	62	61	63	5.3	0.596	-0.086	5.28
1.0	100	78	78	78	70	5.5	0.564	0.000	5.75

N = 9 chi^2 = 7.63
a = 5.53   SE(a) = 0.05
b = 2.24   SE(b) = 0.23

At 7 D.F. and p = 0.05, t = 2.37 and $*chi^2$ = 14.07

Mortality %	10	20	50
Probit	3.718	4.158	5.000
m	-0.8097	-0.6136	-0.2384
SE(m)	0.0538	0.0363	0.0207
m	$\bar{1}$.1903	$\bar{1}$.3864	$\bar{1}$.7616
Antilog m	0.155	0.243	0.577
t.SE(m)	0.1276	0.0861	0.0491
m + t.SE(m)	$\bar{1}$.3179	$\bar{1}$.4725	$\bar{1}$.8107
Antilog	0.208	0.297	0.647
m - t.SE(m)	$\bar{1}$.0627	$\bar{1}$.3003	$\bar{1}$.7125
Antilog	0.115	0.200	0.516

48 hour LC50 = 0.58 (0.52 - 0.65) mg/l copper



x observed percentage mortality

---- provisional line

—o— calculated line and 95% fiducial limits

Fig. 20. Toxicity of copper to Gammarus at 100 hardness for 48 hours

Experiments for 48 hours at a water hardness of 100 mg/l

Table 22. Zinc: 10 Gammarus/1,000ml solution/dish. 100 hardness

Mortality after 48 hours

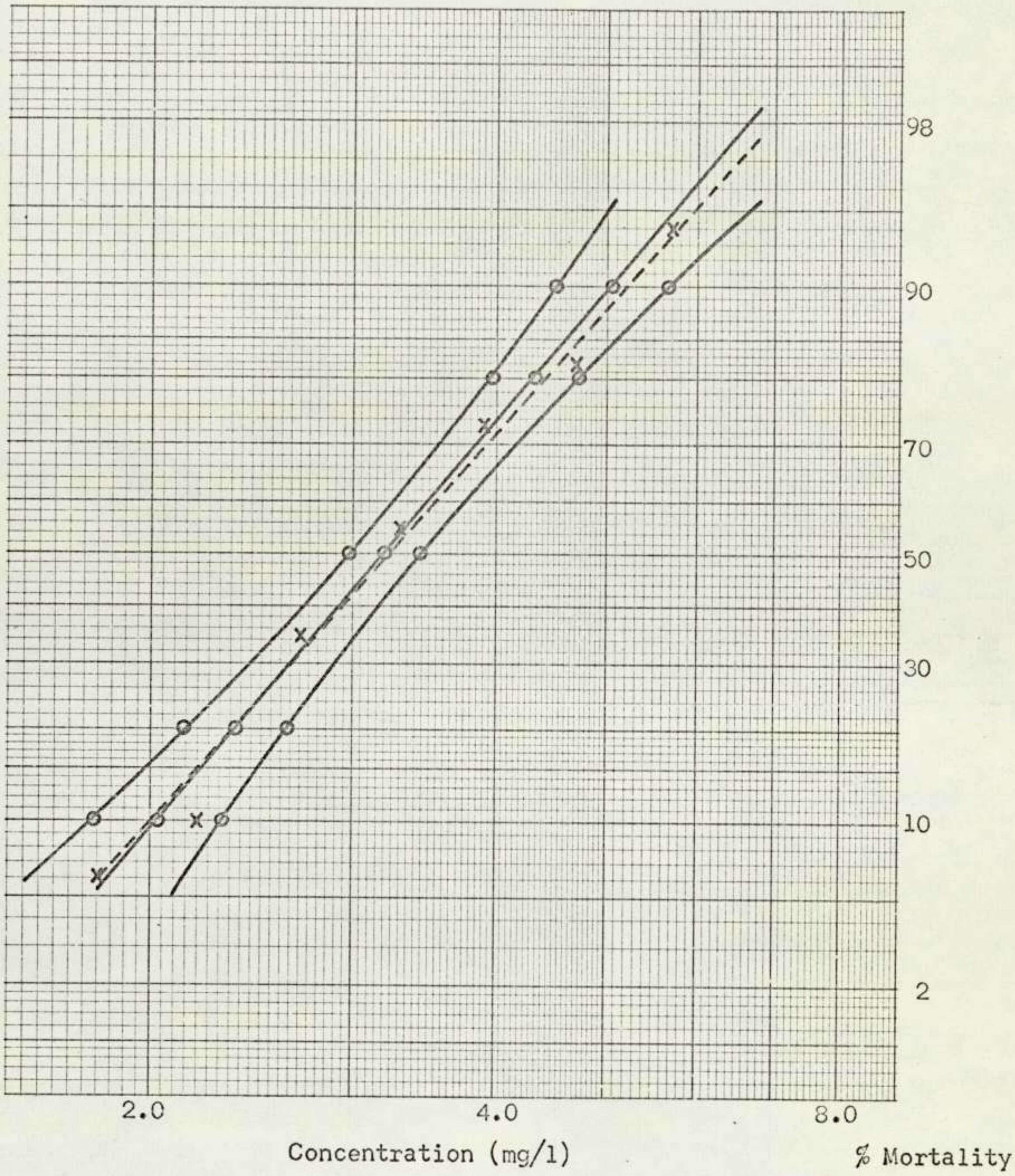
v	n	r	p^1	p	e	Y	w	x	y
Cont	50	1	2	-	-	-	-	-	-
1.8	50	4	8	6	6	3.4	0.173	0.255	3.45
2.2	50	6	12	10	15	4.0	0.389	0.342	3.76
2.7	50	18	36	35	32	4.5	0.545	0.431	4.62
3.3	50	28	56	55	52	5.0	0.612	0.518	5.12
3.9	50	37	74	73	70	5.5	0.564	0.591	5.61
4.7	50	41	82	82	85	6.0	0.428	0.672	5.91
5.6	50	47	94	94	93	6.5	0.263	0.748	6.55
6.8	20	20	100	100	98	7.1	0.108	0.832	7.51

N	=	8	chi^2	=	2.05
a	=	1.73	SE(a)	=	0.05
b	=	6.47	SE(b)	=	0.34

At 6 D.F. and p = 0.05, t = 2.45 and $*chi^2$ = 12.59

Mortality %	10	20	50	80	90
Probit	3.718	4.158	5.000	5.842	6.282
m	0.3077	0.3757	0.5058	0.6360	0.7040
SE(m)	0.0230	0.0182	0.0126	0.0158	0.0202
Antilog m	2.03	2.37	3.20	4.32	5.06
t.SE(m)	0.0565	0.0446	0.0309	0.0388	0.0496
m + t.SE(m)	0.3642	0.4203	0.5367	0.6748	0.7536
Antilog	2.31	2.63	3.44	4.73	5.67
m - t.SE(m)	0.2512	0.3311	0.4749	0.5972	0.6544
Antilog	1.78	2.14	2.98	3.96	4.51

48 hour LC50 = 3.2 (3.0 - 3.4) mg/l zinc



x observed percentage mortality

---- provisional line

—o— calculated line and 95% fiducial limits

Fig. 21. Toxicity of zinc to Gammarus at 100 hardness for 48 hours

1.8 mg/l was slightly lower than desirable, as most mortalities were below 50%, and the highest was only 80%. Three experiments were added, giving a total of 50 animals tested at each concentration. (Table 62). The chi^2 value of 2.49 is well within the 5% level of 12.59, (Table 23) and again all the observed mortalities are enclosed by the 95% fiducial lines (Fig. 22). A 48hrLC50 value of 1.3 (1.1 - 1.4) has been calculated.

Nickel: All the concentrations, from 180 mg/l to 1,200 mg/l, were tested simultaneously, with 50 animals at each concentration. The highest mortality obtained was only 62%. (Table 63). From Table 24 it can be seen that a high chi^2 value of 13.08 was obtained, compared with the 5% value of 16.92. Although not significant, it is reflected in Fig. 23, where the provisional and calculated straight lines differ appreciably. The fiducial limits for 10%, 20%, 50% and 80% have been calculated, although only the first three are plotted in Fig. 23. Four of the experimental mortalities fall outside the 95% fiducial lines, and which have obviously caused the high chi^2 value. The 48hrLC50 and 95% limits were obtained as 940 (780 - 1,130) mg/l.

Lead: The results of four experiments are combined, with 100 animals tested at the low concentrations, and 50 at each of the higher ones. (Fig. 64). Very little mortality was obtained, only reaching 32% at 18.0 mg/l. Although lead is highly toxic, it readily forms insoluble compounds, causing only small amounts to remain in solution. In this experiment, insoluble precipitates were obtained, probably basic lead carbonate. This would greatly reduce the toxicity of the solution, thus accounting for the low mortalities. A corrected mortality of 3% was obtained at 1.0 mg/l, but as this is so unrelated to the higher concentrations, has been neglected. The four highest concentrations, 3.3 mg/l to 18.0 mg/l gave mortalities almost co-linear in Fig. 24, and

Experiments for 48 hours at a water hardness of 100 mg/l

Table 23. Chromium: 10 Gammarus/1,000ml solution/dish, 100 hardness

Mortality after 48 hours

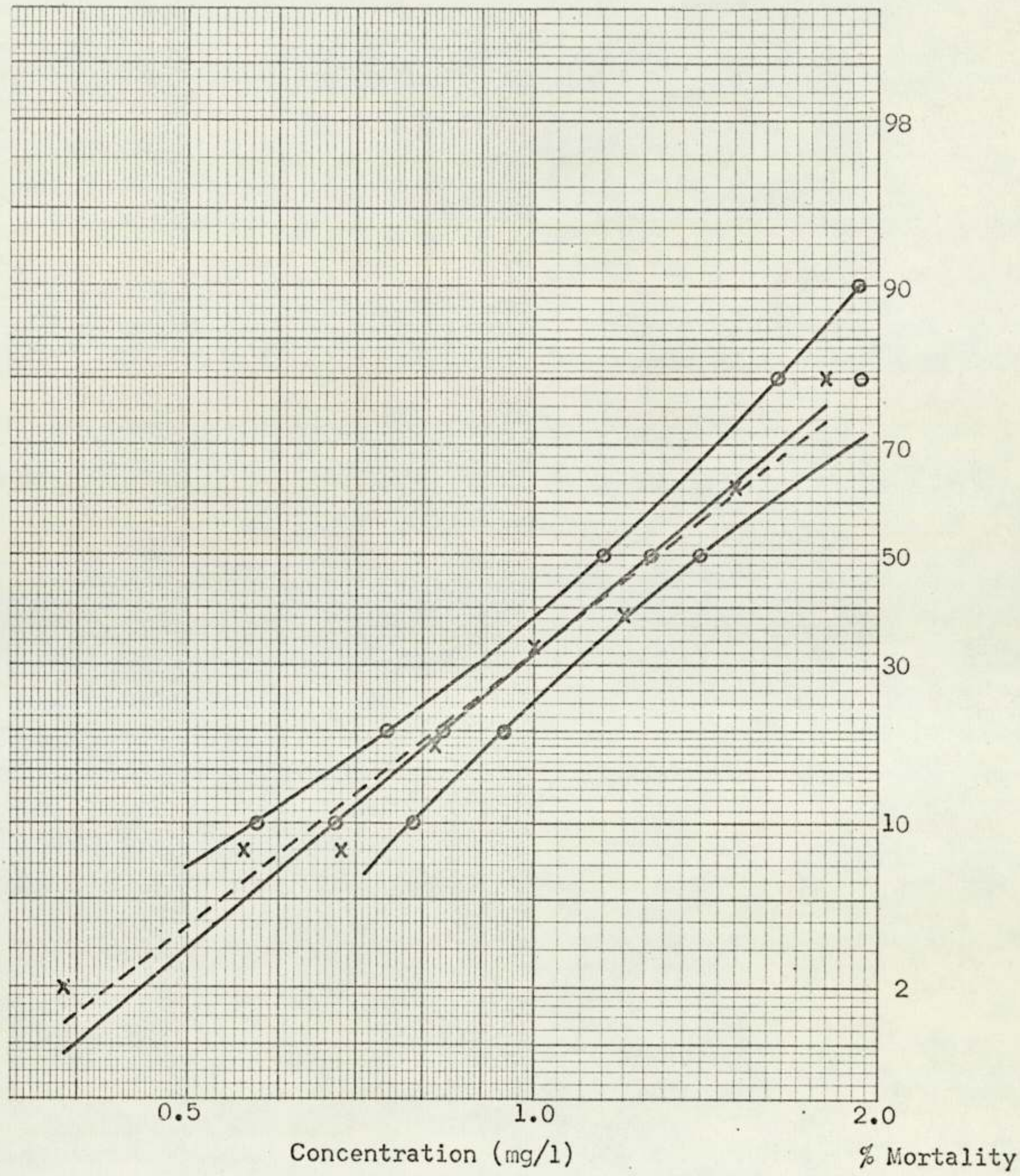
v	n	r	p^1	p	e	Y	w	x	y
Cont	50	1	2	-	-	-	-	-	-
0.39	50	2	4	2	2	2.9	0.051	-0.409	2.95
0.56	50	5	10	8	6	3.4	0.173	-0.252	3.63
0.68	50	5	10	8	12	3.8	0.315	-0.167	3.62
0.82	50	10	20	18	20	4.2	0.458	-0.083	4.09
1.0	50	17	34	33	32	4.5	0.545	0.000	4.56
1.2	50	20	40	39	45	4.9	0.608	0.079	4.72
1.5	50	32	64	63	61	5.3	0.596	0.176	5.33
1.8	50	40	80	80	74	5.6	0.543	0.255	5.82

N = 8 $\quad$ chi^2 = 2.49
a = 4.52 $\quad$ SE(a) = 0.05
b = 4.61 $\quad$ SE(b) = 0.32

At 6 D.F. and p = 0.05, t = 2.45 and $*chi^2$ = 12.59

Mortality %	10	20	50	80	90
Probit	3.718	4.158	5.000	5.842	6.282
m	-0.1733	-0.0778	0.1048	0.2876	0.3830
SE(m)	0.0283	0.0210	0.0179	0.0310	0.0400
m	$\bar{1}$.8267	$\bar{1}$.9222	0.1048	0.2876	0.3830
Antilog m	0.671	0.836	1.27	1.94	2.41
t.SE(m)	0.0695	0.0515	0.0439	0.0760	0.0980
m + t.SE(m)	$\bar{1}$.8962	$\bar{1}$.9737	0.1487	0.3636	0.4810
Antilog	0.787	0.941	1.40	2.31	3.03
m - t.SE(m)	$\bar{1}$.7572	$\bar{1}$.8707	0.0609	0.2116	0.2850
Antilog	0.572	0.742	1.15	1.63	1.93

48 hour LC50 = 1.3 (1.1 - 1.4) mg/l chromium



x observed percentage mortality

---- provisional line

—o— calculated line and 95% fiducial limits

Fig. 22. Toxicity of chromium to Gammarus at 100 hardness for 48 hours

Experiments for 48 hours at a water hardness of 100 mg/l

Table 24. Nickel: 10 Gammarus/800ml solution/dish. 100 hardness

Mortality after 48 hours

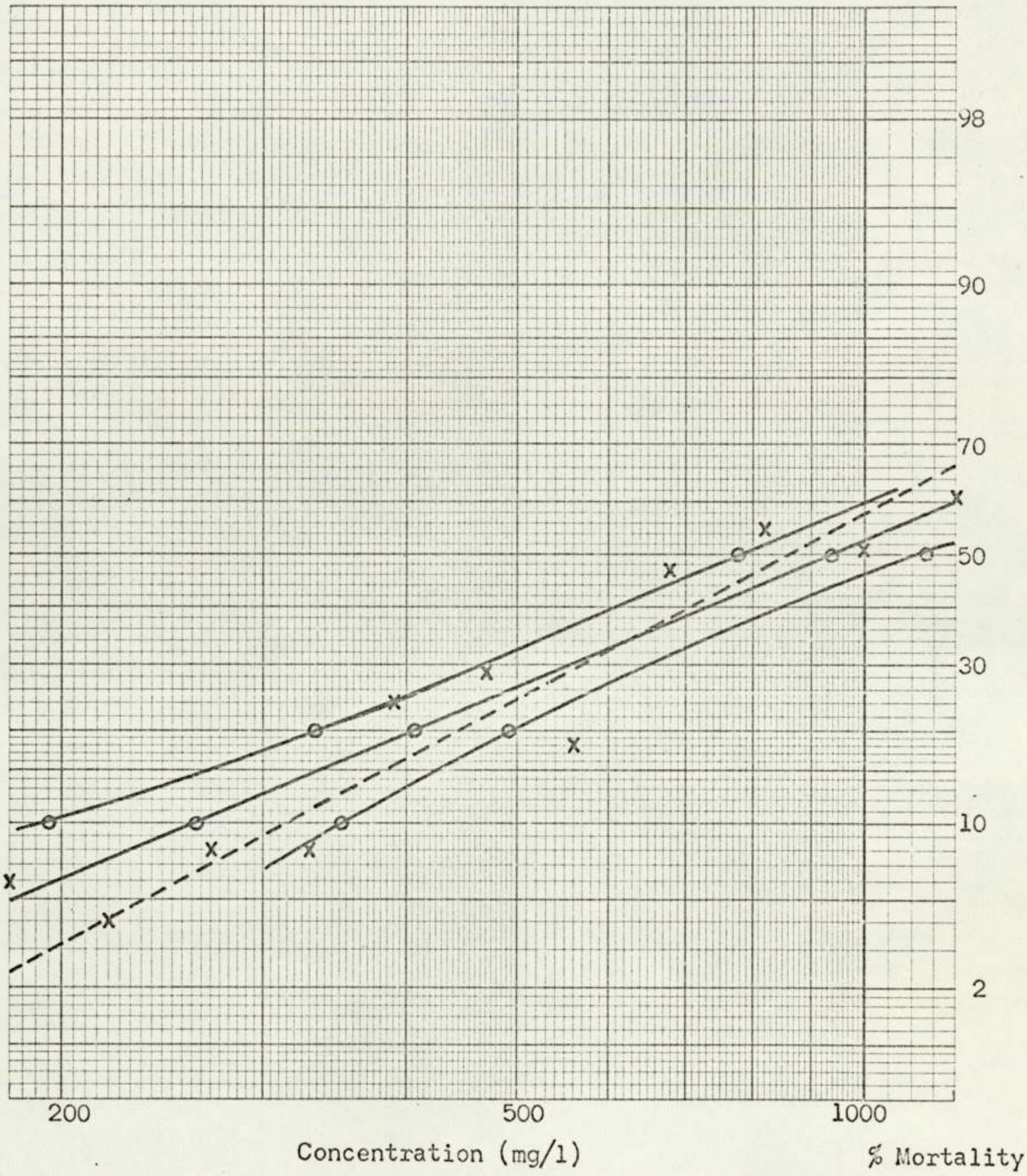
v	n	r	p^1	p	e	Y	w	x	y
Cont	50	1	2	-	-	-	-	-	-
180	50	4	8	6	2	2.9	0.051	2.255	3.86
220	50	3	6	4	4	3.2	0.115	2.342	3.25
270	50	5	10	8	7	3.5	0.206	2.431	3.60
330	50	5	10	8	11	3.8	0.314	2.518	3.62
390	50	13	26	24	16	4.0	0.389	2.591	4.34
470	50	15	30	29	23	4.3	0.490	2.672	4.45
560	50	10	20	18	30	4.5	0.545	2.748	4.13
680	50	24	48	47	39	4.7	0.585	2.832	4.93
820	50	28	56	55	48	4.9	0.607	2.914	5.13
1000	50	26	52	51	58	5.2	0.606	3.000	5.02
1200	50	31	62	61	66	5.4	0.582	3.176	5.28

N = 11 $\quad$ chi^2 = 13.08
a = -1.88 $\quad$ SE(a) = 0.08
b = 2.31 $\quad$ SE(b) = 0.35

At 9 D.F. and p = 0.05, t = 2.26 and $*chi^2$ = 16.92

Mortality %	10	20	50	80
Probit	3.718	4.158	5.000	5.842
m	2.4185	2.6086	2.9726	3.3365
SE(m)	0.0564	0.0378	0.0359	0.0734
Antilog m	262	406	939	2,170
t.SE(m)	0.1273	0.0855	0.0812	0.1657
m + t.SE(m)	2.5458	2.6941	3.0538	3.5022
Antilog	351	494	1,132	3,178
m - t.SE(m)	2.2912	2.5231	2.8914	3.1708
Antilog	195	333	779	1,482

48 hour LC50 = 940 (780 - 1,130) mg/l nickel



x observed percentage mortality

---- provisional line

—o— calculated line and 95% fiducial limits

Fig. 23. Toxicity of nickel to Gammarus at 100 hardness for 48 hours

Experiments for 48 hours at a water hardness of 100 mg/l

Table 25. Lead: 10 Gammarus/1,000ml solution/dish. 100 hardness

Mortality after 48 hours

v	n	r	p^1	p	e	Y	w	x	y
Cont	100	2	2	-	-	-	-	-	-
0.47	100	2	2	0	0	-	-	-	-
0.68	100	2	2	0	0	-	-	-	-
1.0	100	5	5	3	0	-	-	-	-
1.8	50	1	2	0	0	-	-	-	-
3.3	50	2	4	2	2	2.9	-	-	-
5.6	50	4	8	6	6	3.4	-	-	-
10.0	50	8	16	14	14	3.9	-	-	-
18.0	50	16	32	31	30	4.5	-	-	-

Only the four highest concentrations give values which would be usable in the calculations. As these are almost co-linear, and all below 50%, the 48 hour LC50 has been estimated by extrapolation of the provisional straight line. No confidence limits can be placed on the extrapolated line.

48 hour LC50 = 32 mg/l lead

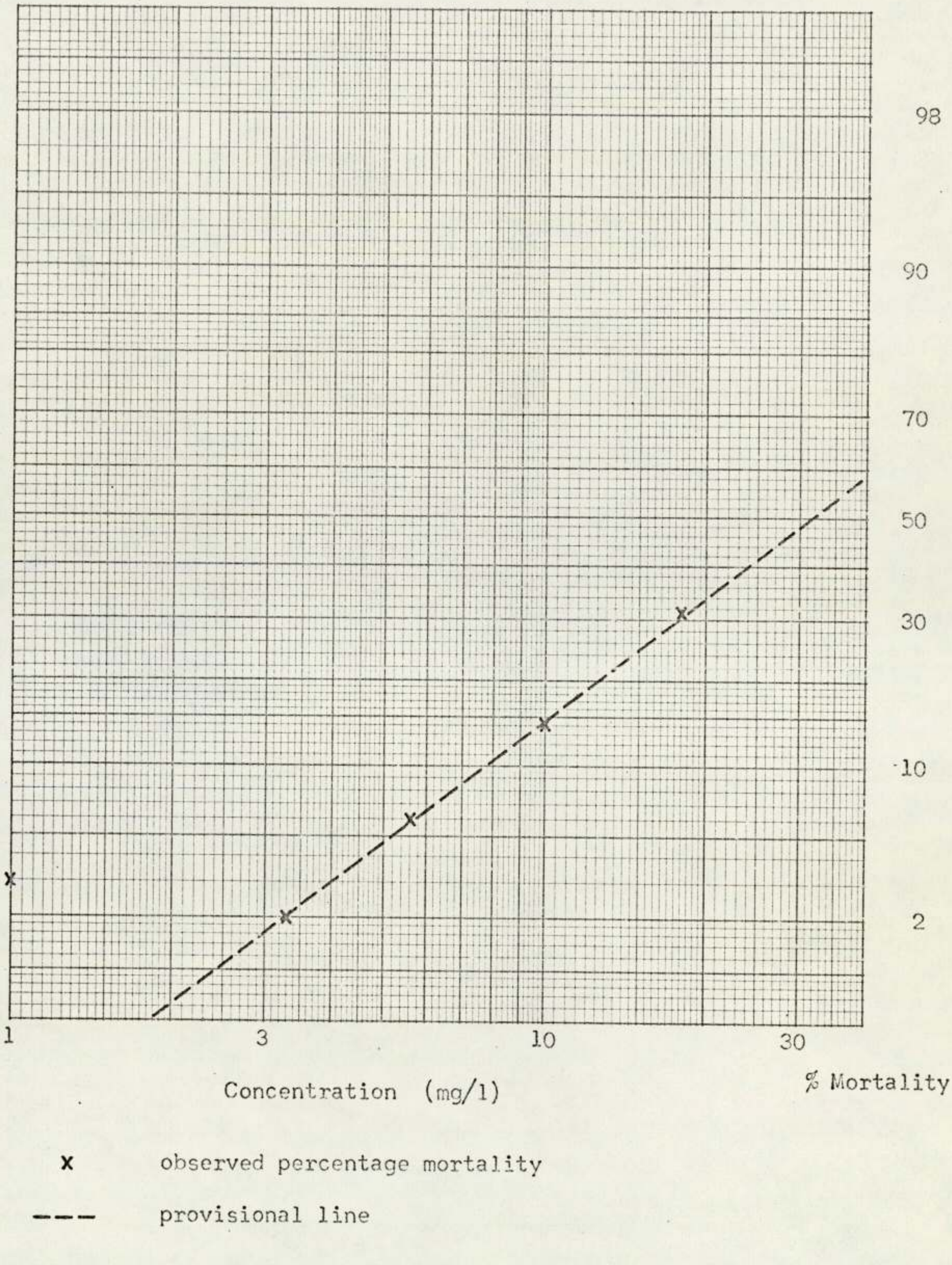


Fig. 24. Toxicity of lead to Gammarus at 100 hardness for 48 hours

which have been used to plot the provisional line. As this does not reach 50% within the tested concentration range, no further analysis is justifiable. (Table 25). The provisional line has been extended to 50%, and a 48hrLC50 value of 32 mg/l extrapolated. No fiducial limits can be given for this value.

Cadmium: This was tested in three experiments, which have been combined in Table 65. The initial range of from 0.39 mg/l to 1.2 mg/l was supplemented in the third experiment by a range of from 0.15 mg/l to 0.33 mg/l, with a total of 50 animals at each concentration. It is realised that this method of testing is open to large errors when combining the results. However, even with the limited range of from 0.39 mg/l to 1.2 mg/l, large discrepancies from the provisional straight line occurred. The large scatter of the combined results, shown in Fig. 25 have produced a chi^2 value exceeding the 5% level, indicating a significant difference from the calculated straight line. (Table 26). As the provisional and calculated straight lines are almost identical, the chi^2 value is unlikely to be greatly reduced by performing a second cycle of calculations. A value of 0.82 mg/l was calculated as the 48hrLC50.

Ammonia: A range of concentrations of from 68 mg/l to 270 mg/l, as nitrogen, was tested simultaneously with 50 animals at each concentration. (Table 66). The mortalities extended from 36% to 100%, all except one above 50%. The chi^2 value obtained, 3.02, is well below the 5% level of 11.07, so that 95% fiducial limits have been calculated. (Table 27, Fig. 26). A 48hrLC50 value of 78 (70 - 86) mg/l, as nitrogen, has been calculated.

The toxicity of ammonia is dependent upon the concentration of undissociated ammonia. This is in turn dependent upon the pH, which in the experiment was measured at 0, 24, and 48 hours. The ammonium

<u>Experiments for 48 hours at a water hardness of 100 mg/l</u>

Table 26. Cadmium: 10 Gammarus/1,000ml solution/dish. 100 hardness

Mortality after 48 hours

v	n	r	p^1	p	e	Y	w	x	y
Cont	50	1	2	-	-	-	-	-	-
0.15	50	9	18	16	11	3.8	0.315	-0.824	4.03
0.22	50	13	26	24	16	4.0	0.389	-0.658	4.34
0.33	50	8	16	14	26	4.4	0.519	-0.481	4.00
0.39	50	11	22	20	30	4.5	0.545	-0.409	4.19
0.47	50	22	44	43	35	4.6	0.567	-0.328	4.83
0.56	50	20	40	39	40	4.7	0.585	-0.252	4.72
0.68	50	21	42	41	45	4.9	0.607	-0.167	4.77
0.82	50	19	38	37	50	5.0	0.612	-0.086	4.67
1.0	50	34	68	67	56	5.2	0.606	0.000	5.43
1.2	50	34	68	67	61	5.3	0.596	0.079	5.44

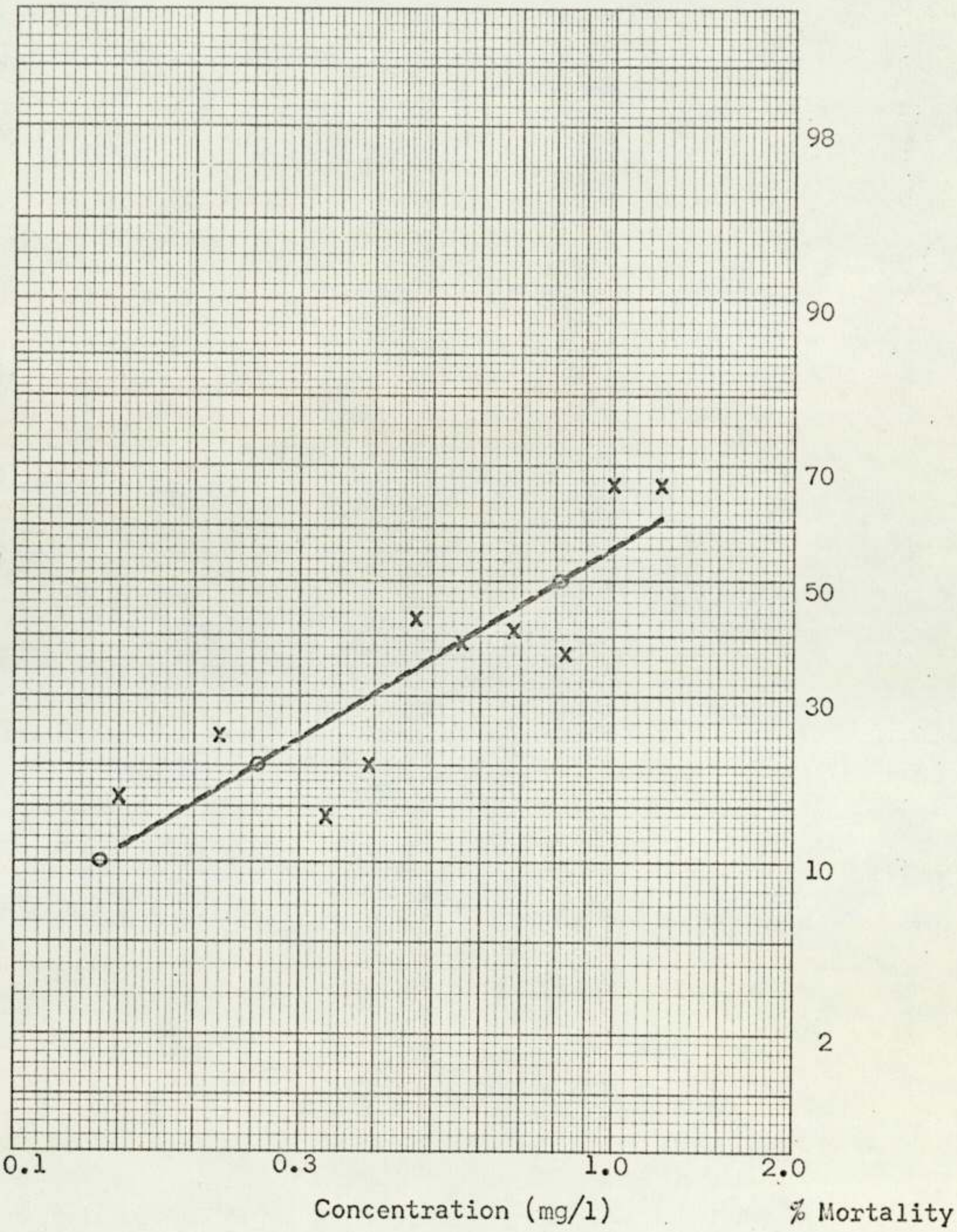
N = 10 chi^2 = 16.23
a = 5.14   SE(a) = 0.09
b = 1.66   SE(b) = 0.35

At 8 D.F. and p = 0.05, t = 2.31 and $*chi^2$ = 15.51

Mortality %	10	20	50	80	90
Probit	3.718	4.158	5.000	5.842	6.282
m	-0.8580	-0.5934	-0.0871	0.4192	0.6838
SE(m)	0.0942	0.0603	0.0453	0.1074	0.1445
m	$\bar{1}.1420$	$\bar{1}.4066$	$\bar{1}.9129$	0.4192	0.6838
Antilog m	0.139	0.255	0.818	2.62	4.82

Due to scatter of experimental results, a significant value of chi^2 obtained at p = 0.05 level. This is unlikely to be greatly reduced by a second cycle of calculations. Confidence limits, have, therefore, not been determined.

48 hour LC50 = 0.82 mg/l cadmium



x observed percentage mortality

---- provisional line

—o— calculated line

Fig. 25. Toxicity of cadmium to Gammarus at 100 hardness for 48 hours

Experiments for 48 hours at a water hardness of 100 mg/l

Table 27. Ammonia: 10 Gammarus/800ml solution/dish. 100 hardness

Mortality after 48 hours

Concentration as mg/l nitrogen

v	n	r	p^1	p	e	Y	w	x	y
Cont	50	0	0	-	-	-	-	-	-
68	50	18	36	36	34	4.6	0.600	1.832	4.64
82	50	30	60	60	53	5.1	0.634	1.914	5.25
100	50	36	72	72	73	5.6	0.559	2.000	5.58
120	50	40	80	80	86	6.1	0.405	2.079	5.80
150	50	49	98	98	95	6.6	0.238	2.176	6.91
180	50	49	98	98	98	7.1	0.110	2.255	7.05
220	50	50	100	100	99	7.3	0.076	2.342	7.68
270	50	50	100	100	-	-	-	-	-

N = 7 chi^2 = 3.02
a = -5.83 SE(a) = 0.07
b = 5.73 SE(b) = 0.51

At 5 D.F. and p = 0.05, t = 2.57 and $*chi^2$ = 11.07

Mortality %	10	20	50	80	90
Probit	3.718	4.158	5.000	5.842	6.282
m	1.6675	1.7443	1.8913	2.0383	2.1151
SE(m)	0.0387	0.0300	0.0173	0.0141	0.0200
Antilog m	46.5	55.5	77.8	109.2	130.3
t.SE(m)	0.0995	0.0771	0.0445	0.0362	0.0514
m + t.SE(m)	1.7670	1.8214	1.9358	2.0745	2.1665
Antilog	58.4	66.3	86.3	118.7	146.8
m - t.SE(m)	1.5680	1.6672	1.8468	2.0021	2.0637
Antilog	37.0	46.5	70.3	100.5	115.8

The ammonium chloride was added to the experimental dishes approximately 17 hours before the start of the experiment. The pH was measured at the beginning of the experiment, and after 24 and 48 hours. The pH value was found to vary from approximately 7.9 to 8.1, with no correlation between pH and ammonium chloride concentration, and a value of 8.0 has therefore been used.

$$\text{Un-ionised or undissociated ammonia concentration} = \frac{\text{Concentration of nitrogen}}{1 + \text{Antilog (pKa - pH)}}$$

At 10°C, pKa = 9.73

For 50% mortality, nitrogen concentration = 77.8 mg/l

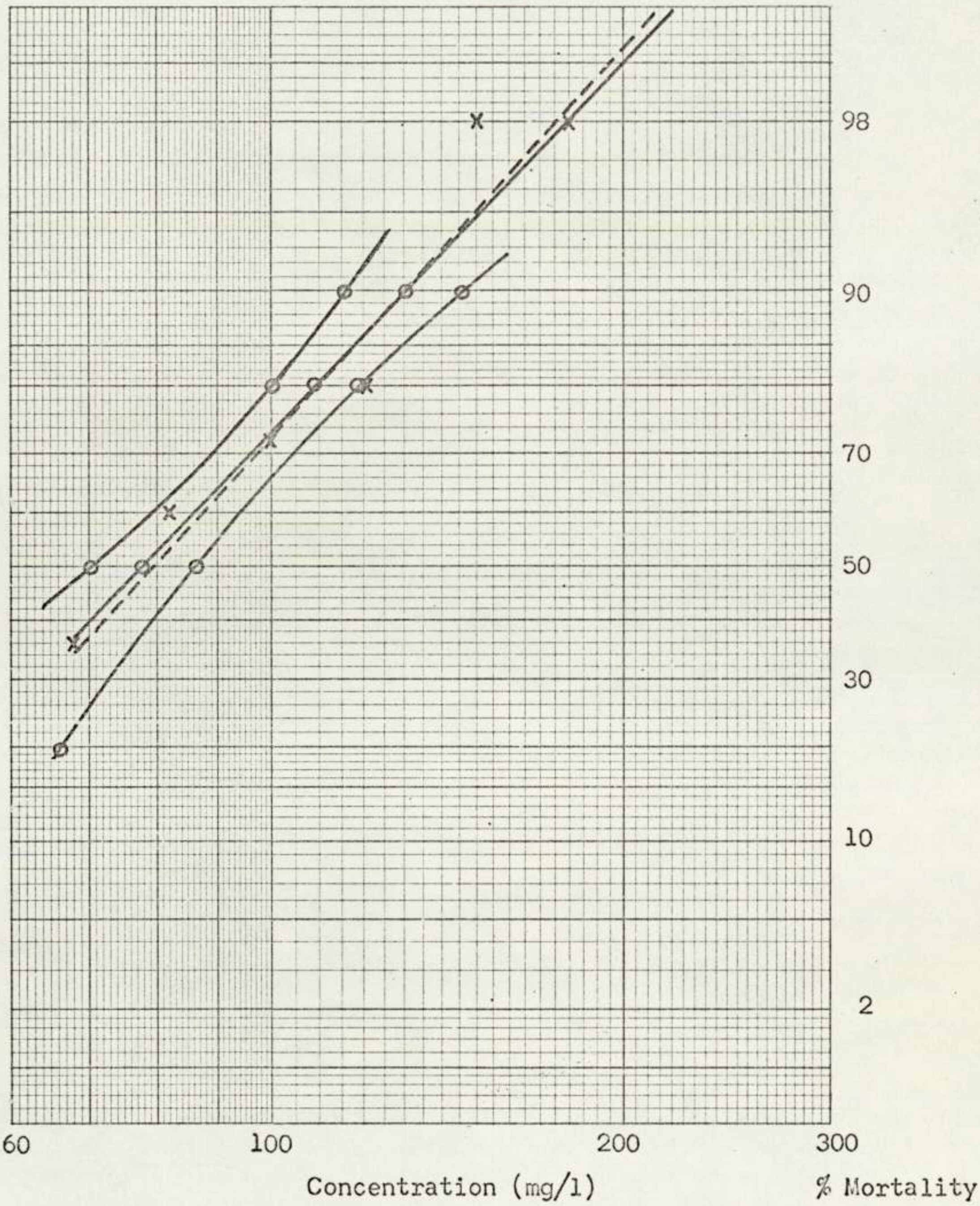
$$\text{Undissociated ammonia} = \frac{77.8}{1 + \text{Antilog } (9.73 - 8.0)}$$

$$= 1.42 \text{ mg/l}$$

Similarly 70.3 and 86.3 mg/l nitrogen equivalent to 1.28 and 1.58 mg/l undissociated ammonia.

48 hour LC50 = 78 (70 - 86) mg/l ammonia (as nitrogen)

or 1.42 (1.28 - 1.58) mg/l undissociated ammonia



x observed percentage mortality

---- provisional line

—o— calculated line and 95% fiducial limits

Fig. 26. Toxicity of ammoniacal nitrogen to Gammarus at 100 hardness for 48 hours

chloride solution was added approximately 17 hours before the start of the experiment to allow the pH to stabilize. The pH values obtained ranged from 7.9 to 8.1, but no correlation between concentration and pH could be observed. By assuming a uniform pH of 8.0 throughout the range, the 48hrLC50 has been expressed in terms of undissociated ammonia. Table 27 includes the necessary calculations, giving a 48hrLC50 value of 1.42 (1.28 - 1.58) mg/l of undissociated ammonia.

Phenol: A total of 50 animals were simultaneously tested at each concentration over the range of from 47 mg/l to 220 mg/l. (Table 67). The mortalities extended from 8% to 90%, well distributed about the 50% level. However, they were very scattered about the provisional straight line (Fig. 27, line 1), so that a very high chi^2 value was obtained in the subsequent analysis. (Table 28). This value, 34.02, was well above the 5% level of 14.07 indicating a very high significant difference from the straight line. The calculated straight line from this was therefore used as a second provisional line. (Fig. 27, line 2). A second cycle of analysis was performed in an attempt at reducing the high chi^2 value. However, the second chi^2 value was 33.05, still well above the 5% level. Because of this, further calculations have not been carried out, and a 48hr LC50 value of 103 mg/l has been obtained from this second set of calculations. The 95% fiducial limits cannot be determined because of the large significant difference.

Cyanide: The toxicity of cyanide was tested between 0.33 mg/l and 1.5 mg/l, with 50 animals at each concentration. (Table 68). This range gave mortalities of between 12% and 100%. (Table 29). In the subsequent analysis, a chi^2 value of 7.68 was obtained, below the 5% level of 11.07. The 95% fiducial limits were calculated and drawn with the straight line in Fig. 28. From this it may be seen that two of the experimental mortalities are outside the 95% limits. The 48hrLC50 and

Experiments for 48 hours at a water hardness of 100 mg/l

Table 28. Phenol: 10 Gammarus/1,000ml solution/dish. 100 hardness

Mortality after 48 hours

v	n	r	p^1	p	e	Y	w	x	y
Cont	50	2	4	-	-	-	-	-	-
47	50	4	8	4	3	3.1	0.063	1.672	3.27
56	50	4	8	4	6	3.4	0.135	1.748	3.27
68	50	5	10	6	14	3.9	0.310	1.832	3.55
82	50	15	30	27	27	4.4	0.484	1.914	4.39
100	50	39	78	77	43	4.8	0.571	2.000	5.69
120	50	40	80	79	60	5.3	0.577	2.079	5.75
150	50	36	72	71	78	5.8	0.477	2.176	5.53
180	50	41	82	81	88	6.2	0.354	2.255	5.81
220	50	45	90	90	95	6.6	0.227	2.342	6.19

N = 9 chi^2 = 34.02
a = -4.38 SE(a) = 0.17
b = 4.67 SE(b) = 1.05

At 7 D.F. and p = 0.05, t = 2.37 and $*chi^2$ = 14.07

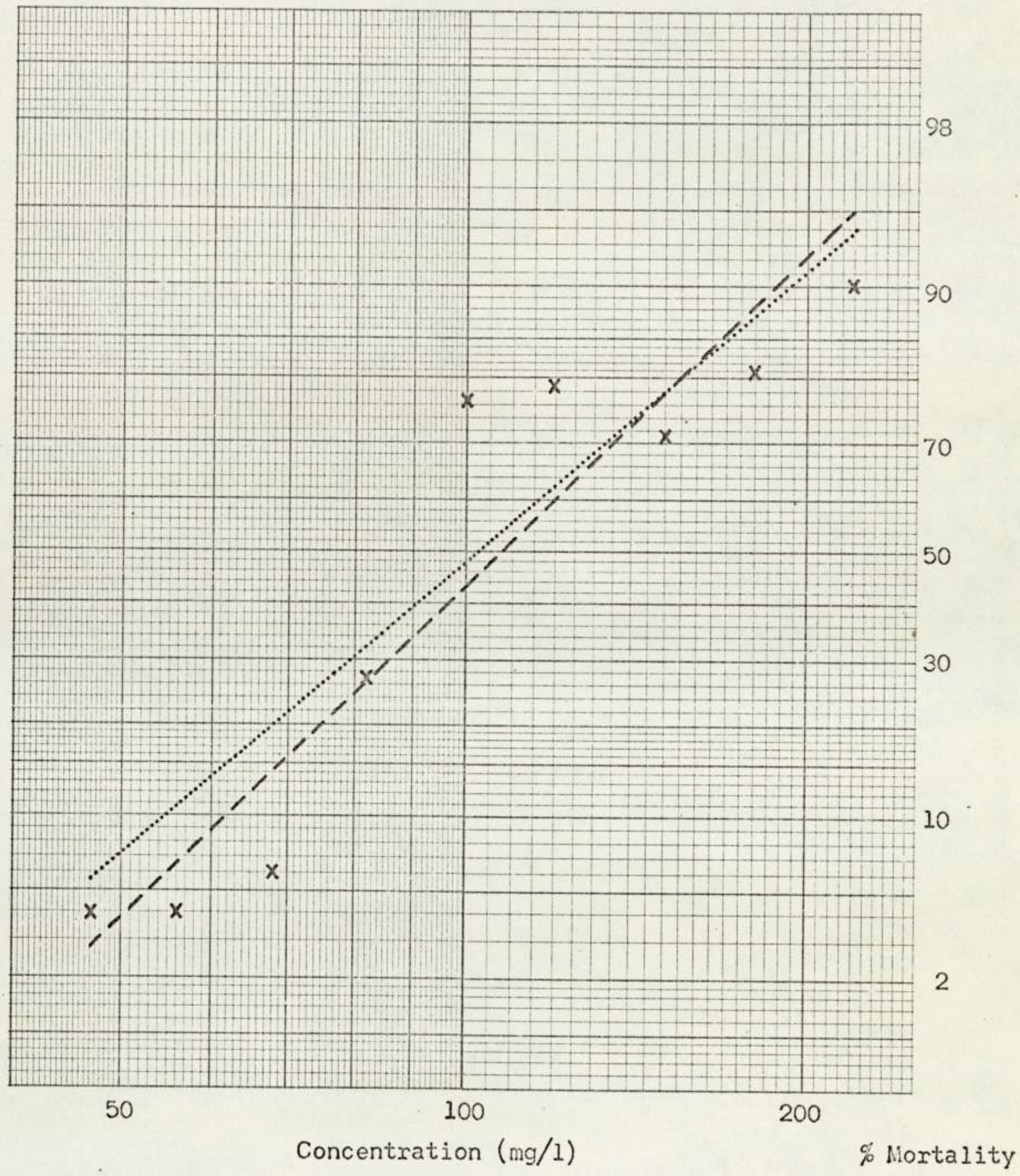
As there is a significant difference in the value of chi^2, a second cycle of calculations has been carried out, using the first set of results as the provisional line for the second cycle.

v	n	r	p^1	p	e	Y	w	x	y
Cont	50	2	4	-	-	-	-	-	-
47	50	4	8	4	5	3.4	0.135	1.672	3.27
56	50	4	8	4	11	3.8	0.272	1.748	3.41
68	50	5	10	6	20	4.2	0.420	1.832	3.68
82	50	15	30	27	32	4.5	0.512	1.914	4.39
100	50	39	78	77	48	4.9	0.582	2.000	5.68
120	50	40	80	79	62	5.3	0.577	2.079	5.75
150	50	36	72	71	78	5.8	0.477	2.176	5.53
180	50	41	82	81	88	6.2	0.354	2.255	5.81
220	50	45	90	90	94	6.6	0.227	2.342	6.19

N = 9 chi^2 = 33.05
a = -4.67 SE(a) = 0.16
b = 4.80 SE(b) = 0.91

A significant value of chi^2 has again been obtained. The 48 hour LC50 has been calculated as 103 mg/l.

48 hour LC50 = 103 mg/l phenol



x observed percentage mortality

---- provisional line (1)

.... provisional line (2)

Fig. 27. Toxicity of phenol to Gammarus at 100 hardness for 48 hours

Experiments for 48 hours at a water hardness of 100 mg/l

Table 29. Cyanide: 10 Gammarus/800ml solution/dish. 100 hardness

Mortality after 48 hours

Concentration as mg/l CN

v	n	r	p^1	p	e	Y	w	x	y
Cont	50	2	4	-	-	-	-	-	-
0.33	50	6	12	8	8	3.6	0.199	-0.481	3.59
0.39	50	13	26	23	18	4.1	0.384	-0.409	4.27
0.47	50	15	30	27	36	4.6	0.536	-0.328	4.40
0.56	50	36	72	71	58	5.2	0.585	-0.252	5.53
0.68	50	38	76	75	78	5.8	0.477	-0.167	5.67
0.82	50	44	88	88	91	6.3	0.321	-0.086	6.16
1.0	50	50	100	100	97	6.9	0.148	0.000	7.34
1.2	50	50	100	100	-	-	-	-	-
1.5	50	50	100	100	-	-	-	-	-

N = 7 chi^2 = 7.68

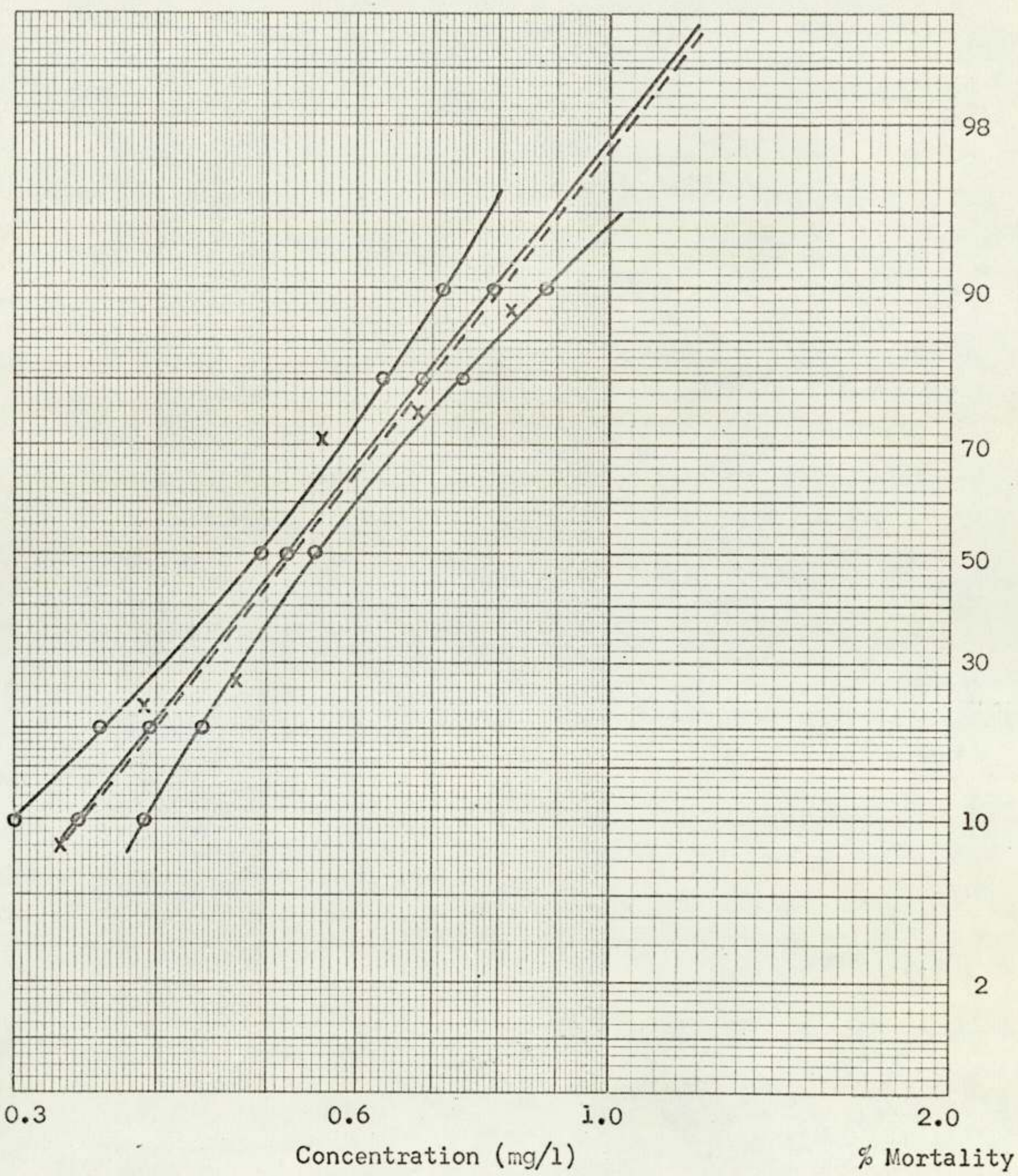
a = 6.98 SE(a) = 0.11

b = 6.99 SE(b) = 0.83

At 5 D.F. and p = 0.05, t = 2.57 and $*chi^2$ = 11.07

Mortality %	10	20	50	80	90
Probit	3.718	4.158	5.000	5.842	6.282
m	-0.4663	-0.4034	-0.2829	-0.1625	-0.0995
SE(m)	0.0223	0.0173	0.0100	0.0141	0.0173
m	$\bar{1}.5337$	$\bar{1}.5966$	$\bar{1}.7171$	$\bar{1}.8375$	$\bar{1}.9005$
Antilog m	0.342	0.395	0.521	0.688	0.795
t.SE(m)	0.0573	0.0445	0.0257	0.0362	0.0445
m + t.SE(m)	$\bar{1}.5910$	$\bar{1}.6411$	$\bar{1}.7428$	$\bar{1}.8737$	$\bar{1}.9450$
Antilog	0.390	0.438	0.553	0.747	0.881
m - t.SE(m)	$\bar{1}.4764$	$\bar{1}.5521$	$\bar{1}.6914$	$\bar{1}.8013$	$\bar{1}.8560$
Antilog	0.299	0.357	0.491	0.633	0.718

48 hour LC50 = 0.52 (0.49 - 0.55) mg/l cyanide



x observed percentage mortality

---- provisional line

—o— calculated line and 95% fiducial limits

Fig. 28. Toxicity of cyanide to Gammarus at 100 hardness for 48 hours

95% limits were calculated as 0.52 (0.49 - 0.55) mg/l.

The results of these nine sets of experiments have been used to determine which toxic substances should be further investigated. From the 48hrLC50 values which were obtained and the recorded concentrations in rivers it is likely that copper (0.58 mg/l), zinc (3.2 mg/l) and chromium (1.3 mg/l) would be the principle toxic metals occurring in the rivers of the area. Cyanide, with a 48hrLC50 of 0.52 mg/l, is obviously toxic, but this toxicity depends on the concentration of free molecular cyanide. (Herbert et al, 1965). Since cyanide readily forms complexes, little free molecular cyanide occurs in natural waters. (Jenkins et al, 1966). Cadmium, having a 48hrLC50 of 0.82 mg/l could be an important toxic substance, but the amount found in rivers is usually very small. However, both cadmium and nickel have been found to exhibit long term toxic effects which are not apparent from 48 hour tests. (Jackson and Brown, 1970). Lead is not likely to be an important toxic substance, as amounts present are usually very small, and any lead in solution would readily precipitate. Ammonia and phenol are not thought likely to cause much mortality, as the quantities found are small compared with their toxicities, measured over a 48 hour period.

Toxicity threshold value for Copper, Zinc and Chromium at 100 mg/l water hardness

From the 48hrLC50 values it was considered worthwhile to determine the toxicity of copper, zinc and chromium in more detail. This was undertaken to determine the threshold values of these metals, as given by the concentration which, when further reduced, would not increase the median survival time. The experiments were examined for mortality at various times, and the results analysed according to the statistical procedure given earlier. (Page 106). The complete results and initial analysis, with the appropriate graphs, are given in Appendix 3, with a summary and subsequent analysis presented below.

Copper: This was tested over a concentration range of from 0.033 mg/l to 6.8 mg/l, examined at intervals up to a period of 600 hours. (Table 69). At the last time, the control mortality had reached nearly 50%, probably due to lack of food and cannibalism. The results of the initial analysis, (Table 69, Fig. 43) are summarised in Table 30. From this the theoretical concentrations necessary to kill 10%, 20% and 50% of the test animals have been plotted against their respective times in Fig. 29. Smooth curves were obtained up to approximately 400 hours. After this the concentrations required to kill the three given percentages drops sharply, especially for the 10% and 20% levels. This indicates an increase in the susceptibility of the animals, which could be a result of the long period of starvation. The 10% and 20% curves have reached their thresholds, the lines having become parallel to the time axis. The 50% line has approached this state, but the change above 400 hours has prevented this from occurring fully. However, a 50% threshold value can be satisfactorily deduced. The three thresholds have been extrapolated as 10%, 0.11 mg/l; 20%, 0.14 mg/l; and 50%, 0.20 mg/l.

Zinc: A wide range of concentrations, from 0.15 mg/l to 33.0 mg/l was used, over a period of 270 hours. In the concentrations of 10.0 mg/l and over, 100% mortality occurred in 48 hours or less, and extended down to 1.5 mg/l at the end of the test. (Table 70, Fig. 44). Control mortality after 270 hours was 22%. In the analysis, high chi^2 values were obtained at 35, 48, 72 and 96 hours, all values exceeding 26.0, at either 6 or 7 degrees of freedom. This indicates a very high significant difference from the theoretical straight line, but the 10%, 20% and 50% mortality concentrations have been calculated. When these are plotted against the observation time, (Fig. 30), they show little deviation from what might be expected. The three lines are parallel to each other for their length, and at the lower concentration end have begun to become asymptotic to the time axis. However, the range of concentrations finished higher than would have been desired at the lower end, preventing conclusive thresholds being obtained. By extending the lines, the thresholds may be estimated as 10%, 0.16 mg/l; 20%, 0.20 mg/l; and 50%, 0.35 mg/l.

Chromium (hexavalent): The experiment with chromium was continued for 96 hours, using a concentration range of 0.15 mg/l to 3.3 mg/l. (Table 71, Fig. 45). At the end of this period, 100% mortality had occurred in the four highest concentrations of 1.0 mg/l and above. The results of the limited number of lower concentrations still available produced a significant difference at the 5% level. (Table 32). The calculated LC10, LC20 and LC50 values at each observation time are plotted in Fig. 31. It is evident that the thresholds have not been reached after 96 hours, but the lines may tentatively be extended. Both the 10% and 20% lines will obviously extend to below 0.2 mg/l, and it is suggested they reach down to 0.1 mg/l. The 50% threshold could have a maximum of 0.15 mg/l, but could also extend towards the 0.1 mg/l level.

These three experiments at 100 mg/l hardness may be compared with the results of those examined only after 48 hours. From the three graphs, Figs. 29, 30 and 31, the 48hrLC50 values can be extracted, and are, respectively, copper, 0.72 mg/l; zinc, 2.4 mg/l; and chromium 1.6 mg/l. These differ from the values of 0.58 mg/l, 3.2 mg/l and 1.3 mg/l obtained in the earlier experiments, but by an amount not greater than 25%. This difference is therefore not thought significant. It is likely that the results of the second set of experiments are more correct, in view of the greater number of observations which were made.

Experiments for over 48 hours at a water hardness of 100 mg/l

Table 30. Copper: 15 Gammarus/800ml solution/dish. 100 hardness

Time (hrs)	N	chi^2	a	SE(a)	b	SE(b)	Conc (mg/l) for % mortality 10	20	50	80	90
7	6	2.39	2.69	0.08	2.15	0.37	3.02	4.84	12.0	29.5	47.3
13	10	4.06	3.99	0.05	1.68	0.13	0.69	1.26	4.00	12.7	23.1
24	12	5.07	4.74	0.04	1.67	0.09	0.24	0.45	1.43	4.59	8.43
35	14	7.11	5.03	0.04	1.80	0.09	0.19	0.33	0.97	2.83	4.97
48	14	9.58	5.22	0.06	1.96	0.10	0.17	0.29	0.78	2.09	3.51
72	14	11.42	5.59	0.07	2.31	0.15	0.15	0.24	0.55	1.28	2.00
96	12	16.63	5.82	0.10	2.35	0.25	0.13	0.19	0.45	1.02	1.57
127	11	6.85	6.38	0.07	2.95	0.20	0.12	0.17	0.34	0.66	0.92
168	10	3.25	6.66	0.06	3.21	0.17	0.12	0.17	0.30	0.56	0.77
218	10	7.69	6.89	0.09	3.27	0.30	0.11	0.15	0.26	0.48	0.65
242	10	3.89	7.10	0.07	3.67	0.26	0.12	0.16	0.27	0.45	0.60
272	8	5.82	7.26	0.11	3.80	0.48	0.12	0.15	0.25	0.42	0.55
336	8	4.15	7.56	0.10	4.01	0.42	0.11	0.14	0.23	0.37	0.48
415	8	3.30	7.91	0.10	4.63	0.48	0.12	0.15	0.23	0.36	0.44
510	9	7.39	7.41	0.14	3.24	0.53	0.07	0.09	0.18	0.33	0.45
600	8	6.05	7.85	0.15	3.77	0.61	0.08	0.10	0.17	0.29	0.38

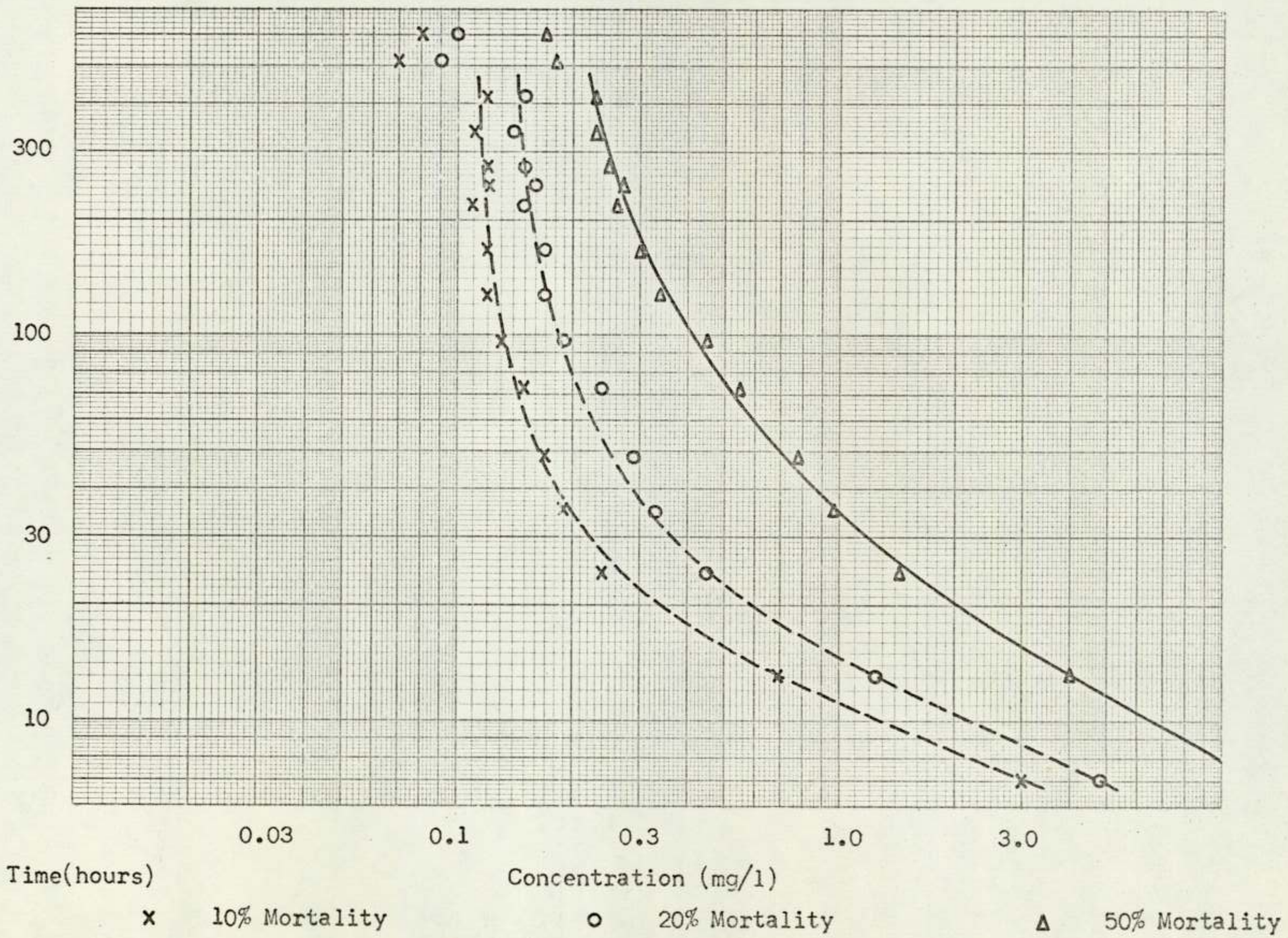


Fig. 29. Toxicity of copper to Gammarus at 100 hardness

Table 31. Zinc: 15 Gammarus/800ml solution/dish. 100 hardness

Time (hrs)	N	chi^2	a	SE(a)	b	SE(b)	Conc (mg/l) for % mortality 10	20	50	80	90
8	5	1.52	0.08	0.07	3.36	0.37	12.1	16.4	29.2	52.0	70.4
13	7	12.09	0.92	0.14	3.68	0.57	5.78	7.61	12.9	21.8	28.8
24	8	10.62	1.93	0.12	3.93	0.42	2.86	3.70	6.05	9.92	12.8
35	8	33.38	3.06	0.21	3.17	0.74	1.62	2.23	4.11	7.58	10.4
48	8	32.84	3.64	0.20	2.94	0.73	1.06	1.49	2.89	5.58	7.88
72	9	31.00	4.52	0.20	3.48	0.71	0.59	0.79	1.37	2.39	3.20
96	8	26.33	4.90	0.20	4.13	0.74	0.52	0.66	1.05	1.69	2.16
128	8	8.06	5.32	0.11	4.01	0.44	0.40	0.51	0.83	1.35	1.74
168	8	8.65	5.85	0.13	3.81	0.53	0.27	0.36	0.60	0.99	1.30
200	8	6.98	5.98	0.12	3.96	0.50	0.27	0.35	0.56	0.92	1.19
240	7	5.54	6.18	0.12	3.91	0.54	0.23	0.30	0.50	0.82	1.06
270	7	3.19	6.34	0.09	4.05	0.42	0.22	0.29	0.47	0.75	0.97

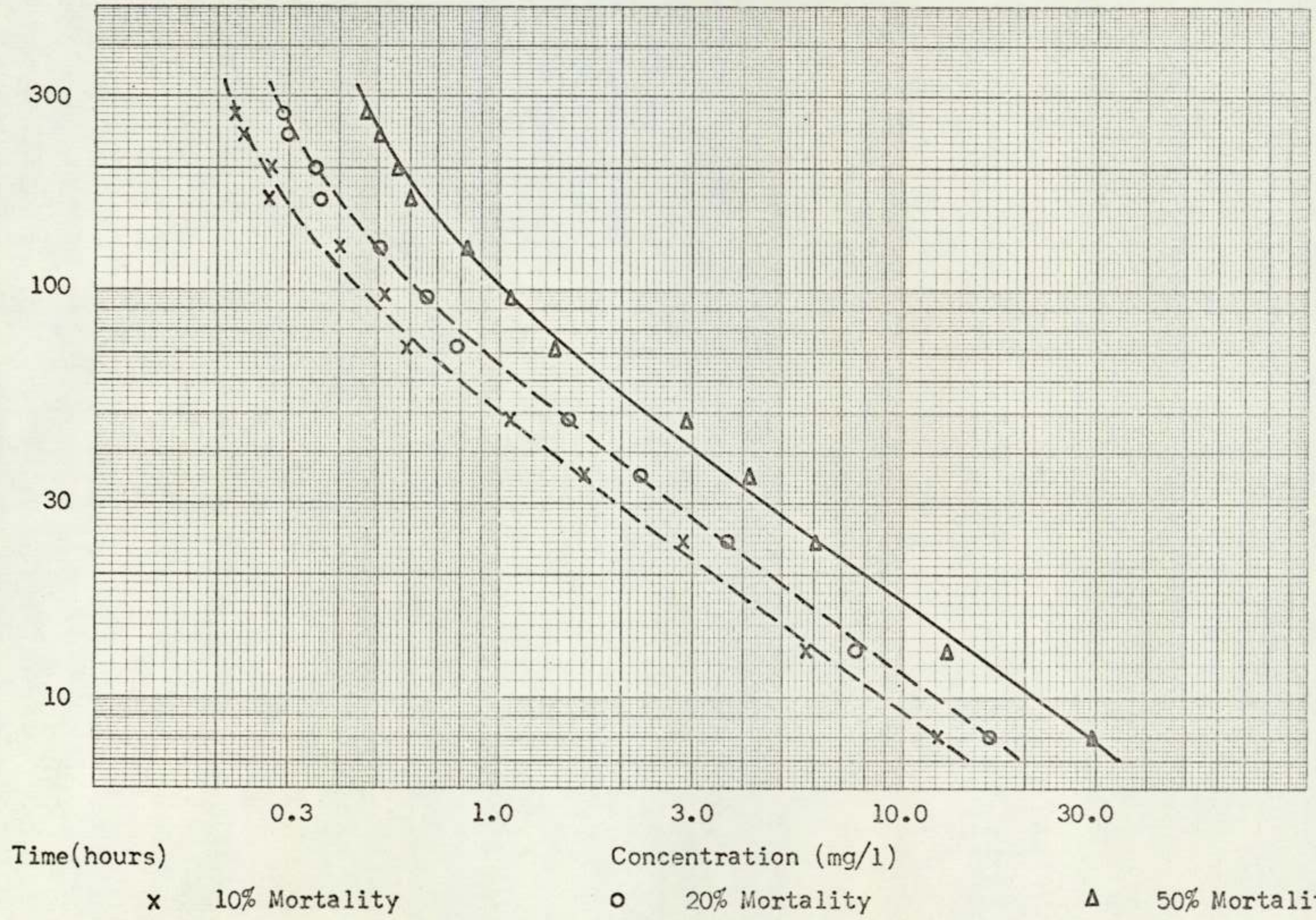


Fig. 30. Toxicity of zinc to Gammarus at 100 hardness

Table 32. Chromium: 15 Gammarus/800ml solution/dish. 100 hardness

Time (hrs)	N	chi^2	a	SE(a)	b	SE(b)	Conc (mg/l) for % mortality 10	20	50	80	90
21	8	5.87	3.08	0.13	0.95	0.36	4.71	13.6	104	-	-
34	9	2.30	3.68	0.05	1.37	0.14	1.06	2.22	9.20	37.9	79.5
48	8	6.69	4.43	0.09	2.40	0.31	0.50	0.77	1.73	3.88	5.93
72	6	3.15	6.35	0.09	5.41	0.48	0.33	0.39	0.56	0.80	0.97
96	6	11.77	7.82	0.20	6.36	1.11	0.23	0.26	0.36	0.49	0.57

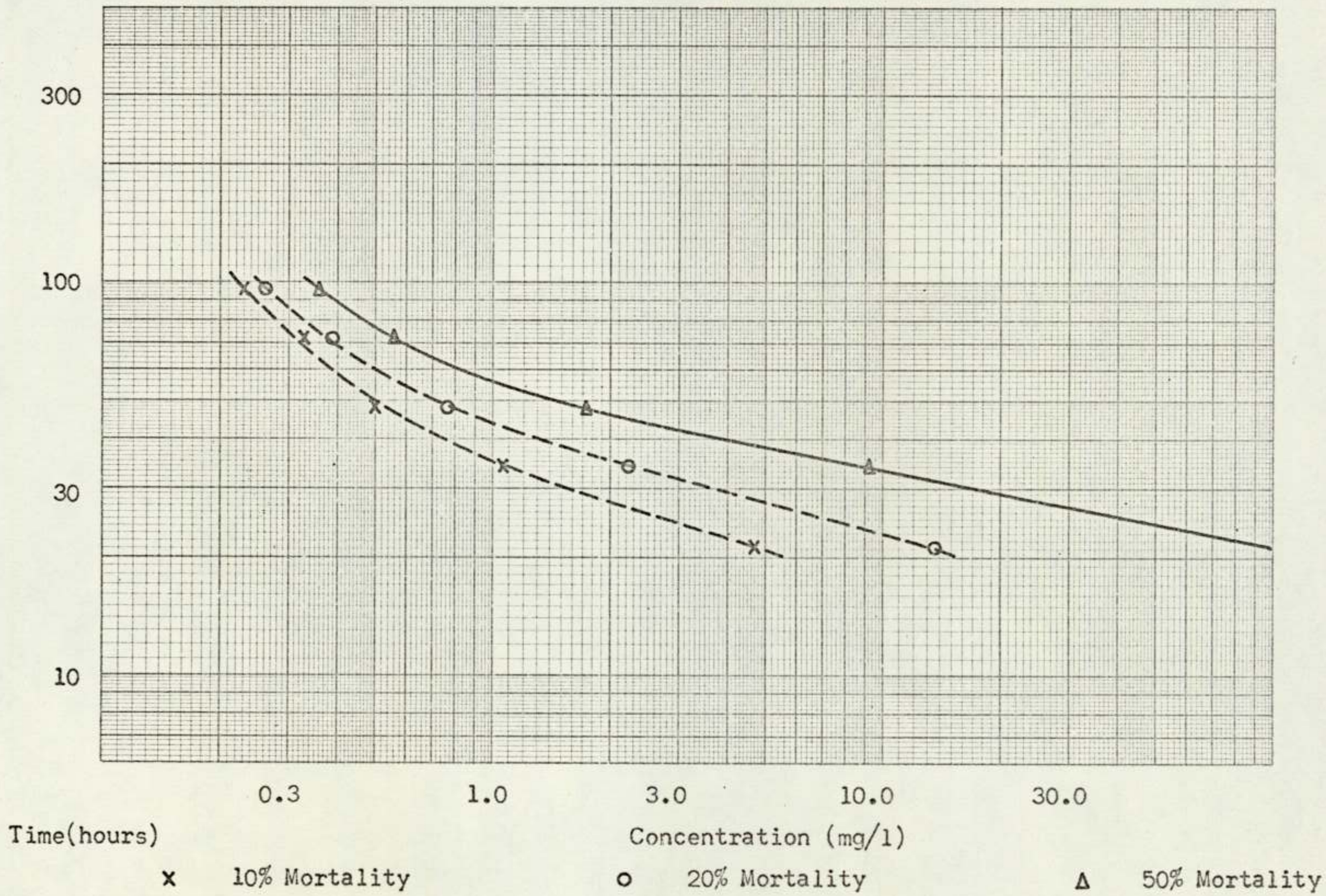


Fig. 31. Toxicity of chromium to Gammarus at 100 hardness

Effect of hardness on the toxicity of Copper, Zinc and Chromium

The toxicity of metals is affected by the hardness of the solution. The rivers of the area are always harder than the 100 mg/l used in the previous experiments, and overall had a mean hardness of approximately 375 mg/l (Table 10). Because of this, the toxicity of metals in the rivers is unlikely to be as high as determined in the experiments at 100 mg/l hardness. Three experiments, with copper, zinc and chromium, each at 100, 200 and 400 mg/l hardness were performed in order to discover the effect of hardness on the toxicity of these metals. In order that approximately equal mortalities should occur at each hardness, it was necessary to use higher concentration ranges in the harder waters, than in the softer water of 100 mg/l hardness.

Copper: All the experimental results are given in Table 33, where it may be seen that at each hardness, four concentrations were used from the range 0.27 mg/l to 4.7 mg/l. Only small mortalities occurred at 400 mg/l hardness until 96 hours, the end of the experiment. The 96 hour mortalities for each hardness have been plotted in Fig. 32. This shows the large difference in copper concentration necessary to kill 50% of the animals at the three hardnesses. By increasing the hardness from 100 mg/l to 400 mg/l, it has been necessary to increase the copper concentration from 0.3 mg/l to 3.0 mg/l, a factor of ten.

Zinc: Table 34 gives the results of the test with zinc at the three hardnesses. The zinc concentration ranged from 1.5 mg/l to 10.0 mg/l. After 48 hours, each hardness had a mortality of at least 50% in the highest concentrations. However, to maintain uniformity, the 96 hour mortalities have been plotted in Fig. 32. This has given lines which are all between 50% and 100% mortality. It is obvious from Fig. 32 that the effect of differences in hardness on zinc is much less than that on copper, as the three lines are much closer together. The 96hrLC50

Table 33. Copper: Effect of hardness. 15 Gammarus/800ml solution/dish. Mortality and percentage dead at given times

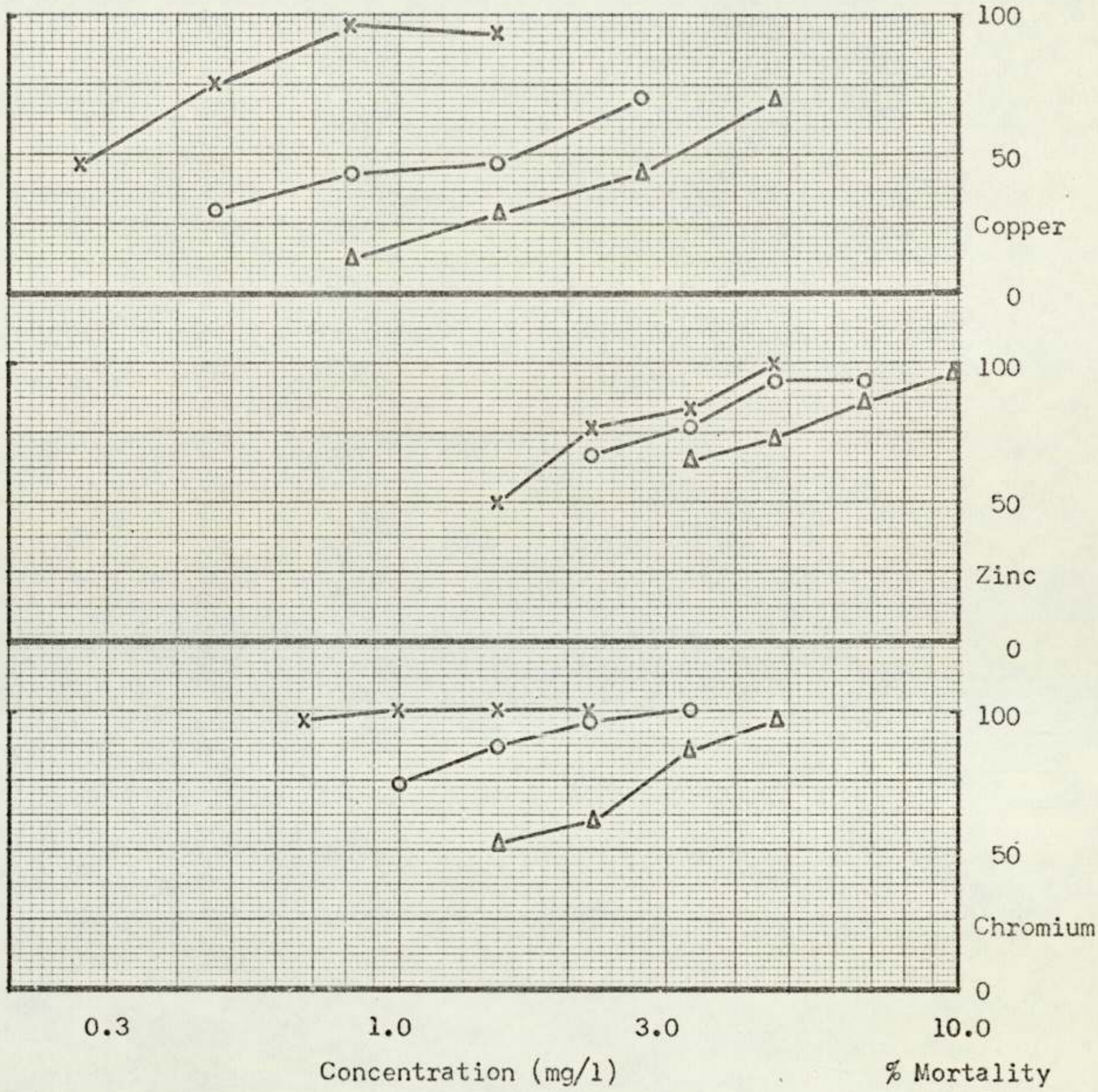
	Time (hrs)	12				22				34				48				72				96			
Hardness	Conc(mg/1)	No	No	Tot	%	No	No	Tot	%	No	No	Tot	%	No	No	Tot	%	No	No	Tot	%	No	No	Tot	%
100	Control	0	0	0	0	0	0	0	0	0	1	1	3	0	1	1	3	0	1	1	3	0	1	1	3
100	0.27	1	1	2	7	4	5	9	30	4	5	9	30	5	7	12	40	5	8	13	43	6	8	14	47
100	0.47	7	4	11	37	13	7	20	67	13	8	21	70	14	8	22	73	14	9	23	77	14	9	23	77
100	0.82	8	10	18	60	10	10	20	67	12	10	22	73	12	11	23	77	14	14	28	93	15	14	29	97
100	1.5	9	9	18	60	10	11	21	70	12	14	26	87	12	15	27	90	13	15	28	93	13	15	28	93
200	Control	0	0	0	0	0	0	0	0	1	0	1	3	1	0	1	3	1	0	1	3	1	0	1	3
200	0.47	0	0	0	0	1	0	1	3	2	1	3	10	2	2	4	13	4	2	6	20	6	3	9	30
200	0.82	0	0	0	0	5	2	7	23	5	3	8	27	5	5	10	33	7	5	12	40	7	6	13	43
200	1.5	1	1	2	7	3	1	4	13	4	2	6	20	7	5	12	40	7	6	13	43	7	7	14	47
200	2.7	0	0	0	0	2	1	3	10	3	2	5	17	6	5	11	37	7	8	15	50	9	9	18	60
400	Control	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
400	0.82	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	4	13
400	1.5	0	0	0	0	1	0	1	3	1	0	1	3	1	1	2	7	1	1	2	7	5	4	9	30
400	2.7	0	1	1	3	0	1	1	3	2	2	4	13	2	2	4	13	3	3	6	20	7	6	13	43
400	4.7	0	0	0	0	0	0	0	0	0	1	1	3	2	2	4	13	6	7	13	43	12	9	21	70

Table 34. Zinc: Effect of hardness. 15 Gammarus/800ml solution/dish. Mortality and percentage dead at given times

	Time (hrs)	10				22				33				48				70				96			
Hardness	Conc(mg/l)	No	No	Tot	%	No	No	Tot	%	No	No	Tot	%	No	No	Tot	%	No	No	Tot	%	No	No	Tot	%
100	Control	0	0	0	0	0	1	1	3	0	1	1	3	0	1	1	3	0	1	1	3	1	1	2	7
100	1.5	0	0	0	0	0	0	0	0	0	1	1	3	2	3	5	17	2	5	7	23	7	8	15	50
100	2.2	0	0	0	0	0	0	0	0	0	0	0	0	4	0	4	13	6	8	14	47	11	12	23	77
100	3.3	0	0	0	0	0	0	0	0	3	3	6	20	5	5	10	33	10	9	19	63	15	10	25	83
100	4.7	1	2	3	10	6	3	9	30	8	6	14	47	11	10	21	70	14	14	28	93	15	15	30	100
200	Control	0	0	0	0	0	1	1	3	0	1	1	3	1	1	2	7	1	1	2	7	1	1	2	7
200	2.2	0	0	0	0	0	0	0	0	2	0	2	7	4	3	7	23	8	3	11	37	11	9	20	67
200	3.3	0	0	0	0	1	0	1	3	3	1	4	13	6	3	9	30	10	8	18	60	11	12	23	77
200	4.7	0	0	0	0	3	3	6	20	7	5	12	40	8	10	18	60	11	15	26	87	13	15	28	93
200	6.8	0	0	0	0	6	1	7	23	10	7	17	57	13	10	23	77	14	14	28	93	14	14	28	93
400	Control	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	3
400	3.3	0	0	0	0	2	1	3	10	5	1	6	20	8	4	12	40	11	8	19	63	11	9	20	67
400	4.7	0	0	0	0	2	3	5	17	5	7	12	40	8	10	18	60	11	11	22	73	11	11	22	73
400	6.8	0	0	0	0	1	3	4	13	5	6	11	37	11	10	21	70	14	11	25	83	14	12	26	87
400	10.0	0	0	0	0	3	2	5	17	8	6	14	47	13	11	24	80	15	14	29	97	15	14	29	97

Table 35. Chromium: Effect of hardness. 15 Gammarus/800ml solution/dish. Mortality and percentage dead at given times

	Time (hrs)	12				22				35				48				72				96			
Hardness	Conc(mg/1)	No	No	Tot	%	No	No	Tot	%	No	No	Tot	%	No	No	Tot	%	No	No	Tot	%	No	No	Tot	%
100	Control	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	3	1	0	1	3
100	0.68	0	0	0	0	0	1	1	3	0	1	1	3	1	3	4	13	9	10	19	63	14	15	29	97
100	1.0	0	0	0	0	0	0	0	0	0	2	2	7	2	3	5	17	11	15	26	87	15	15	30	100
100	1.5	0	0	0	0	1	0	1	3	2	0	2	7	8	4	12	40	15	15	30	100	15	15	30	100
100	2.2	0	0	0	0	0	0	0	0	1	2	3	10	9	4	13	43	15	15	30	100	15	15	30	100
200	Control	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
200	1.0	0	0	0	0	0	1	1	3	0	1	1	3	1	1	2	7	8	6	14	47	10	12	22	73
200	1.5	0	0	0	0	1	0	1	3	1	0	1	3	2	0	2	7	11	7	18	60	13	13	26	87
200	2.2	0	0	0	0	0	1	1	3	0	1	1	3	2	6	8	27	11	13	24	80	14	15	29	97
200	3.3	0	0	0	0	0	0	0	0	0	1	1	3	2	2	4	13	14	14	28	93	15	15	30	100
400	Control	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	3
400	1.5	0	0	0	0	0	0	0	0	0	2	2	7	0	4	4	13	1	6	7	13	6	10	16	53
400	2.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	2	6	20	11	9	20	67
400	3.3	0	0	0	0	0	0	0	0	1	0	1	3	1	2	3	10	7	7	14	47	14	12	26	87
400	4.7	0	0	0	0	0	0	0	0	0	2	2	7	1	5	6	20	12	13	55	83	14	15	29	97



x 100 hardness o 200 hardness Δ 400 hardness

Water hardness expressed as equivalent concentration of calcium carbonate, mg/l.

Fig. 32. Effect of water hardness on toxicity of copper, zinc and chromium to Gammarus after 96 hours

values are approximately 1.5 mg/l and 3.0 mg/l at 100 mg/l and 400 mg/l water hardness respectively, a factor of only two.

Chromium (hexavalent): The range of concentrations chosen, 0.68 mg/l to 4.7 mg/l was somewhat higher than desirable. (Table 35). This has produced 100% mortality in three of the four concentrations at 100 mg/l hardness after 96 hours, and over 50% in all concentrations at 200 mg/l and 400 mg/l hardness. Although no 96hrLC50 values can be obtained, it is apparent from Fig. 32 that the hardness has a large effect on the toxicity of chromium. At 1.5 mg/l, increasing the hardness from 100 mg/l to 400 mg/l has resulted in the mortality decreasing from 100% to approximately 50%.

From these three experiments, it is evident that differences in hardness will produce differences in the toxicity of the tested metals. This is greater with copper and chromium than with zinc, where the 48hrLC50 value will be changed less by alteration in the water hardness than with the two former metals. In the field these changes will be important, as less metal will be necessary to render the water as toxic under soft water conditions as under hard water conditions.

As the rivers have a water hardness usually within the range of 250 mg/l to 400 mg/l, the results of the experiments at 100 mg/l hardness could not be used directly in estimating the toxicity of river water. Experiments have therefore been carried out at hardnesses more suitable for this purpose.

Toxicity threshold values for Copper, Zinc, Chromium and Nickel at 300 mg/l water hardness

To determine the thresholds of copper, zinc, chromium and nickel at 300 mg/l water hardness, experiments similar to those at 100 mg/l water hardness were undertaken. The experiments were continued for up to 336 hours, a time which should not produce anomalous results due to long periods of starvation.

Copper: Concentrations of from 0.15 mg/l to 10.0 mg/l were examined for up to 336 hours. At this last time, the six highest concentrations each had 100% mortality (Table 72, Fig. 46). A summary of the analysis of the results is given in Table 36, while Fig. 33 relates concentration to survival time. The threshold values have been reached, and are 10%, 0.31 mg/l; 20%, 0.39 mg/l, and 50% 0.55 mg/l. The 48hrLC50 value has been extrapolated as 4.4 mg/l.

Zinc: This experiment was discontinued when the control mortality reached 31% at 216 hours. (Table 73, Fig. 47). The concentrations ranged from 0.033 mg/l to 6.8 mg/l. Table 37 summarises the analysis of results, and this data is plotted in Fig. 34. Because of the shorter time, the thresholds have not been fully reached, but estimates can be made. With values of 10%, 0.34 mg/l; 20%, approximately 0.4 mg/l, and 50%, approximately 0.5 mg/l, the toxicity of zinc is very similar to that of copper at this hardness. This is supported by the 48hrLC50 value of 5.7 mg/l.

Chromium (hexavalent): With a control mortality only reaching 24% after 330 hours, this experiment was continued for a similar period to that with copper. (Table 74, Fig. 48). The solutions tested ranged from 0.22 mg/l to 10.0 mg/l. The analysis results, summarised in Table 38, are plotted in Fig. 35. Although the thresholds have not been reached, good indications of these are obtainable, and have been taken as 10%, 0.10 mg/l; 20%, 0.16 mg/l, and 50%, 0.30 mg/l. The 48hrLC50 value was obtained from Fig. 35 as 4.8 mg/l.

Nickel: This metal was not tested for over 48 hours at 100 mg/l water hardness, but has been included with the three other metals at 300 mg/l. A much higher range of concentrations, from 4.7 mg/l to 220 mg/l, was

Experiments for over 48 hours at a water hardness of 300 mg/l

Table 36. Copper: 15 Gammarus/800ml solution/dish. 300 hardness

Time (hrs)	N	chi^2	a	SE(a)	b	SE(b)	Conc (mg/l) for % mortality 10	20	50
34	11	2.91	3.61	0.04	1.22	0.09	1.21	2.77	13.5
46	11	9.28	3.80	0.07	1.76	0.17	0.90	1.61	4.84
70	11	4.53	4.32	0.05	1.98	0.11	0.50	0.83	2.14
142	8	6.24	5.43	0.09	3.76	0.35	0.35	0.46	0.77
336	7	8.16	6.09	0.15	4.67	0.75	0.31	0.39	0.58

Table 37. Zinc: 15 Gammarus/800ml solution/dish. 300 hardness

Time (hrs)	N	chi^2	a	SE(a)	b	SE(b)	Conc (mg/l) for % mortality 10	20	50
34	8	7.78	3.36	0.10	1.08	0.29	2.14	5.44	32.5
50	9	13.48	3.90	0.11	1.61	0.30	0.77	1.45	4.84
70	9	3.73	4.23	0.06	1.97	0.16	0.55	0.91	2.45
100	9	5.29	4.60	0.08	2.49	0.24	0.44	0.66	1.45
145	9	3.58	5.11	0.07	3.26	0.22	0.37	0.51	0.92
216	6	2.13	5.62	0.10	4.18	0.50	0.35	0.45	0.71

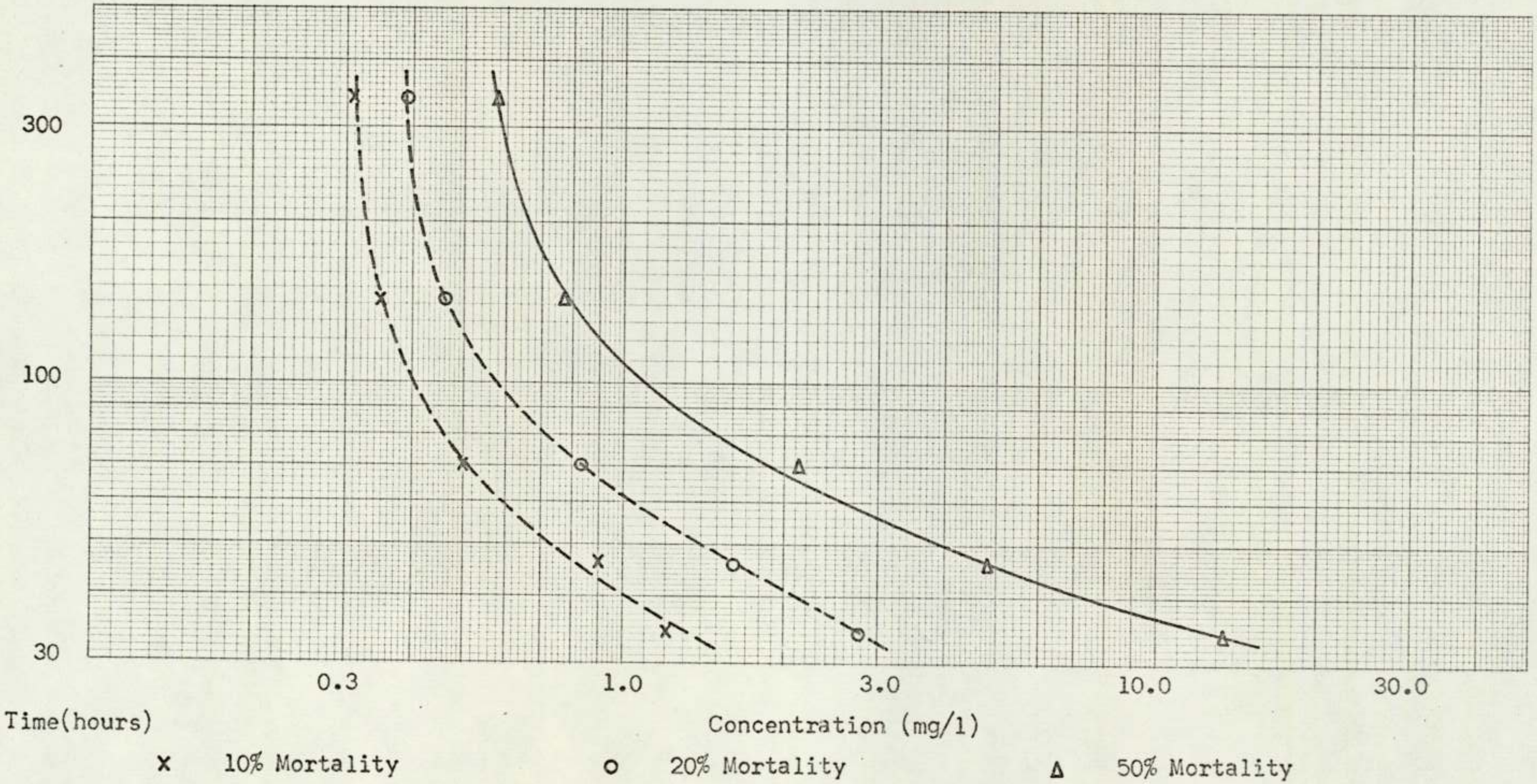


Fig. 33. Toxicity of copper to Gammarus at 300 hardness

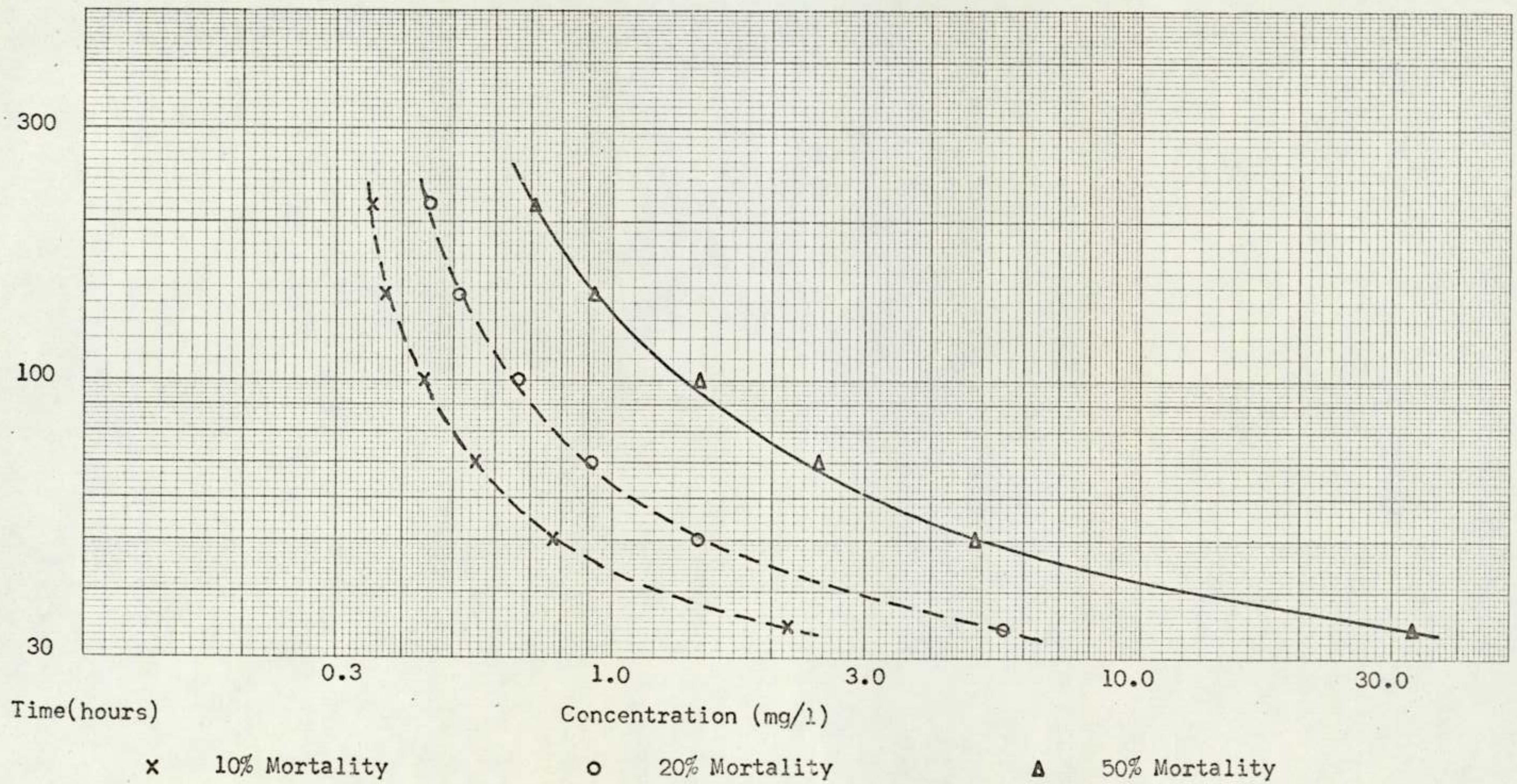


Fig. 34. Toxicity of zinc to Gammarus at 300 hardness

Table 38. Chromium: 15 Gammarus/800ml solution/dish. 300 hardness

Time (hrs)	N	chi^2	a	SE(a)	b	SE(b)	Conc (mg/l) for % Mortality 10	20	50
30	11	7.89	3.37	0.07	0.97	0.17	2.27	6.41	47.0
48	11	8.92	3.83	0.07	1.71	0.20	0.86	1.55	4.82
72	10	8.18	4.72	0.07	2.33	0.20	0.37	0.58	1.32
96	10	4.15	5.11	0.06	2.54	0.15	0.28	0.42	0.90
142	8	6.39	5.61	0.09	2.80	0.28	0.21	0.30	0.60
213	7	7.08	5.82	0.12	2.76	0.42	0.17	0.25	0.50
330	7	3.27	6.23	0.09	2.86	0.34	0.13	0.19	0.37

Table 39. Nickel: 15 Gammarus/800ml solution/dish. 300 hardness

Results extrapolated from straight line graphs

Time (hrs)	Conc (mg/l) for % mortality 10	20	50
96	98	137	260
165	37	48	80
237	9	13	27

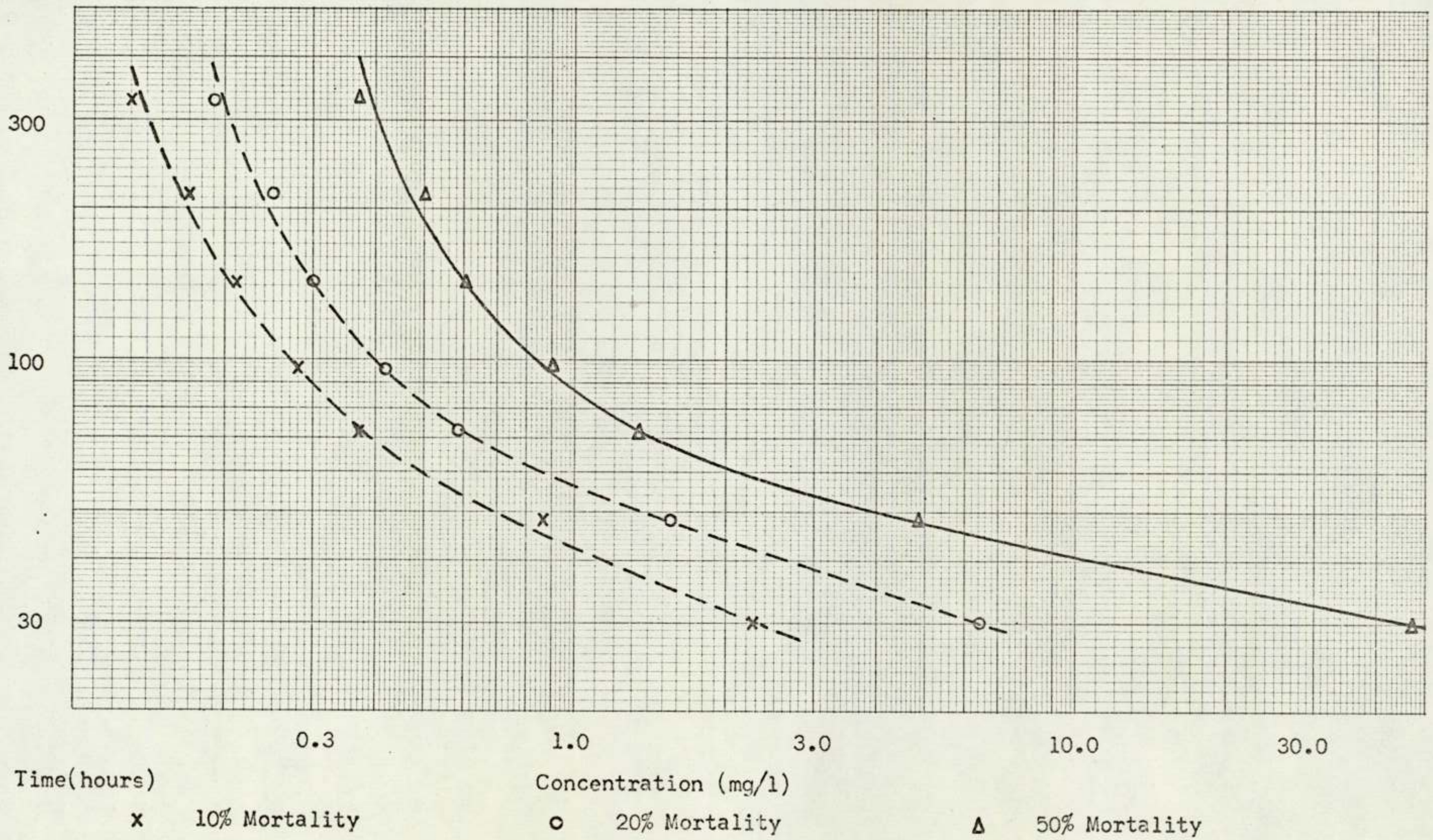


Fig. 35. Toxicity of chromium to Gammarus at 300 hardness

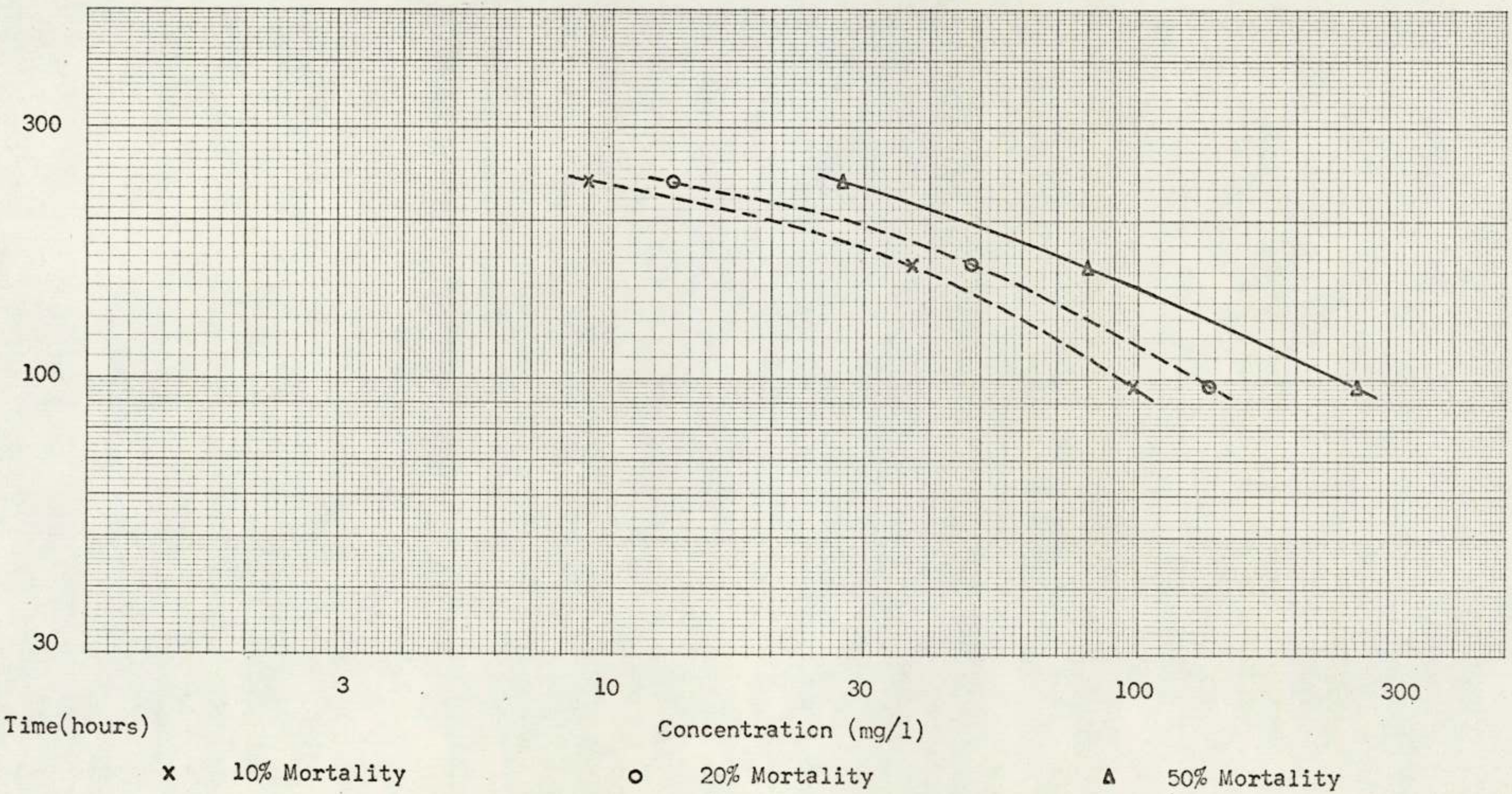


Fig. 36. Toxicity of nickel to Gammarus at 300 hardness

necessary, compared with a maximum of 10.0 mg/l for the other three metals. Unfortunately the control mortality reached 27% after only 237 hours. (Table 75, Fig. 49). Because of the low toxicity of nickel over short periods, some difficulty was found with the analysis of the results. Only the times of 95, 165 and 237 hours produced usable lines, and the concentrations necessary to kill 10%, 20% and 50% have been extrapolated directly from these. (Table 39). No statistical analysis as applied to the other metals has been possible. With this limited amount of data, Fig. 36 has been drawn. Instead of the line turning upwards at the lower concentration end, it has turned downwards. Jackson and Brown (1970) obtained a similar curve with rainbow trout, which flattened out after approximately 8 days for 50% mortality, before turning upwards at lower concentrations.

The four experiments at 300 mg/l water hardness have confirmed that differences occur in the toxicity of these metals at different hardnesses. The toxicities of copper and zinc are very similar at 300 mg/l hardness, differing from those obtained at 100 mg/l hardness, where copper was more toxic than zinc.

The 96hrLC50 values obtained from the experiment with copper at different water hardnesses (Fig. 32) were 0.3 mg/l at 100 mg/l hardness and 3.0 mg/l at 400 mg/l. By extrapolating a figure of approximately 2.0 mg/l for 300 mg/l hardness, a factor of approximately 7 is obtained for the differences in the LC50 values at 300 mg/l and 100 mg/l water hardness. Similar methods for zinc give 1.5 mg/l and 2.5 mg/l, a factor of approximately 1.7. Assuming that these two factors will also apply at 48 hours, the toxicities of copper and zinc at 300 mg/l water hardness can be calculated from the 48hrLC50 values at 100 mg/l hardness. From the values of copper, 0.72 mg/l and zinc, 2.4 mg/l, 48hrLC50 values at 300 mg/l water hardness can be estimated for copper as 5.0 mg/l and for zinc as 4.1 mg/l. These estimates compare favourably with the experimental values of 4.4 mg/l and 5.7 mg/l obtained at 300 mg/l water hardness. Chromium does not respond to this treatment so easily, as no good factor can be obtained from the experiment at different hardnesses. From the 48hrLC50 values obtained experimentally at 100 mg/l and 300 mg/l, namely 1.6 mg/l and 4.8 mg/l respectively, a factor of 3 can be calculated. This is less than would be expected from Fig. 32, where the plotted lines are similar to those for copper.

These results show that copper is the most affected by changes in hardness, followed by chromium, with zinc the least affected of the three metals tested.

Long-term toxic effect of Nickel at 200 mg/l water hardness

This experiment differed from all others, in that it was designed to determine the long term toxic effect of nickel. The apparatus used was perspex troughs, with recirculation of the test solution (Fig. 18). Nickel does not readily form insoluble compounds with substances found in natural waters, and therefore adding food to the test solutions is unlikely to have greatly affected the amounts of soluble nickel. In the control tank, mortality was reduced to approximately 25% of the mortality of the previous experiments where no food was provided. A mortality of 50% did not occur until 93 days (Fig. 50), as compared to 25 days (600 hours) in the experiment with copper at 100 mg/l water hardness. Table 76 gives the observation times and mortality of the present experiment. These figures have been corrected for the extrapolated control mortality, and plotted in Fig. 50. From this, the times necessary to kill 10% and 50% have been extrapolated for each test concentration, and plotted in Fig. 37.

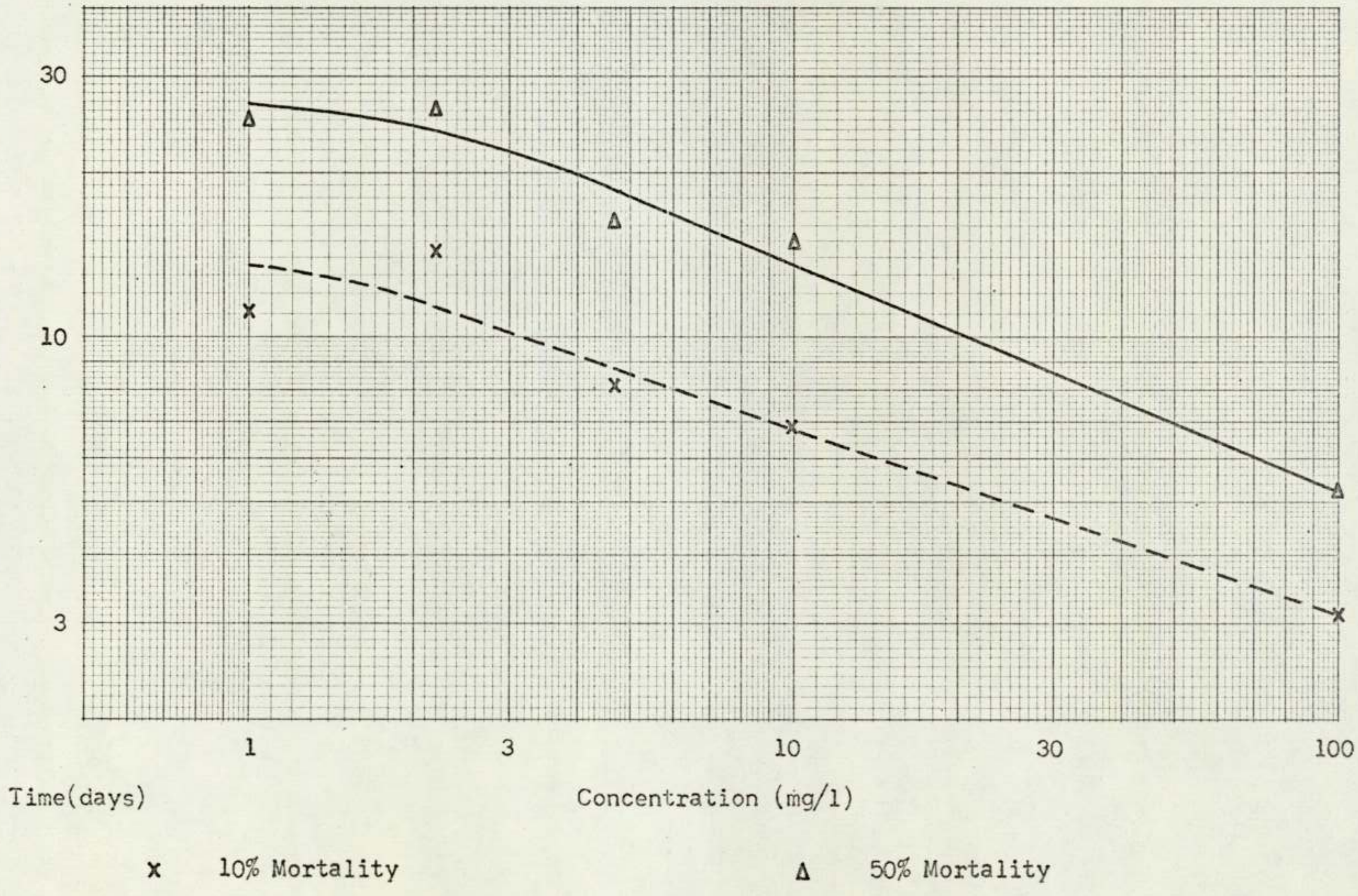


Fig. 37. Toxicity of nickel to Gammarus at 200 hardness

Table 40. Toxicity of nickel at 200 mg/l water hardness

Concentration (mg/l)	Time (days) 10% Mortality	50% Mortality
100	3.1	5.2
10	6.8	15.0
4.7	8.1	16.5
2.2	14.2	26.0
1.0	11.0	25.0

The curve has turned downwards at the lower concentrations, similar to the experiment at 300 mg/l hardness. It is evident that nickel at a concentration of 1.0 mg/l is very toxic to Gammarus over a long period.

Toxicity of mixtures of Copper and Zinc at 100 mg/l water hardness

Metal pollution in rivers is usually due to the presence of more than one metal. It is therefore important to know the effect of metals in conjunction with one another. To this end, two tests with mixtures of copper and zinc were undertaken at 100 mg/l water hardness. The concentrations of each metal were selected at logarithmically equi-spaced intervals. The first test consisted of five concentrations each of copper and zinc, and the second, six concentrations of copper with five of zinc. (Tables 77 and 78). The mortalities obtained ranged from 33% to 100% in the first test, and from 20% to 79% in the second. (Tables 41 and 42). The 48hrLC50 values obtained from the earlier experiments, of copper, 0.72 mg/l and zinc, 2.4 mg/l, have been used to express each experimental concentration as a proportion of the 48hrLC50 value. The two proportions for each mixture have been added, and the sum of proportions plotted against mortality in Fig. 38. Although some scatter of points has been obtained, a line has been plotted through

Experiments with mixtures of copper and zinc for 48 hours at 100 hardness

From experiments with copper and zinc for over 48 hours,

48 hour LC50 for copper = 0.72 mg/l

and zinc = 2.4 mg/l

Table 41. 12 Gammarus/800ml solution/dish. 100 hardness
Mortality after 48 hours

Zinc		Copper		Sum of	Mortality	
Conc (mg/l)	Prop	Conc (mg/l)	Prop	Proportions	Total	%
1.70	0.71	0.080	0.11	0.82	13	54
1.70	0.71	0.106	0.15	0.86	15	62
1.70	0.71	0.141	0.20	0.91	20	83
1.70	0.71	0.188	0.26	0.97	22	92
1.70	0.71	0.250	0.35	1.06	21	87
1.85	0.77	0.080	0.11	0.88	13	54
1.85	0.77	0.106	0.15	0.92	15	62
1.85	0.77	0.141	0.20	0.97	17	71
1.85	0.77	0.188	0.26	1.03	23	96
1.85	0.77	0.250	0.35	1.12	23	96
2.02	0.84	0.080	0.11	0.95	15	62
2.02	0.84	0.106	0.15	0.99	17	71
2.02	0.84	0.141	0.20	1.04	23	96
2.02	0.84	0.188	0.26	1.10	23	96
2.02	0.84	0.250	0.35	1.19	23	96
2.20	0.92	0.080	0.11	1.03	15	62
2.20	0.92	0.106	0.15	1.07	8	33
2.20	0.92	0.141	0.20	1.12	20	83
2.20	0.92	0.188	0.26	1.18	19	79
2.20	0.92	0.250	0.35	1.27	21	87
2.40	1.00	0.080	0.11	1.11	15	62
2.40	1.00	0.106	0.15	1.15	14	58
2.40	1.00	0.141	0.20	1.20	22	92
2.40	1.00	0.188	0.26	1.26	24	100
2.40	1.00	0.250	0.35	1.35	22	92

Table 42. 15 Gammarus/800ml solution/dish. 100 hardness

Mortality after 48 hours

Zinc		Copper		Sum of	Mortality	
Conc (mg/l)	Prop	Conc (mg/l)	Prop	Proportions	Total	%
1.26	0.52	0.037	0.05	0.57	22	24
1.26	0.52	0.050	0.07	0.59	20	22
1.26	0.52	0.067	0.09	0.61	29	32
1.26	0.52	0.090	0.13	0.65	36	40
1.26	0.52	0.120	0.17	0.69	52	58
1.26	0.52	0.161	0.22	0.74	57	63
1.40	0.58	0.037	0.05	0.63	28	31
1.40	0.58	0.050	0.07	0.65	21	23
1.40	0.58	0.067	0.09	0.67	33	37
1.40	0.58	0.090	0.13	0.71	45	50
1.40	0.58	0.120	0.17	0.75	52	58
1.40	0.58	0.161	0.22	0.80	47	52
1.55	0.65	0.037	0.05	0.70	18	20
1.55	0.65	0.050	0.07	0.72	18	20
1.55	0.65	0.067	0.09	0.74	32	35
1.55	0.65	0.090	0.13	0.78	26	29
1.55	0.65	0.120	0.17	0.82	32	35
1.55	0.65	0.161	0.22	0.87	47	52
1.72	0.72	0.037	0.05	0.77	34	38
1.72	0.72	0.050	0.07	0.79	25	28
1.72	0.72	0.067	0.09	0.81	37	41
1.72	0.72	0.090	0.13	0.84	39	43
1.72	0.72	0.120	0.17	0.89	49	54
1.72	0.72	0.161	0.22	0.94	64	71
1.90	0.79	0.037	0.05	0.84	35	39
1.90	0.79	0.050	0.07	0.86	34	38
1.90	0.79	0.067	0.09	0.88	45	50
1.90	0.79	0.090	0.13	0.92	45	50
1.90	0.79	0.120	0.17	0.96	55	61
1.90	0.79	0.161	0.22	0.99	71	79

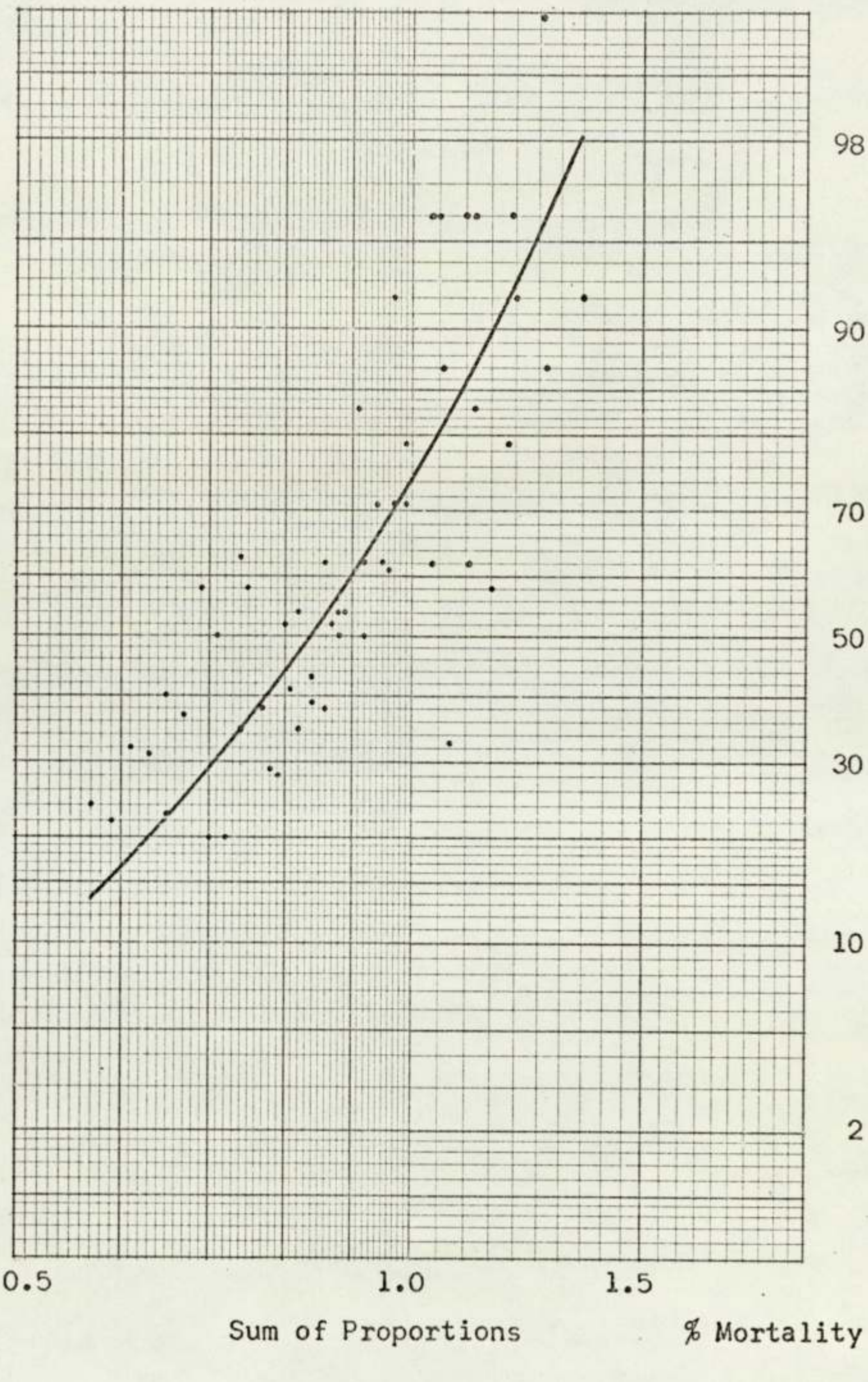


Fig. 38 . Toxicity of mixtures of copper and zinc to Gammarus after 48 hours at 100 hardness

them. The sum of proportions value of 1.0 corresponds to a mortality of 74%, while the "48hrLC50" value is 0.84 sum of proportions, suggesting a slight "more-than-additive" effect.

Experiments with mixtures of Copper, Zinc and Chromium at 300 mg/l water hardness

Mixtures of these three metals have been tested at 300 mg/l water hardness to determine how the metals present in the rivers might react together. Sums of proportions of 0.50, 0.75, 1.00, 1.25 and 1.50 were chosen for the initial experiment. One of the three metals was selected to represent 25%, 50% or 75% of the chosen sum of proportions value, the remaining two metals to contribute in equal proportions. This was repeated with the three metals in turn, producing a total of nine different mixtures at each of the five different sums of proportions. This is shown in Table 43, which also includes the proportion of the 48hrLC50 value contributed by each metal in the mixtures. The 48hrLC50 values are those obtained from the experiments at 300 mg/l water hardness, being copper, 4.4 mg/l; zinc, 5.7 mg/l and chromium, 4.8 mg/l. Table 44 gives the concentrations of the three metals related to the proportion of the 48hrLC50 value. The mortality in each experimental dish is given in Table 79, with the percentage mortality at each observation time shown in Table 80. The control mortality was fortunately only 2% throughout the experiment, and has been neglected in the calculations. Table 45 gives the percentage mortalities in each mixture for the five different sums of proportions. It does not appear that varying the relative proportions of each metal has had any great effect on the mortalities within each sum of proportions. In view of this, the results within each sum of proportions have been combined, and a percentage mortality calculated for each observation time (Table 46) which has been plotted in Fig. 39. Only 30% of the test animals had died at 1.0 sum of proportions after 48 hours, lower than the expected 50%, due to above-average resistance of these animals. Table 47 gives the extrapolated sum of proportions value for the three higher observation times, which have been plotted in Fig. 40 so that the "48hrLC50" value of 1.4 sum of proportions could be obtained.

As the relative proportions of each metal does not appear to have any effect on the mortality, a second experiment was performed, using all three metals present in equi-proportional amounts. A stock solution of the three mixed metals was used to prepare a range of from 0.10 to 0.82 sum of proportions. (Table 81). Control mortality reached 42% at the end of the test at 336 hours, and at the same time, 100% mortality had occurred in all solutions of 0.33 sum of proportions and over. The results were analysed by the same statistical procedure as used for the previous tests of over 48 hours (Table 48). The sums of proportions necessary to kill 10%, 20% and 50% have been calculated, and have been plotted in Fig. 40. At the higher observation times, the lines have curved upwards, showing that the thresholds have been approached. The three threshold sum of proportions values extrapolated are 10%, 0.07; 20%, 0.09, and 50%, 0.15, while the "48hrLC50" is 0.82 sum of proportions.

The three experiments on mixtures have produced results which support the generally accepted belief that the toxicity of mixtures can be calculated from the addition of the toxicities of the separate components of the mixture. Although the "48hrLC50" value obtained at 100 mg/l water hardness was 0.84 sum of proportions, the logarithmic mean of the two values of 0.82 and 1.4 at 300 mg/l water hardness was 1.07, very close to the expected value of 1.0.

Experiments with mixtures of copper, zinc and chromium for over 48 hours at a water hardness of 300 mg/l

Total sum of proportions to add up to 0.50, 0.75, 1.00, 1.25 and 1.50, with copper, zinc and chromium to be 25%, 50% or 75% of the total sum of proportions, with equal percentages of the remaining two metals.

Table 43. Proportion of 48 hour LC50 value of each metal in each mixture

Percentage of total		Metal	Total sum of proportions 0.50	0.75	1.00	1.25	1.50
Copper	25%	Copper	0.125	0.187	0.250	0.313	0.375
		Zinc	0.187	0.282	0.375	0.468	0.562
		Chromium	0.187	0.282	0.375	0.468	0.562
Copper	50%	Copper	0.250	0.375	0.500	0.625	0.750
		Zinc	0.125	0.187	0.250	0.313	0.375
		Chromium	0.125	0.187	0.250	0.313	0.375
Copper	75%	Copper	0.375	0.562	0.750	0.940	1.120
		Zinc	0.062	0.094	0.125	0.156	0.187
		Chromium	0.062	0.094	0.125	0.156	0.187
Zinc	25%	Copper	0.187	0.282	0.375	0.468	0.562
		Zinc	0.125	0.187	0.250	0.313	0.375
		Chromium	0.187	0.282	0.375	0.468	0.562
Zinc	50%	Copper	0.125	0.187	0.350	0.313	0.375
		Zinc	0.250	0.375	0.500	0.625	0.750
		Chromium	0.125	0.187	0.250	0.313	0.375
Zinc	75%	Copper	0.062	0.094	0.125	0.156	0.187
		Zinc	0.375	0.562	0.750	0.940	1.120
		Chromium	0.062	0.094	0.125	0.156	0.187
Chromium	25%	Copper	0.187	0.282	0.375	0.468	0.562
		Zinc	0.187	0.282	0.375	0.468	0.562
		Chromium	0.125	0.187	0.250	0.313	0.375
Chromium	50%	Copper	0.187	0.282	0.375	0.468	0.562
		Zinc	0.187	0.282	0.375	0.468	0.562
		Chromium	0.125	0.187	0.250	0.313	0.375
Chromium	50%	Copper	0.125	0.187	0.250	0.313	0.375
		Zinc	0.125	0.187	0.250	0.313	0.375
		Chromium	0.250	0.375	0.500	0.625	0.750
Chromium	75%	Copper	0.062	0.094	0.125	0.156	0.187
		Zinc	0.062	0.094	0.125	0.156	0.187
		Chromium	0.375	0.562	0.750	0.940	1.120

Experiments with mixtures of copper, zinc and chromium for over 48 hours at a water hardness of 300 mg/l

From the experiments at 300 hardness for over 48 hours

48 hour LC50 for copper = 4.4 mg/l
zinc = 5.7 mg/l
chromium = 4.8 mg/l

Table 44. Concentrations (mg/l) of copper, zinc and chromium for each proportion of 48 hour LC50 value

Proportion	Copper	Zinc	Chromium
48 hour LC50	4.4	5.7	4.8
0.062	0.272	0.353	0.297
0.094	0.413	0.535	0.451
0.125	0.550	0.712	0.600
0.156	0.686	0.889	0.748
0.187	0.822	1.065	0.897
0.250	1.100	1.425	1.200
0.282	1.240	1.607	1.353
0.313	1.377	1.784	1.502
0.375	1.650	2.137	1.800
0.468	2.059	2.667	2.246
0.500	2.200	2.850	2.400
0.562	2.472	3.203	2.697
0.625	2.750	3.562	3.000
0.750	3.300	4.275	3.600
0.940	4.136	5.358	4.512
1.120	4.928	6.384	5.376

Table 45. Percentage mortality in each mixture

As the control mortality is only 2% throughout this has been neglected

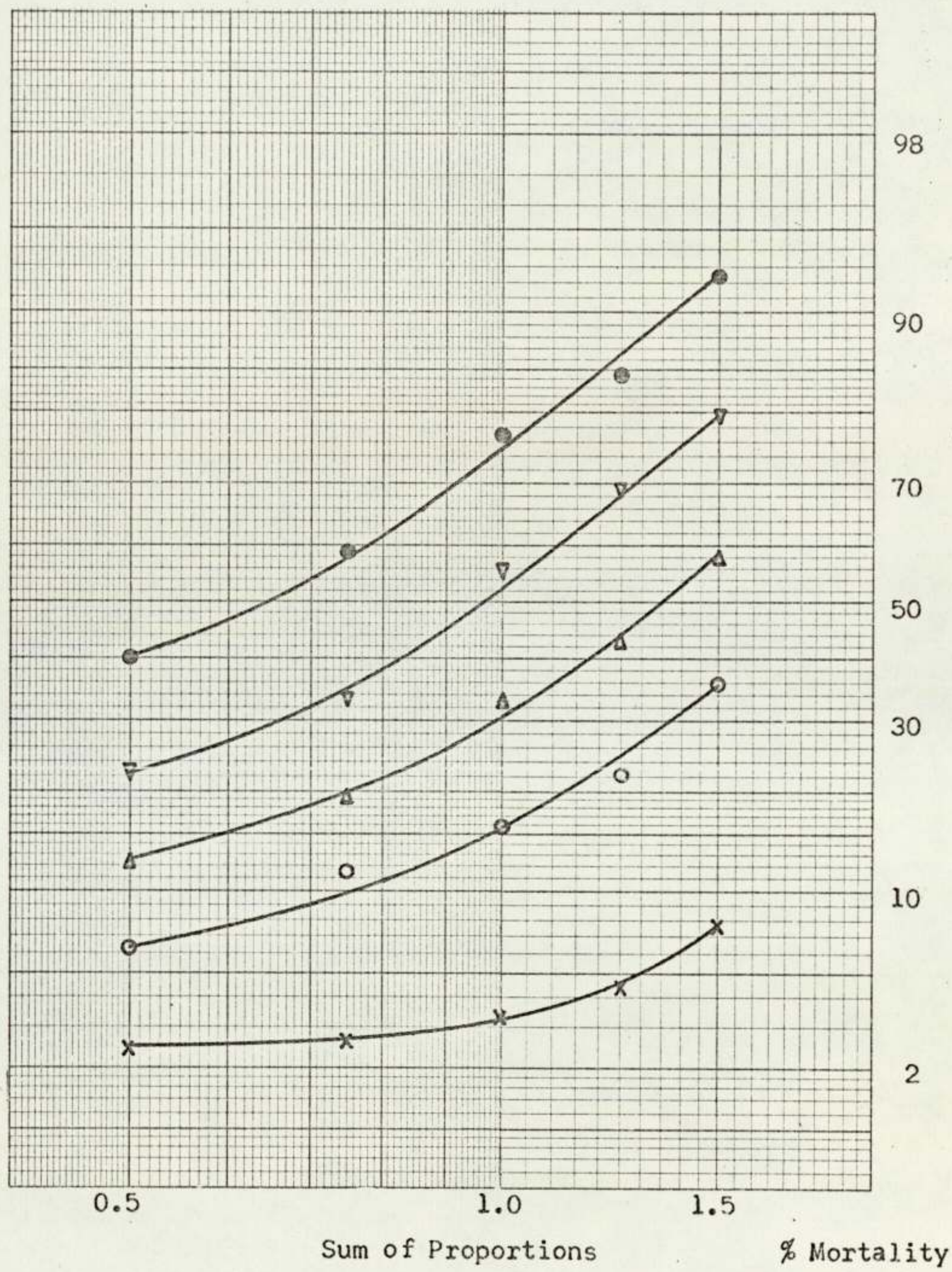
Sum of Proportions	Mixture Percentage		Time (hours) 22	35	48	69	96
Control			2	2	2	2	2
0.50	Copper	25	0	2	7	18	27
		50	0	2	4	13	27
		75	4	9	18	33	56
	Zinc	25	2	7	13	27	33
		50	2	2	9	13	38
		75	2	7	9	20	44
	Chromium	25	7	11	13	22	44
		50	0	7	16	24	47
		75	4	9	20	29	44
0.75	Copper	25	0	9	20	36	71
		50	0	4	4	18	31
		75	4	11	18	40	78
	Zinc	25	2	16	22	33	49
		50	0	4	11	24	64
		75	9	22	38	58	76
	Chromium	25	4	11	20	36	56
		50	4	18	27	33	56
		75	0	7	13	27	49
1.00	Copper	25	4	13	31	49	62
		50	2	13	27	47	73
		75	2	9	24	47	73
	Zinc	25	2	13	36	53	80
		50	2	18	31	53	82
		75	7	24	42	69	87
	Chromium	25	0	9	24	47	67
		50	4	13	33	71	78
		75	4	29	49	64	84
1.25	Copper	25	0	22	51	82	89
		50	2	22	47	69	80
		75	4	29	40	67	76
	Zinc	25	2	11	42	67	80
		50	7	27	44	76	89
		75	7	24	42	67	82
	Chromium	25	7	18	31	71	93
		50	4	20	38	58	84
		75	7	27	49	64	84
1.50	Copper	25	9	27	49	78	91
		50	7	40	67	87	96
		75	11	42	67	87	96
	Zinc	25	7	40	51	78	91
		50	11	40	64	82	93
		75	9	38	58	78	87
	Chromium	25	2	29	58	80	93
		50	4	27	53	69	89
		75	9	40	56	78	96

Table 46. Total and percentage mortality in each sum of proportion
45 Gammarus/mixture
9 Mixtures/sum of proportions
405 Gammarus/sum of proportions

Sum of	Time (hours) 22		35		48		69		96	
Proportions	No	%	No	%	No	%	No	%	No	%
0.50	10	2.5	25	6.2	49	12.1	90	22.2	162	40.0
0.75	11	2.7	46	11.3	78	19.2	137	33.8	238	58.8
1.00	13	3.2	64	15.8	134	33.1	225	55.8	309	76.3
1.25	18	4.4	90	22.2	173	42.7	279	68.9	341	84.2
1.50	31	7.6	145	35.8	235	58.0	322	79.4	374	92.4

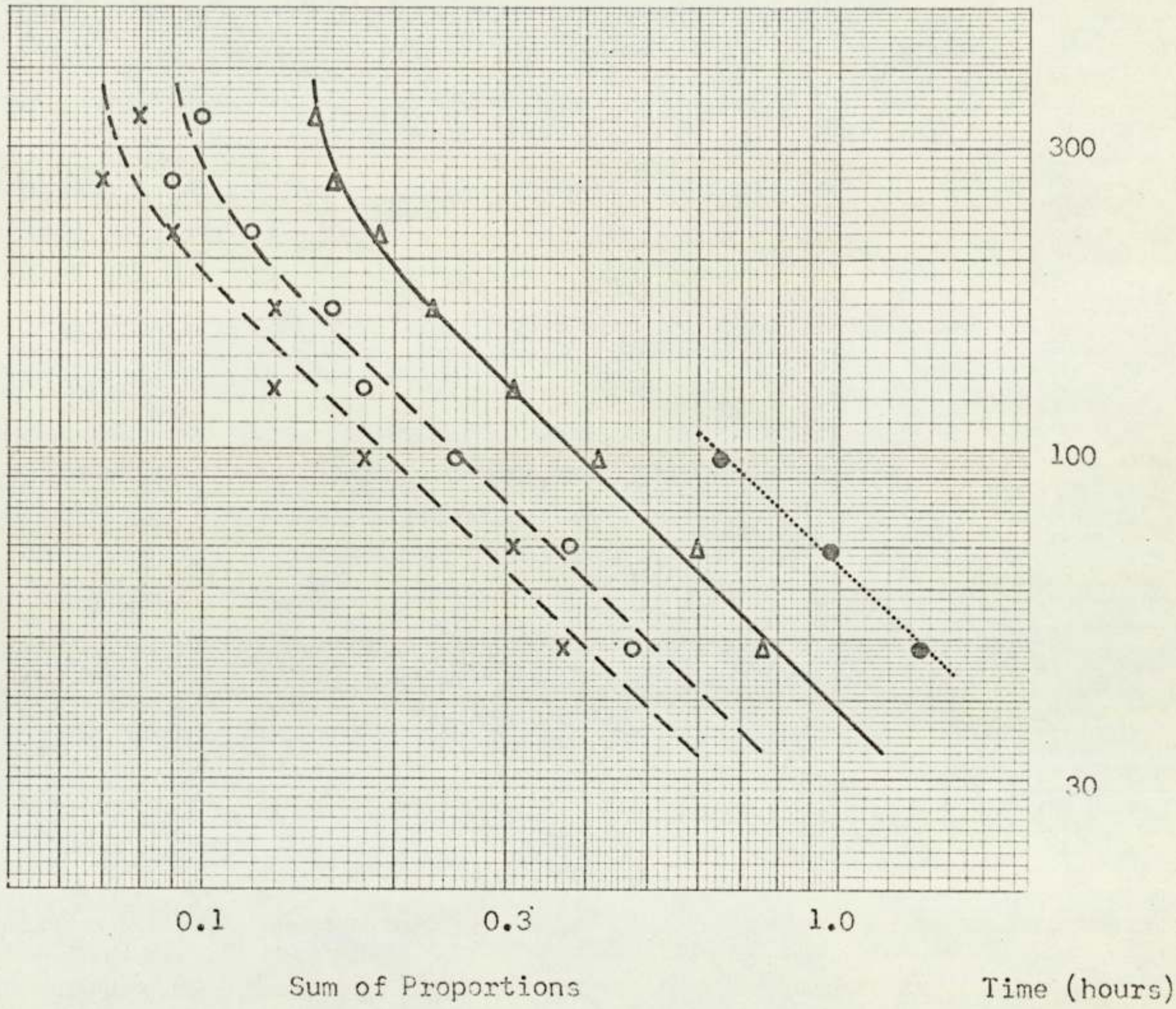
Table 47. Extrapolated Sum of Proportions for 50% mortality after given times

Time (hours)	Sum of Proportions
22	-
35	-
48	1.35
69	0.97
96	0.65



x 22 hours
o 35 hours
Δ 48 hours
∇ 69 hours
● 96 hours

Fig. 39 . Toxicity of mixtures of copper, zinc and chromium to Gammarus at 300 hardness



x 10% Mortality Equi-proportional mixtures

o 20% Mortality Equi-proportional mixtures

Δ 50% Mortality Equi-proportional mixtures

● 50% Mortality Variable proportional mixtures

Fig. 40. Toxicity of mixtures of copper, zinc and chromium at 300 hardness

Experiments with mixtures of copper, zinc and chromium for over 48 hours at a water hardness of 300 mg/l

Each metal to be 33.3% of the total sum of proportions

From the experiments at 300 hardness for over 48 hours,

48 hr LC50 for	copper	=	4.4 mg/l
	zinc	=	5.7 mg/l
	chromium	=	4.8 mg/l

A stock solution of the metals was prepared such that 1.0ml diluted to 800ml would have a Sum of Proportions value of 0.1, consisting of equal proportions of copper, zinc and chromium

	Copper	Zinc	Chromium
Stock solution (mg/l)	117.4	152.0	128.0
1.0ml diluted to 800ml(mg/l)	0.1467	0.1900	0.1600
48 hr LC50	4.4	5.7	4.8
Proportion of 48 hr LC50	0.033	0.033	0.033
Sum of Proportions		0.1	

A range of volumes from 1.0 to 8.2ml was used to prepare solutions with a Sum of Proportions value of 0.1 to 0.82

Table 48. Summary of analysis of results

Time (hrs)	N	chi^2	a	SE(a)	b	SE(b)	S of P for % mortality 10	20	50
48	9	3.26	4.05	0.38	5.48	0.06	0.37	0.47	0.76
70	9	6.67	4.39	0.58	5.98	0.08	0.31	0.38	0.60
96	12	10.05	3.59	0.39	6.35	0.08	0.18	0.25	0.42
125	12	12.41	3.43	0.41	6.73	0.09	0.13	0.18	0.31
167	10	12.25	5.18	0.74	8.27	0.12	0.13	0.16	0.23
220	9	17.22	4.29	1.09	8.14	0.17	0.09	0.12	0.19
265	8	19.34	3.48	1.47	7.77	0.21	0.07	0.09	0.16
336	7	18.79	4.22	1.78	8.43	0.25	0.08	0.10	0.15

The effect of dissolved oxygen concentration on the toxicity of Copper and Zinc

Two tests, at 300 mg/l water hardness, were carried out with less than 100% saturation of dissolved oxygen, but only for a limited period of 48 hours. In the first, with copper, four metal concentrations of from 1.0 mg/l to 10.0 mg/l were used at each dissolved oxygen concentration, with 30 test animals at each metal concentration. The second, with zinc, had nine metal concentrations of from 0.47 mg/l to 10.0 mg/l, but with only 15 test animals at each metal concentration. (Tables 82 and 83). The mortalities have been corrected for the control mortalities (Table 84) and plotted against metal concentration for each separate dissolved oxygen concentration. Because of the mortality ranges obtained, the 48hrLC50 values could only be extrapolated from the three higher dissolved oxygen concentration for both metals. These values are given in Table 49, where they are also expressed as a proportion of the 100% saturated value.

Table 49. Extrapolated 48hrLC50 values for each dissolved oxygen concentration.

Metal	Dissolved Oxygen Concentration (mg/l)	Extrapolated 48hrLC50	Proportion of 48hr LC50 at 100% saturation
Copper	11.1	3.5	1.0
	4.8	2.1	0.60
	2.3	0.4	0.12
	1.7	-	-
Zinc	10.7	6.6	1.0
	4.5	2.9	0.44
	2.8	0.5	0.08
	1.4	-	-

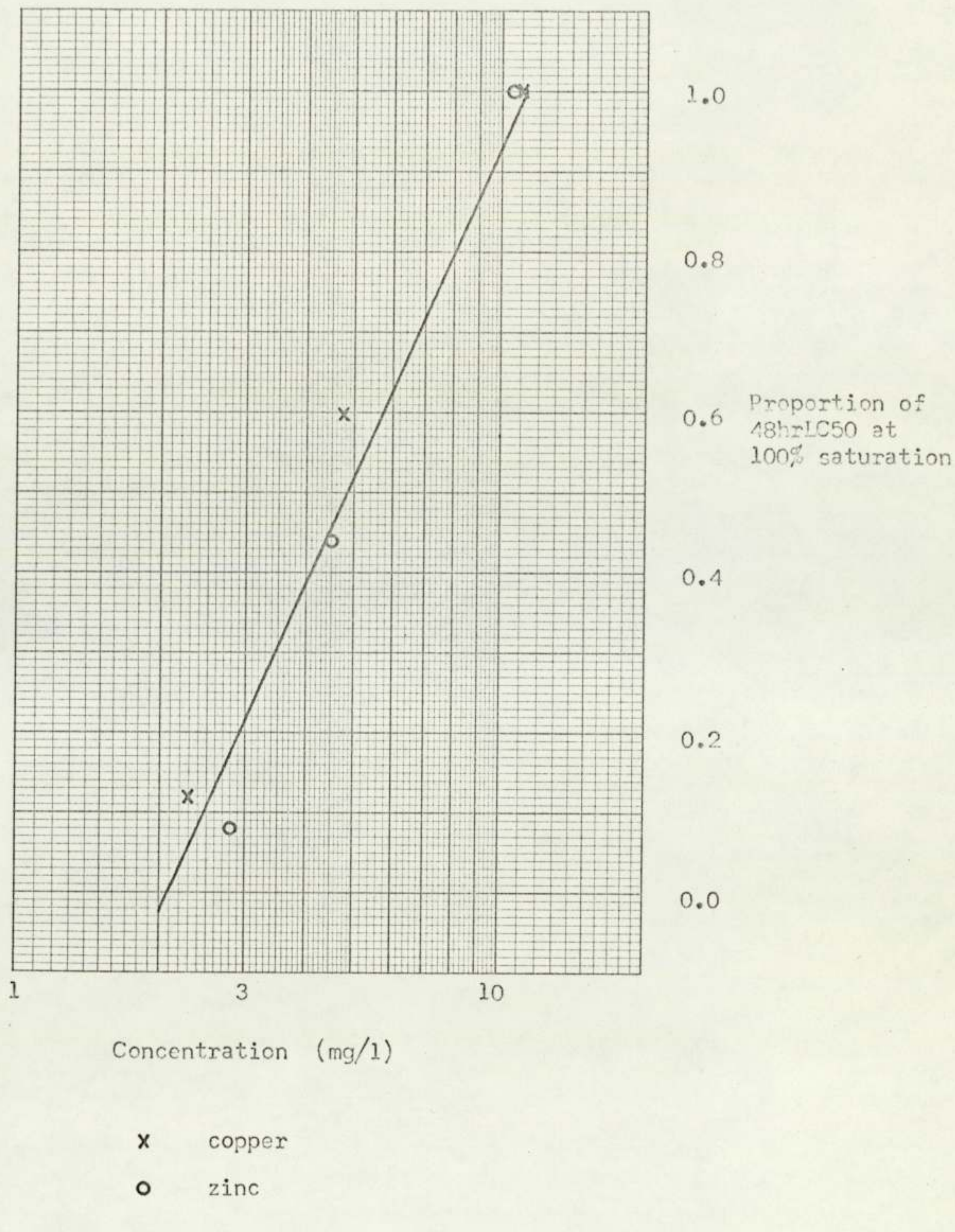


Fig. 41. Proportion of 48hrLC50 value at 100% saturation related to concentration of dissolved oxygen

It can be seen that the toxicity of both copper and zinc increases as the dissolved oxygen concentration is reduced. This is shown by the proportion of the 48hrLC50 value under saturated conditions which is sufficient to produce 50% mortality after 48 hours at the reduced oxygen level.

These proportions are plotted against the dissolved oxygen concentration (Fig. 41), so that the proportion of the 48hrLC50 value for any given concentration can be obtained.

Summary of Results of Toxicity Tests

The initial experiments at 100 mg/l water hardness for a limited period showed which substances were likely to prove toxic in the rivers of the area, and these were therefore investigated in greater detail. The 48hrLC50 values obtained from these experiments are given in Table 50, together with the 95% fiducial limits where these have been calculated.

Table 50. Toxicity of chemicals tested for 48 hours at 100 mg/l water hardness.

Chemical	48hrLC50	95% fiducial limits	
Cyanide	0.52	0.49	0.55
Copper	0.58	0.52	0.65
Cadmium	0.82		
Chromium	1.3	1.1	1.4
Ammonia - undissociated	1.42	1.28	1.58
Zinc	3.2	3.0	3.4
Lead	32		
Ammonia - total	78	70	86
Phenol	103		
Nickel	940	780	1130

It was decided that copper, zinc and chromium should be further studied in view of their high toxicities and common occurrence in local river waters. This was carried out at both 100 mg/l and 300 mg/l water hardness, over time periods extending up to 600 hours. These experiments enabled the threshold values to be determined, except for chromium at 100 mg/l hardness where only estimates could be made. The threshold values have been extrapolated for the 10% and 20% mortality in addition to the more usual 50% mortality level, as these lower levels may be more useful in relation to permissible field mortality. (Table 51). At the same time, the 48hrLC50 values have been obtained for the three metals.

Table 51. Toxicity threshold values for Copper, Zinc and Chromium for over 48 hours at 100 mg/l and 300 mg/l water hardness.

All concentrations are given in mg/l.

Metal	Water Hardness	48hrLC50	Threshold value for given mortality 10%	20%	50%
Copper	100	0.72	0.11	0.14	0.20
	300	4.4	0.31	0.39	0.55
Zinc	100	2.4	0.16	0.20	0.35
	300	5.7	0.34	0.40	0.50
Chromium	100	1.6	(0.10)	(0.10)	(0.15)
	300	4.8	0.10	0.16	0.30

Nickel was tested at 200 mg/l water hardness over a time period of up to 25 days, to determine the long term effect of this metal. For this experiment it was necessary to provide food to avoid mortality due to starvation. A short term experiment at 300 mg/l water hardness did not give results suitable for extrapolation of the threshold of nickel. It was found that at both 200 mg/l and 300 mg/l water hardness, the graphs suggests that the toxicity extends down to low concentrations of nickel.

To discover the effects of metals in combination, experiments with mixtures of copper and zinc were carried out at 100 mg/l water hardness, and with mixtures of copper, zinc and chromium at 300 mg/l hardness. The experiments at 100 mg/l hardness and the initial experiment at 300 mg/l hardness enabled the '48hrLC50' values of 0.84 and 1.4 sum of proportions respectively to be found, but were of insufficient duration to allow any thresholds to be obtained. From the experiment at 300 mg/l water hardness with mixtures containing the three metals in equi-proportional amounts, the '48hrLC50' of 0.82 sum of proportion has been obtained. Threshold values of 10%, 0.07; 20%, 0.09 and 50%, 0.15 were also extrapolated from this latter experiment.

Two experiments at a dissolved oxygen content of less than 100% saturation were performed with copper and zinc to discover the effect of reduced oxygen content on the toxicity of the two metals. (Fig. 41). This data has been used to determine the proportion of the 100% saturated 48hrLC50 value which will produce 50% mortality at various dissolved oxygen concentrations (Table 52). This data would obviously be of use when calculating the toxicity of river water, which is often below saturation, especially when organic pollution is also present.

Table 52. Proportion of 100% saturated 48hrLC50 value in relation to the dissolved oxygen concentration.

Temperature = 9.8°C   100% saturation = 11.3 mg/l dissolved oxygen

Dissolved Oxygen Concentration (mg/l)	Percentage Saturation	Proportion of 100% saturated 48hrLC50
11.3	100	1.00
11	97	0.98
10	88	0.93
9	80	0.87
8	71	0.80
7	62	0.72
6	53	0.63
5	44	0.52
4	35	0.38
3	27	0.21
2	18	-
1	9	-

Discussion of Toxicity Test Results

The results of the toxicity experiments with Gammarus pulex can be analysed in relation to similar experiments by other workers, using the same or different species of Gammarus, other invertebrates or fish.

Jones (1937) tested the toxicities of copper and zinc to Gammarus pulex. The experiments were carried out in Aberystwyth tapwater, which is very soft, containing only approximately 1 mg/l calcium. Copper at a concentration of 5×10^{-4}N, approximately 30 mg/l copper, gave a survival time of about one hour. With a reduction of the copper to approximately 0.13 mg/l, survival time was under four hours (Jones, 1938b). From the present studies at a concentration of

30 mg/l copper and 100 mg/l water hardness, the median survival time was 16 hours (Fig. 29) while at 300 mg/l hardness, Gammarus survived for 30 hours (Fig. 33). Jones found zinc fatal at a concentration of 0.01N, approximately 0.3 mg/l zinc, when the survival time was only about five hours. In the present work at 100 mg/l water hardness, approximately 50 mg/l zinc was necessary to kill 50% of the test animals in five hours (Fig. 30), and this concentration increased to much higher than 50 mg/l at 300 mg/l hardness (Fig. 34). A concentration of 0.3 mg/l zinc at both 100 mg/l and 300 mg/l water hardness enabled a proportion of Gammarus to survive indefinitely. The much higher toxicities of copper and zinc obtained by Jones can be attributed to the effect of the water hardness, where a decrease in hardness increases the toxicity.

Arthur and Leonard (1970) used an American species, Gammarus pseudolimnaeus in experiments with copper, at a water hardness of 45 mg/l, and found the 96hrLC50 value to be 0.02 mg/l. From Fig. 32, the 96hrLC50 value of copper at three hardnesses can be estimated, at 100 mg/l hardness, 0.3 mg/l; 200 mg/l, 1.0 mg/l and at 400 mg/l, 3.0 mg/l. This represents a three-fold decrease in toxicity for a two-fold increase in water hardness. On this basis a 96hrLC50 value at 50 mg/l hardness can be estimated as 0.1 mg/l copper. This can be compared with the value of 0.02 mg/l for G. pseudolimnaeus; thus it would appear that G. pulex is more tolerant of copper. A concentration of only 0.008 mg/l produced 50% mortality of G. pseudolimnaeus after six weeks, a level which is unlikely to have any effect on G. pulex.

Learner and Edwards (1963), experimenting with Nais, found the threshold for copper was approximately 0.4 mg/l copper at 320 mg/l hardness, and approximately 0.2 mg/l at 18 mg/l water hardness. At 300 mg/l hardness, Gammarus had a threshold of 0.55 mg/l copper which decreased to 0.20 mg/l at 100 mg/l hardness (Table 51). These figures suggest that at 300 mg/l hardness Gammarus is more tolerant to copper than is Nais, but in softer water, Gammarus is less tolerant. Anderson (1944) determined the threshold concentrations for 50% immobilization of Daphnia magna in Lake Erie water for a wide range of chemicals by tests of 16 hours duration. The threshold concentration for copper was approximately 0.04 mg/l; for zinc, less than about 20 mg/l and for chromium, much less than 0.16 mg/l or 0.30 mg/l, depending on the salt used. In later tests, lasting for 64 hours, Anderson (1950) was able to establish more reliable threshold values. These included copper, 0.010 mg/l and 0.013 mg/l depending upon the salt; zinc, less than 0.07 mg/l; nickel, less than 0.3 mg/l and chromium, less than 1.2 mg/l. His most toxic salt tested was cadmium at less than 0.0012 mg/l. These values are lower than for Gammarus, except for chromium, which may be less toxic.

Much more laboratory work has been carried out using fish as test animals, particularly species of trout. Because of possible differences in the toxicological process, the relative toxicity of chemicals to species of fish and invertebrates may differ.

The high toxicity of copper has led to many tests being carried out to ascertain the toxic level to fish. This knowledge is important in water management, as during the summer period, copper salts are sometimes applied to reservoirs to control algal growth. In experiments with rainbow trout in a soft water of 15-20 mg/l hardness, the 7 day LC50 value for copper was 0.044 mg/l, and in hard water of 320 mg/l, the 3 day LC50 value was 1.1 mg/l (Lloyd, 1961). In similar hard water a 2 day LC50 value of only 0.27 mg/l copper has been obtained (Herbert and Vandyke, 1964). Brown (1968) gives a graph relating the 48hrLC50 value of copper to water hardness, from which values of 0.5 mg/l at 320 mg/l hardness, 0.2 mg/l at 100 mg/l and 0.08 mg/l at 30 mg/l hardness can be obtained. Compared with the values for Gammarus of

4.4 mg/l copper at 300 mg/l hardness and 0.72 mg/l at 100 mg/l hardness, the change in LC50 value for rainbow trout is only approximately half of that in respect of Gammarus for a similar change in water hardness. Complications arise when organic material is present, as soluble organo-copper complexes are formed (Herbert et al, 1965).

Zinc is less toxic than copper, but as it is commonly found in rivers, its toxicity has often been studied. Lloyd (1961) examined zinc in both soft and hard water. In soft water of 15-20 mg/l hardness, he obtained a 7 day LC50 of 0.56 mg/l zinc, which increased to 3.5 mg/l in 320 mg/l hardness water for a three day period. Herbert and Vandyke (1964) found the 48hrLC50 to be 2.46 mg/l zinc in 320 mg/l hardness water, whilst Herbert and Shurben (1963) obtained a range of from 1.5 mg/l to 3.8 mg/l zinc in similar water. In very soft water of only 12 mg/l hardness, Lloyd (1960) did not find any threshold. Brown (1968) discovered that the 48hrLC50 decreased from 3.0 mg/l zinc at 300 mg/l hardness to 1.8 mg/l at 100 mg/l and 0.8 mg/l at 30 mg/l water hardness. In the present laboratory experiments, Gammarus was found to have 48hrLC50 values of 2.4 mg/l zinc at 100 mg/l hardness and 5.7 mg/l at 300 mg/l hardness, with thresholds of 0.35 mg/l and 0.50 mg/l respectively. Using a number of fish species, Ball (1967b) determined the 5 day LC50 values of zinc to rainbow trout as 4.6 mg/l, bream (Abramis brama (L.)), 14.3 mg/l; perch (Perca fluviatilus L.), 16.0 mg/l and roach (Rutilus rutilus (L.)), 17.3 mg/l in hard water of 290 mg/l $CaCO_3$. Gammarus therefore appears slightly more resistant to zinc than rainbow trout, but markedly less resistant than the other three species. Temperature is known to affect zinc toxicity, with a decrease in survival time of rainbow trout for an increase in temperature. However, the threshold remains at the same level at different temperatures (Lloyd, 1960). Exposure of rainbow trout to sub-lethal concentrations of zinc has been found to increase the 48hrLC50 value (Edwards and

Brown, 1967).

Nickel and cadmium have been found to give similar types of toxicity curves with rainbow trout (Ball, 1967c; Jackson and Brown, 1970). In these the LC50 value decreases steadily with increasing exposure time until approximately 7 days, when a wide concentration range produces similar median survival times. Further reduction in concentration beyond this range leads to increased survival times, and enables the long term threshold concentration to be ascertained. A 48hrLC50 value of 100 mg/l nickel at 320 mg/l water hardness has been obtained for rainbow trout (Jackson and Brown, 1970). Using the relation between water hardness and 48hrLC50 obtained by Brown (1968) this may be reduced to approximately 50 mg/l at 100 mg/l hardness. This is a high enough level to suggest non-toxicity, similar to the 48hrLC50 value of 940 mg/l nickel for Gammarus at 100 mg/l water hardness (Fig. 23). However, for longer periods, the concentration is much less, being reduced to 5 mg/l for 50% survival of trout after 12 days. Nickel concentrations of only 1 mg/l at 200 mg/l water hardness (Fig. 37) and 25 mg/l at 300 mg/l hardness (Fig. 36) are obviously toxic to Gammarus. Cadmium has been found to be more toxic than nickel, with 48hrLC50 values of approximately 10 mg/l (Ball, 1967c) and 2.5 mg/l cadmium (Jackson and Brown, 1970) being obtained in hard water, which decreased to threshold levels of approximately 0.03 mg/l and 0.01 mg/l cadmium respectively. Brown (1968) gives a 48hrLC50 of 5.0 mg/l cadmium at 300 mg/l water hardness, decreasing to 1.0 mg/l at 100 mg/l hardness. This latter value is similar to the 48hrLC50 value of 0.82 mg/l cadmium found for Gammarus from the laboratory experiments at 100 mg/l water hardness.

Chromium is a metal that does not appear to show a good threshold with rainbow trout (Jackson and Brown, 1970). Herbert et al (1965) suggests that chromium is unlikely to contribute appreciably to the

Table 53. Median lethal concentration of certain metals to species of fish and invertebrates

Metal	Species	Water Hardness mg/l as $CaCO_3$	Time	Median Lethal Concentrations(mg/l)	Reference
Copper	Rainbow Trout	15 - 20	7 days	0.044	Lloyd, 1961
		30	2 days	0.08	Brown, 1968
		100	2 days	0.2	Brown, 1968
		320	2 days	0.5	Brown, 1968
		320	2 days	0.27	Herbert and Vandyke, 1964
		320	3 days	1.1	Lloyd, 1961
	Gammarus pulex	100	2 days	0.72	This work
		300	2 days	4.4	This work
	Gammarus pseudolimnaeus	45	4 days	0.02	Arthur and Leonard, 1970
		45	6 weeks	0.008	Arthur and Leonard, 1970
	Nais	18	12 hours	0.2	Learner and Edwards, 1963
		320	12 hours	0.4	Learner and Edwards, 1963
	Daphnia magna	-	16 hours	0.04	Anderson, 1944
		-	64 hours	0.010	Anderson, 1950
		-	64 hours	0.013	Anderson, 1950

Metal	Species	Water Hardness mg/l as $CaCO_3$	Time	Median Lethal Concentrations(mg/l)	Reference
Zinc	Rainbow Trout	15 - 20	7 days	0.56	Lloyd, 1961
		30	2 days	0.8	Brown, 1968
		100	2 days	1.8	Brown, 1968
		290	5 days	4.6	Ball, 1967b
		300	2 days	3.0	Brown, 1968
		320	2 days	2.46	Herbert and Vandyke, 1964
		320	2 days	1.5 - 3.8	Herbert and Shurben, 1963
		320	3 days	3.5	Lloyd, 1961
	Bream	290	5 days	14.3	Ball, 1967b
	Perch	290	5 days	16.0	Ball, 1967b
	Roach	290	5 days	17.3	Ball, 1967b
	Gammarus pulex	100	2 days	2.4	This work
		300	2 days	5.7	This work
	Daphnia magna	-	16 hours	20	Anderson, 1944
		-	64 hours	0.07	Anderson, 1950
Chromium	Rainbow Trout	-	2 days	65	Jackson and Brown, 1970
		-	7 days	20	Jackson and Brown, 1970
		-	48 days	4	Jackson and Brown, 1970

Metal	Species	Water Hardness mg/1 as $CaCO_3$	Time	Median Lethal Concentrations(mg/1)	Reference
Chromium	Gammarus pulex	100	2 days	1.6	This work
		300	2 days	4.8	This work
	Daphnia magna	-	16 hours	0.16	Anderson, 1944
		-	16 hours	0.30	Anderson, 1944
		-	64 hours	1.2	Anderson, 1950
Nickel	Rainbow Trout	100	2 days	50	Brown, 1968
		300	2 days	90	Brown, 1968
		320	2 days	100	Jackson and Brown, 1970
	Gammarus pulex	100	2 days	940	This work
Cadmium	Rainbow Trout	100	2 days	1.0	Brown, 1968
		290	2 days	10.0	Ball, 1967c
		300	2 days	5.0	Brown, 1968
		-	2 days	2.5	Jackson and Brown, 1970
	Gammarus pulex	100	2 days	0.82	This work
	Daphnia magna	-	64 hours	0.0012	Anderson, 1950

short term toxicity of river water. A 48hrLC50 value of 65 mg/l chromium supports this, but the level decreases to 20 mg/l at 7 days and to 4 mg/l at 48 days (Jackson and Brown, 1970). The laboratory experiment with Gammarus gave a 48hrLC50 of 4.8 mg/l chromium at 300 mg/l water hardness, showing that Gammarus is less resistant to chromium than rainbow trout. A threshold level of only 0.30 mg/l chromium was also obtained for Gammarus (Fig. 35).

The toxicity of phenol to trout varies with temperature, (Brown et al, 1967) but in the opposite direction to the effect with zinc. With phenol an increase in temperature causes an increase in the 48hrLC50. At $10^{o}C$, the 48hrLC50 of pure phenol is 7.2 mg/l, increasing to 10 mg/l at $18^{o}C$. This value at $10^{o}C$ is much lower than the 48hrLC50 value of 103 mg/l obtained for Gammarus in the laboratory experiment. Phenol toxicity to trout is unaffected by changes in water hardness (Herbert, 1962).

Ammonia toxicity is more difficult to determine, as it is dependent upon the concentration of undissociated ammonia. The toxicity is known to depend on the temperature, dissolved oxygen and carbon dioxide concentrations, pH and bicarbonate alkalinity of the water. With an increase in temperature, the 48hrLC50 value of ammonia to trout decreases, but the value for undissociated ammonia increases (Brown, 1968). For five species of fish, Ball (1967a) obtained thresholds of from 0.29 mg/l to 0.41 mg/l undissociated ammonia, with a value of 0.41 mg/l for trout. All these values are much lower than the 48hrLC50 value of 1.42 mg/l found for Gammarus in this work.

As toxic substances rarely occur separately, many workers have used the "sum of proportions" rule as the basis for the calculation of the toxicity of mixtures (Lloyd, 1961; Herbert and Shurben, 1964; Herbert and Vandyke, 1964; Brown et al, 1965; Brown, 1968; Brown et al, 1969; Brown and Dalton, 1970). In these, it was possible to calculate the total toxicity of the mixture by the addition of the individual toxicities, when the latter are expressed as a proportion of the individual 48hrLC50 value under the same experimental conditions. Brown (1968) states that the theoretical value of 1.0 might validly lie between 0.75 and 1.30, as determined by the slope of the graphs. Usually the experiment has been limited to 48 hours and only a pair of chemicals. However, Brown and Dalton (1970) tested the method with mixtures of three chemicals, using copper and zinc with either nickel or phenol. The 48hr sum of proportions values were between 1.01 and 1.07. As the concentration of chemicals in rivers is not constant, Brown et al (1969) studied the effect of fluctuating mixtures of ammonia, phenol and zinc. They found that provided the maximum concentrations were not sufficiently high so as to cause irreversible toxicity, the overall toxicity could be calculated from the mean of the fluctuating concentrations. The 48hrLC50 values ranged from 0.85 to 1.45 sum of proportions. In the tests giving the higher values of 1.45, zinc was present in proportions of over 70% of the mixture, suggesting some slight "less-than-additive" effect. The toxicities of the mixtures used in the laboratory experiments with Gammarus have been similarly calculated by the addition of the individual proportional toxicities. The laboratory experiments at both 100 mg/l and 300 mg/l water hardness gave 48hrLC50 sum of proportions values of between 0.82 and 1.4, similar to that obtained for fish. To increase the usefulness of the experiments with Gammarus, one experiment at 300 mg/l water hardness was continued for a much longer period than 48 hours. It was found that results similar to those of single substances were obtained, and that threshold values of 10%, 0.07; 20%, 0.09 and 50%, 0.15 sum of proportions could be extrapolated (Fig. 40).

By using the thresholds obtained for the three metals separately, a threshold of the mixture of copper, zinc and chromium can be calculated. Each threshold is expressed as a proportion of the appropriate 48hrLC50 value, and these proportions summed.

Metal	50% Threshold	48hrLC50	Proportion
Copper	0.55	4.4	0.125
Zinc	0.50	5.7	0.088
Chromium	0.30	4.8	0.062
Total	-	-	0.275

The value of 0.27 may be compared with the experimental value of 0.15 obtained from the test with mixtures of the same metals. The '48hrLC50' sum of proportion of this latter test was 0.82, somewhat lower than 1.0 as expected, suggesting the test animals were more sensitive than average. This could mean that the 50% threshold is slightly below average, and may be nearer 0.20. In the earlier experiment at 300 mg/l water hardness with variable proportional mixtures, the '48hrLC50' was 1.4 sum of proportions. It can be seen from Fig. 40 that the two lines for 50% mortality are parallel, and extention of the time from the 48hr value of 1.4 would lead to a threshold value very close to the calculated value of 0.27.

Because of the variability of the resistance of Gammarus, it therefore seems reasonable to use a value of 0.20 as the 50% sum of proportions threshold value. This value is likely to be of use when determining the proportion of the 48hrLC50 value which will theoretically allow indefinite survival.

Brown (1968) has studied the effect of reduced dissolved oxygen concentration on the toxicity of copper, zinc, lead and gas-liquor phenols. The results are expressed in proportions of the 48hrLC50 at 100% saturation. It was found that the 48hrLC50 proportion dropped to 0.91 at 75% saturation and 0.79 at 50%. This drop is less than that for Gammarus where proportions of 0.83 at 8.5 mg/l dissolved oxygen (75% saturation) 0.59 at 5.6 mg/l (50%) and 0.17 at 2.8 mg/l (25%) were obtained for copper and zinc (Fig. 41). These figures show that Gammarus is less tolerant of toxic chemicals at reduced dissolved oxygen concentrations than is rainbow trout.

The results of the laboratory experiments have shown that the metals copper, zinc and chromium are all toxic to Gammarus in small concentrations. Nickel is also toxic, but because of the long period required, laboratory experiments need to be maintained for longer than practicable using simple apparatus. Cadmium, lead, ammonia and phenol are unlikely to be major sources of toxicity in rivers, since the amounts occurring or their toxicities are limited. Cyanide readily forms complexes, and free cyanide will not occur due to complexing in rivers (Jenkins et al, 1966). It has been shown that water hardness and dissolved oxygen concentration can modify the individual toxicity of chemicals. The toxicity of mixtures to Gammarus can be described by the summation of the proportional toxicities of the components of the mixture. In general, Gammarus is less sensitive to toxic substances than is trout, but from the limited experiments by other workers, Gammarus appears more sensitive to zinc and less sensitive to ammonia than freshwater coarse fish. An exception with trout is with chromium, as here Gammarus is less tolerant. The increase in toxicity due to a reduction of dissolved oxygen concentration is also greater for Gammarus than for trout.

5. SYNTHESIS OF FIELD AND LABORATORY RESULTS

By using the results of the laboratory toxicity experiments and the chemical data collected from the field studies, an attempt was made to account for the distribution of Gammarus in the streams of the area. It has already been shown in section 3 that the distribution of Gammarus was correlated with the mean concentrations of the four major toxic metals, copper, zinc, chromium and nickel, found in the streams. The chemical data from the field studies was re-examined with reference to the laboratory results to determine whether the distribution of Gammarus could be similarly correlated and an attempt made to account for any discrepancies which occurred.

The mean concentrations of copper, zinc and chromium for the 24 month period at the main stations, 1-24, and the data from the additional stations, 25-37, have been extracted from Table 9 and are given in Table 54. The 48hrLC50 values at 300 mg/l water hardness (Table 51) have been used to determine the proportion of the 48hrLC50 concentration which was found in the field, enabling a sum of proportions to be calculated. Nickel has not been included, as the 48hrLC50 of 940 mg/l in 100 mg/l hardness water (Table 50) would be even greater at 300 mg/l, (Brown, 1968) and the field concentrations would contribute very little to the overall sum of proportions. The sums of proportions from Table 54 have been plotted on a line diagram (Fig. 42) in the same manner as for the individual chemicals (Fig. 15). It can be seen that the lowest value with Gammarus absent is 0.069, and the highest value with Gammarus present is 0.043 giving a very clear demarkation between presence and absence of Gammarus. Although 0.05 is slightly below the mean of the two values, it is proposed that this sum of proportions of the 48hrLC50 values should be taken as the field threshold, thus providing an additional safety margin.

Table 54. Sums of Proportions of copper, zinc and chromium from field chemical survey, relative to laboratory 48hrLC50 values

	Concentrations (mg/l)			Sum of
Station	Copper	Zinc	Chromium	Proportions
1a	0.13	0.18	0.04	0.069
2a	0.13	0.20	0.03	0.071
3	0.27	1.25	0.62	0.410
4a	0.33	0.73	0.08	0.220
5a	0.21	1.40	0.12	0.318
6	0.41	8.75	0.45	1.722
7a	0.14	0.41	0.03	0.110
8	0.09	2.57	0.05	0.482
9	0.14	1.33	0.10	0.286
10a	0.15	0.43	0.04	0.118
11a	6.60	0.60	0.04	1.613
12a	2.36	0.60	0.08	0.658
13a	0.35	1.00	0.19	0.294
14	0.34	1.14	0.17	0.313
15	0.26	0.78	0.12	0.221
16a	0.07	0.31	0.05	0.081
17a	0.36	0.55	0.24	0.228
18a	0.20	0.31	0.13	0.127
19a	0.05	0.10	0.02	0.033
20	0.05	0.10	0.01	0.031
21	0.07	0.12	0.02	0.041
22	0.07	0.13	0.02	0.043
23	0.06	0.09	0.02	0.033
24	0.06	0.10	0.02	0.035
25	0.06	0.08	0.02	0.032
26	0.02	0.05	0.02	0.017
27	0.03	0.36	0.02	0.074
28	0.02	0.09	0.03	0.026
29	0.17	0.19	0.14	0.101
30	0.16	4.86	0.03	0.895
31	0.09	6.30	0.03	1.132
32	0.19	1.26	0.15	0.295
33	0.19	2.22	0.12	0.457
34	0.03	0.12	0.03	0.034
35	0.04	0.16	0.03	0.043
36	0.02	0.10	0.02	0.026
37	1.11	4.23	0.30	1.057

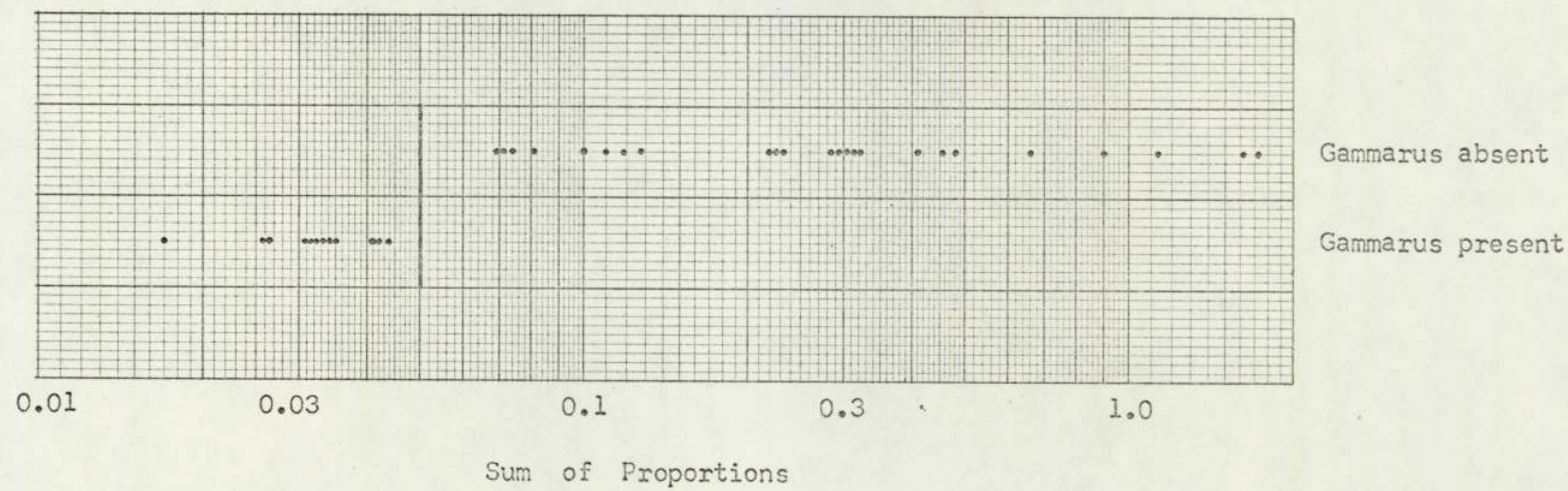


Fig. 42. Sums of proportions of copper, zinc and chromium from field chemical survey, relative to laboratory 48hrLC50 values.

In pollution and fishery work, methods of predicting the safe levels of pollution have frequently been used. These are the concentrations of pollutant which do not have an adverse sublethal or chronic effect on fish (Sprague, 1971). An 'application factor' is often used, which is the proportion of the known LC50 value at which the pollutant should be safe, and for which values of from 0.01 to 0.4 have been suggested. Higher values of from 0.6 to 0.7 have also been used, but these are only applicable for limited periods, frequently 48 hours. Herbert et al (1965) found that only a small percentage of rainbow trout would die within two days if the sum of the proportions of the 48hrLC50 values ever exceeded 0.7. Brown et al (1970), using data from Lloyd and Jordan (1963, 1964) calculated that 50% observed mortality occurred at a concentration level of 0.66 of the predicted value, based on the sum of the proportions of the 48hrLC50 values. This was similar to the level they obtained for studies on rivers, including the Tame and Cole.

It is, however, unlikely that fish would be able to survive for long periods at such high proportions. Sprague, Elson and Saunders (1965) found that Atlantic salmon could migrate upstream in a river with between 0.35 and 0.43 of the LC50 concentration of zinc and copper, with salmon parr living at a value of between 0.1 and 0.3. A mixed coarse fish population was found living in a sewage effluent channel at proportions of from 0.3 to 0.4, relative to rainbow trout (Allen et al, 1958). Edwards and Brown (1967) analysing the results from 100 stations within the Trent River Authority area, suggested that fish populations could be expected to exist where the sum of proportions of the 48hrLC50 values did not exceed 0.3 to 0.4, provided other conditions were also satisfied. Herbert et al (1965), however, thought that a factor of 0.2, with adequate dissolved oxygen, would be necessary before a fishery of some kind could be maintained. A concentration of 0.7 of the 48hrLC50 of zinc killed 10% of a batch of rainbow trout in 48 hours, and 32% in 6 days. A decrease to 0.4 caused only 3% mortality within 48 hours, and 25% in 5 months. A further reduction to 0.2 of the 48hrLC50 value produced no mortality in 200 fish within 48 hours, but 18% had died within 6 months (Brown et al, 1970). It was also shown that 0.2 of the 48hrLC50 of either cadmium, nickel, or chromium would cause over 50% mortality to rainbow trout within 10 days. A single 24 hour exposure to the 48hrLC50 concentration of cadmium caused 90% mortality within 10 days. This type of delayed action will be important in polluted water, and exposes one of the problems in assessing the long term toxicity from short term experiments. Lloyd and Orr (1969) experimenting with ammonia toxicity to trout concluded that the 'no-effect' level was 0.12 of the 48hrLC50 value. A value of 0.1 has frequently been used (Sprague, 1971) as a convenient proportion when no better data has been available. This value may still be too high, as application factors of 0.1 or 0.05 of the threshold (20 day LC50) are widely accepted in Holland, Germany and Switzerland (Warner, 1967). The U.S. National Technical Advisory Committee (1968) has recommended that levels of 0.1 or 0.05 should be used for non-persistent poisons, whereas levels down to 0.01 are more suitable for persistent chemicals and pesticides. Waller et al (1971) confirmed with a computer simulation that an application factor of 0.01 of the 96hrLC50 value for zinc should not normally cause extinction of populations of the fathead minnow (*Pimephales promelas* Rafinesque).

The value of 0.05 obtained from the present field studies does not therefore appear out of order. It is, however, only based on the three metals, copper, zinc and chromium, and if other chemical factors were included, would be higher. Nevertheless, it is thought that these three metals are probably the most important in the rivers of the industrial Midlands.

In the laboratory experiments with mixtures of copper, zinc and chromium, at various sums of proportions, the thresholds for 10%, 20% and 50% mortality have been found. Due to the slight above average susceptibility, indicated by a 48hrLC50 sum of proportions value of 0.82 instead of the expected 1.0, a small correction is necessary as previously applied to the 50% threshold. The threshold sum of proportions can therefore be taken as 10%, 0.09; 20%, 0.12 and 50%, 0.20. These values can be compared to the field threshold of 0.05 sum of proportions.

From the thresholds obtained from the laboratory experiments with single metals, (Table 51) sums of proportions for 10%, 20% and 50% mortality can be calculated, relative to the 48hrLC50. The values obtained, 10%, 0.15; 20%, 0.19 and 50%, 0.27 are somewhat higher than those for the single experiment with mixtures. It is not thought that this difference is significant, but represents experimental variation.

The laboratory experiments for determining the threshold values were all performed under saturated dissolved oxygen conditions. A reduction in the concentration of dissolved oxygen will lead to an increase in toxicity of copper and zinc (Fig. 41). Brown (1968) found it also applied to lead and gas-liquor phenols. It is probable that an increase in the toxicity of other metals will occur as dissolved oxygen concentration is reduced. From the field chemical data, a threshold value of 8.5 mg/l dissolved oxygen was obtained. This is based on day-time measurements and is probably much lower for a 24 hour period. By using Fig. 41, a factor of 0.83 at 10^{o}C can be extrapolated for correction of the 48hrLC50 value. Accepting that a similar factor is applicable to the threshold concentration for the three separate metals and for mixtures, the threshold values need to be reduced to allow for the oxygen deficit.

As already shown, water hardness will affect the toxicity of metals.

The rivers in the western, more industrial part of the area are usually at least 300 mg/l hardness, whereas the more rural Cole and Blythe are slightly softer, down to 250 mg/l hardness (Table 10). It is likely that the benthic animals will become acclimatized to a mean hardness, and will have a threshold tolerance to toxic substances. Short term decreases in water hardness should not produce additional mortality due to the increased toxicity of chemicals as the animals can be expected to behave as if still at the acclimatized hardness. However, the period of reduced hardness must not be sufficiently long for reacclimation, or the exposure time to a concentration above the threshold value longer than the reaction time. Increases in water hardness will reduce the toxicity, giving an additional safety margin.

The short term toxicity of metals has been found to increase with increases in temperature, although for zinc at least, the threshold concentration is independent of temperature (Lloyd, 1960). Increases in water temperature during the summer can therefore be expected to cause an increase in short term toxicity of metals, while the reverse will occur in winter. Any increase in toxic concentration above the threshold will cause greater mortality in summer than in winter.

The sum of proportions value calculated from the field data and the laboratory 48hrLC50 values has only included copper, zinc and chromium. As nickel and cadmium are long term poisons their presence in rivers would increase the sum of proportions value. Additional increases would also be caused by other unknown or unmeasured toxic chemicals. This additional toxicity is the reason that the observed 48hrLC50 is approximately 0.66 of the predicted 48hrLC50.

Decreases in the expected toxicity will be caused if complexes are formed with a toxicity less than the uncomplexed material. Copper is known to form complexes of reduced toxicity when non-toxic activated sludge effluent is added to toxic copper solutions (Jackson and Brown, 1970).

If the foregoing effects are considered, it is seen that both reduction in dissolved oxygen concentration and the presence of unknown or unmeasured toxic materials will increase the toxicity of polluted water. Temperature and water hardness variations can cause either an increase or decrease in toxicity, whilst the complexing action of organic pollution will often decrease the toxicity, especially with metals.

The proportion of the population which can be lost by a natural population without causing a long term decline in numbers is unknown. To determine this, information would be needed about population dynamics under field conditions. This would imply a knowledge of the life cycle, including the natality and mortality rates, and the minimum number of animals necessary to maintain the population. Chemicals which do not appear toxic over short or medium term periods can still be toxic over longer periods. The mortality of natural populations will be caused by both short and long term toxic chemicals. However, before long term effects can occur, the concentrations of short term toxic chemicals must be sufficiently low to allow some survival. The animals which are initially killed will be the ones with the lowest resistance, leaving a more resistant population. If different stages of the life-cycle have a different susceptibility, then the stage with the least resistance will become the limiting factor within the population. Waller et al (1970) calculated that if, due to zinc toxicity, the reduction in mean number of eggs laid by female fathead minnows increased from 50% to 79%, then the population would probably become extinct.

Sprague (1971) has suggested that the 'no-effect' concentration might be represented by a 1% or 5% mortality, which are values that can be calculated. Mortalities of this order could probably be accepted by a healthy population without detrimental effect. It is therefore thought that the laboratory thresholds for the sum of proportions, 10%, 0.09; 20%, 0.12 and 50%, 0.20, would require to be reduced to 5% or less to be comparable with the field data. After considering the number of modifying factors already discussed, the laboratory threshold for 5% mortality would probably be close to the value of 0.05 sum of proportions obtained from the field data.

The occurrence of Gammarus in streams has frequently been used as an indication of the degree of pollution. Kolkwitz and Marsson (1908) divided rivers undergoing recovery from organic pollution into four zones; polysaprobic, α-mesosaprobic, β-mesosaprobic and oligosaprobic, within their Saprobiensystem of classification. Tubifex and Chironomus riparius were included in the polysaprobic zone, although C. riparius also extends into the α-mesosaprobic zone. Asellus was placed in both the α-meso and β-mesosaprobic zones. Gammarus is found mainly in the oligosaprobic zone, but at times can survive in the β-mesosaprobic zone. Liebmann (1951) revised the system, but still relied mainly on microscopic organisms. In a more refined method, Woodiwiss (1964) allocated a Biotic Index to each of eleven sub-divisions, based on the number of groups of species and the relative tolerance of the animals. Gammarus was placed in the fourth section, with Biotic Index values of 3 to 7. It followed the sections with Plecoptera, Ephemeroptera and Trichoptera, and was in turn followed by Asellus and Tubificids and/or red chironomids. A seventh section allowed for all the above animals to be absent, and extended down to Biotic Index 0, indicating most severe pollution.

These systems have the disadvantage that only the occurrence, and not the frequency, is used in the classification. Methods using a frequency distribution, often based on percentage occurrence, are also used but the relationship between stations is more difficult with this system. Although suitable for organic pollution, both the Saprobien and Biotic Index methods are less applicable to toxic pollution. The relative tolerance of species to toxic pollution can differ from that due to organic pollution. Additional problems are caused by large clean rivers, where riffle areas are often absent with a consequent reduction in species present.

The maps of the distribution of Gammarus (Fig. 11), Asellus (Fig. 12), Chironomidae (Fig. 13) and Oligochaeta (Fig. 14) have been given in the section on the River Survey. It can be seen from Fig. 11 that the distribution of Gammarus is very restricted in the Cole, Tame and tributaries, but more frequent in the Blythe, Bourne and Langley Brook. The occasional stations on the Blythe with Gammarus absent are due to organic pollution in the upper parts, but before the Cole-Blythe confluence this is unlikely. At this station the substratum is compact and, with a fair depth of water, is not really a riffle area. At times the depth of water can increase to 3' (1m). The Cole, polluted almost at source, recovers to allow Gammarus in parts of the upper stretch. However, the grossly overloaded sewage works at Houndsfield Lane and other sources of organic pollution eliminate Gammarus below the works effluent. Two tributaries have Gammarus present in parts. Organic pollution from Houndsfield Lane continues, with some recovery, to the edge of the industrial area where it is supplemented by toxic discharges, so preventing Gammarus from existing in the lower reaches. Spark Brook and Tyseley Brook are both polluted, with Gammarus absent. It has been shown (Hawkes and Davies, 1970) that the night-time dissolved oxygen levels will eliminate Gammarus from organically polluted waters where the day-time levels appear satisfactory. It was shown by laboratory experiments that at 20^{o}C and 1 mg/l dissolved oxygen, 50% of Gammarus were killed within 5 hours. The absence of Gammarus from parts of Kingshurst Brook is probably due to lack of suitable riffle areas or possibly due to pollution. The Rea has Gammarus present at two stations in the upper parts but the other sources are organically polluted. Toxic pollution and lack of suitable habitats within the culverted section probably account for the absence of Gammarus down to the Tame junction. In the area of the upper Tame and tributaries, Gammarus was found at only four stations, all at the highest station on tributaries. As shown by the chemical analysis (Table 9) and subsequent discussion, the presence of metals, namely copper, zinc, chromium and possibly nickel, is responsible for the lack of Gammarus in the other tributaries, and extending to the main river downstream. It was found by Hawkes and Davies (1970) that the diel dissolved oxygen concentration in organically polluted water was more constant than in cleaner water, although at a lower level. This is caused by suppression of the microflora responsible for the day-time increase in dissolved oxygen concentration. The reduced dissolved oxygen level will increase the toxicity of copper and zinc as shown in the laboratory experiments (Fig. 41).

Asellus (Fig. 12) is slightly less restricted, although as it is present in riffles mainly as a replacement species, it does not usually occur together with Gammarus. In the Cole and Blythe it was found in regions where some recovery from organic pollution had taken place, but was eliminated or reduced in numbers where toxic pollution was present. The distribution in the upper Tame area was restricted by toxic pollution.

Chironomidae (Fig. 13) were found in almost all stations of the Blythe, Cole and Rea, but were absent from much of the Tame except in some higher reaches. The distribution map of Oligochaeta (Fig. 14) shows occurrence at most stations sampled. Very high toxic levels have eliminated it from parts of the upper Tame and tributaries and adverse physical conditions probably account for the absence at other stations.

It is apparent from these distributions that Oligochaeta can live in the majority of the polluted water of the Tame, provided the toxic level is not too great. Where the toxic level is less, Chironomidae can survive, usually maintaining populations even where gross organic pollution is present, such as in parts of the Cole. Asellus and Gammarus are almost completely eliminated by any toxic pollution. In clean water Gammarus is usually present, but is replaced by Asellus as the level of organic pollution increases.

In laboratory and field toxicity experiments, trout have been widely used as the test animal. They have the advantage of being easily obtainable from fish hatcheries in large numbers and in a required age range, and which can be expected to be a fairly uniform stock. The Salmonidae are the most sensitive fish to both organic and toxic pollution. However, the disadvantages of cost and the necessity of a Home Office licence reduce the advantages. Additionally there is the requirement of a large experimental space, preferably with flowing water and a temperature maintained at a reduced level of 10-15°C. Although some rivers may not be suitable for stocking with trout, it is possible that coarse fish would be able to survive due to their increased tolerance (Alabaster, 1969). However, as coarse fish are not so easily obtainable as trout, experiments are usually performed with fish netted from available sources. Many of the disadvantages found for trout are again present.

It is suggested that the use of Gammarus in toxicity experiments would overcome a number of these disadvantages. Gammarus can be obtained from many streams in large numbers which have a fairly uniform history. If careful grading is employed, a population of animals with a reasonably constant susceptibility should be obtained. Experimental facilities are much simpler than for trout, particularly with regard to space. This, combined with the ease of obtaining specimens, makes it possible to use more animals in each experiment, leading to more accurate results. Additionally no licence is required to perform experiments with Gammarus. The tolerance of Gammarus to pollution is greater than that of trout, and more resembles that of coarse fish. Lastly, if Gammarus is able to maintain a population under natural conditions, there is a possibility that coarse fish will also survive, with the advantage of a food supply.

6. CONCLUSIONS

1. From data obtained in biological and chemical surveys of streams in the Industrial Midlands, the field threshold values were found to be:-

Copper	0.075 mg/l
Zinc	0.15 mg/l
Chromium	0.025 mg/l
Nickel	0.06 mg/l
Ammonia	1.0 mg/l, as nitrogen
B.O.D. 5d, 20°C	7.0 mg/l
Daytime Dissolved Oxygen	8.5 mg/l

No thresholds could be deduced for oxidised nitrogen, permanganate value, pH or temperature.

2. A Toxicity Index*, calculated as the mean of the field concentrations of copper, zinc, chromium and nickel expressed as proportions of their field threshold values, was found to account for the presence or absence of Gammarus within the river system studied.

$$* \text{ Toxicity Index} = \frac{\frac{C_{Cu}}{T_{Cu}} + \frac{C_{Zn}}{T_{Zn}} + \frac{C_{Cr}}{T_{Cr}} + \frac{C_{Ni}}{T_{Ni}}}{4}$$

where C = Mean concentration of the metal present in the river

T = Field threshold concentration of the metal

When Toxicity Index > 1 Gammarus absent

Toxicity Index < 1 Gammarus present

For Gammarus to be present, in the absence of short term acute toxicity, the Toxicity Index should remain below 1 for 70% of the time.

3. At 100 mg/l water hardness, the 48hrLC50 concentrations were:-

Cyanide	0.52	mg/l
Copper	0.72	mg/l
Cadmium	0.82	mg/l
Ammonia - undissociated	1.42	mg/l as nitrogen
Chromium	1.6	mg/l
Zinc	2.4	mg/l
Lead	32	mg/l
Ammonia - total	78	mg/l as nitrogen
Phenol	103	mg/l
Nickel	940	mg/l

4. The toxicity of copper, zinc and chromium to Gammarus decreases as the water hardness increases.

5. At 300 mg/l water hardness, the 48hrLC50 concentrations were:-

Copper	4.4 mg/l
Chromium	4.8 mg/l
Zinc	5.7 mg/l

6. The differences in the 50% threshold concentrations at 100 mg/l and 300 mg/l water hardness were much less than for the 48hrLC50 concentrations. Threshold concentrations at 100 mg/l and 300 mg/l water hardness were respectively:-

Copper	0.20 mg/l and 0.55 mg/l
Zinc	0.35 mg/l and 0.50 mg/l
Chromium	0.15 mg/l and 0.30 mg/l

7. Nickel appeared non-toxic over short time periods, with a 48hrLC50 concentration at 100 mg/l water hardness of 940 mg/l. However, tests over longer periods indicated that it was toxic down to less than 1 mg/l.

8. The toxicity of copper and zinc increased as the dissolved oxygen decreased from 11 mg/l down to 2.5 mg/l.

9. The toxicity to Gammarus of mixtures of copper, zinc and chromium could be predicted by the addition of the component toxicities using the 'sum of proportions' rule.

10. A relationship was established between the observed field threshold toxicity and the experimentally determined 48hrLC50 concentrations of copper, zinc and chromium. It was found that when the concentrations of the three metals were expressed as proportions of their respective 48hrLC50 concentrations at 300 mg/l water hardness, and these proportions summed, then if this sum exceeded 0.05, Gammarus would be absent.

11. The absence of Gammarus pulex from streams could often be accounted for by the concentrations of copper, zinc, chromium and nickel, especially under the sub-saturated dissolved oxygen conditions associated with organic pollution.

12. Oligochaeta, and to a lesser extent, Chironomidae, were widely distributed and were usually only eliminated by extreme pollution.

13. *Gammarus pulex* can be used as an indicator organism for toxic pollution as well as for organic pollution.

14. *Gammarus pulex* is a suitable animal for laboratory toxicity tests, and could, with many advantages, replace the use of fish in toxicity tests.

7. APPENDIX 1. BIOLOGICAL SURVEY

Table 55. Classification of species or groups found during biological sampling

PLATYHELMINTHES

- Planaria torva (O.F. Müller)
- Polycelis nigra (O.F. Müller)
- Polycelis tenuis Ijima
- Polycelis felina (Dalyell)
- Dendrocoelum lacteum (Müll.)

OLIGOCHAETA

HIRUDINEA

- Glossiphonia complanata (L.)
- Helobdella stagnalis (L.)
- Haemopsis sanguisuga (L.)
- Erpobdella testacea (Sav.)
- Erpobdella octoculata (L.)

MOLLUSCA

- Potamopyrgus jenkinsi (Smith)
- Lymnaea peregra (Müll.)
- = Limnaea pereger (Müll.)
- Planorbis sp.
- Ancylus fluviatilis (Müll.)
- Sphaerium sp.
- Pisidium sp.

CRUSTACEA

- Gammarus pulex (L.)
- Asellus aquaticus L.
- Cyclops
- Daphnia

HYDRACARINA

PLECOPTERA

- Isoperla gramatica (Poda)

EPHEMEROPTERA

Baetis rhodani (Pict.)
Ephemerella ignita (Poda)
Rhithrogena semicolorata (Curt.)

HEMIPTERA

Nepa cinerea L.
Corixidae

NEUROPTERA

Sialis lutaria (L.)

TRICHOPTERA

Leptoceridae
Anabolia sp.
Agapetus sp.
Hydropsyche sp.
Polycentropidae

DIPTERA

Tipulidae
Simulium sp.
Chironomidae
Chironomus riparius Meigen
Tabanidae
Eristalis sp.

COELOPTERA

Haliplidae
Dytiscidae
Helophorus sp.
Helmis sp.

PISCES

Nemacheilus barbatulus L. (Stone-loach)
Cottus gobio L. (Bull-head)
Gasterosteus aculeatus L. (Three-spined stickleback)

Table 56. Fauna found at each station.
The names have been abbreviated to the genus or group, except for the following:-

P. torva	=	_Planaria torva_
P. nigra	=	_Polycelis nigra_
P. tenuis	=	_Polycelis tenuis_
P. felina	=	_Polycelis felina_
E. testacea	=	_Erpobdella testacea_
E. octoculata	=	_Erpobdella octoculata_
C. riparius	=	_Chironomus riparius_

Frequency has been recorded, as described in the text, according to the following:-

r	=	rare
o	=	occasional
c	=	common
n	=	numerous
vn	=	very numerous

Wolverhampton Tame

6	Noose Lane	Nil			
8	Moseley Road	Oligochaeta	c		
34	Waddens Brook, Lichfield Road	Oligochaeta	c	Lymnaea	o
		Asellus	o	Sphaerium	r
		Gammarus	o	_P. torva_	r
7	Waddens Brook, Noose Lane	Oligochaeta	c		
		Lymnaea	o		
9	Summerford Road	Oligochaeta	o		
43	Willenhall Works	Oligochaeta	o		

46	Pond overflow, Willenhall Works	Asellus	c		
47	Tributary, Bentley Mill Lane	Oligochaeta	r		
48	Bentley Mill Lane	Oligochaeta	r		
		Chironomidae	r		
32	Bescot	Nil			

Darlaston Brook

44	Meadow Lane, Bilston	Oligochaeta	o		
		Chironomidae	r		
45	Ladymoor Road, Bilston	Lymnaea	c	Oligochaeta	o
		Asellus	o	P. tenuis ? (imm)	r
30	Tributary, Broad Lanes, Bilston	Nil			
31	Bankfield Road, Bilston	Nil			
4	Above Lunt Road Works	Oligochaeta	o		
5	Below Lunt Road Works	Nil			
33	Willenhall Works	Nil			

Tipton Brook

29	Turlshill Road, below Gorge Road Works	Oligochaeta	c	C. riparius	o
		Chironomidae	c	Eristalis	r
2	Jessons Bridge, below Gorge Road Works	Oligochaeta	n	Chironomidae	r
		Sphaerium	o	C. riparius	r
49	Stream above Upper Gornal Works	Oligochaeta	r		
28	Tributary above Upper Gornal Works	Gammarus	o	Dytiscidae	r
		Oligochaeta	o	Sialis	r
		Chironomidae	r	P. nigra	r
		Tipulidae	r		
133	Below Upper Gornal Works	Oligochaeta	o		

1	Jessons Bridge, below Upper Gornal Works	Oligochaeta	n	Chironomidae	r
		Asellus	o	Sphaerium	r
		C. riparius	o		
50	Below Jessons Bridge	Oligochaeta	n	Chironomidae	o
		Asellus	o	C. riparius	r
51	Above Foxyards Works	Oligochaeta	n	E. testacea	r
		Chironomidae	r		
52	Below Foxyards Works	Oligochaeta	c		
3	Toll End Works	Nil			

Oldbury Tame

37	Above Roway Lane Works	Nil			
53	Below Tividale Works	Oligochaeta	n		
54	Tributary below Tividale Works	Oligochaeta	o		
55	Toll End Works	Oligochaeta	r		
56	Holloway Bank	Oligochaeta	n		
57	Hydes Bridge	Oligochaeta	r		

Goscote Brook

35	Wolverhampton Road	Gasterosteus	c	Dytiscidae	r
		Asellus	c	P. nigra	r
		Chironomidae	c	Hydracarina	r
		Gammarus	o	Tipulidae	r
		Oligochaeta	o		
11	Above Goscote Works	Nil			
12	Below Goscote Works	Nil			

Ford Brook

38	Above Walsall Wood Works	Dytiscidae	r		
39	Below Walsall Wood Works	Chironomidae	o	C. riparius	r

36	Tributary above Barns Lane Works	Potamopyrgus	vn	Sphaerium	o
		Gasterosteus	o	Haliplidae	o
		Oligochaeta	o	Corixidae	r
		Lymnaea	o	Gammarus	r
10	Tributary below Barns Lane Works	Oligochaeta	n	Chironomidae	r
		Lymnaea	c		
40	Station Road, Rushall	Oligochaeta	n	<u>C. riparius</u>	r
		Lymnaea	o		
41	Walsall Rail Goods Yard	Oligochaeta	c	<u>C. riparius</u>	r
		Chironomidae	r		
42	Bescot	Oligochaeta	o		
58	Fullbrook, Brockhurst	Chironomidae	c	Lymnaea	r
		Asellus	o	Cyclops	r
		<u>C. riparius</u>	o	Dytiscidae	r
		Oligochaeta	r		

<u>Tame</u>

13	Walsall - West Bromwich Road	Oligochaeta	o		
14	Newton Road	Oligochaeta	c		
134	Hampstead	Oligochaeta	o		
121	Parkhall Farm	Oligochaeta	o	Chironomidae	r
		Daphnia	o	Cyclops	r
122	Water Orton	Oligochaeta	n	Asellus	r
123	Curdworth	Oligochaeta	c		

<u>Rea</u>

59	Callow Brook	Chironomidae	c	Sphaerium	r
		Oligochaeta	o	<u>E. octocutata</u>	r
		Lymnaea	o	Tipulidae	r
		Potamopyrgus	r		

60	Holly Hill	Baetis	c	Oligochaeta	r
		Gammarus	c	Tipulidae	r
		Chironomidae	o	Simulium	o
61	Tessall Lane	Oligochaeta	c	Chironomidae	r
62	Tributary, Fairfax Road	Oligochaeta	c	<u>C. riparius</u>	r
		Chironomidae	c		
63	Wychall Road	Asellus	n	Oligochaeta	c
		Lymnaea	c	Chironomidae	o
64	Merritts Brook, Whitehill Avenue	Oligochaeta	c	Baetis	r
		Chironomidae	o		
65	Merritts Brook, Umberslade Road	Asellus	c	Lymnaea	o
		Oligochaeta	c	Baetis	o
		Chironomidae	c	Ancylus	o
		Sphaerium	c	Haemopsis	r
66	Cartland Road	Chironomidae	n	Lymnaea	r
		Asellus	c	<u>C. riparius</u>	r
		Oligochaeta	o		
67	Dogpool Lane	Chironomidae	n	Ancylus	o
		Asellus	c	Sphaerium	o
		Lymnaea	c	Oligochaeta	o
68	Tributary, Cromwell Lane	Baetis	o	Oligochaeta	o
		Gammarus	o	Tipulidae	r
		Chironomidae	o	Isoperla	r
69	Tributary, Mill Lane	Oligochaeta	n	Chironomidae	c
70	Bourn Brook, above Woodgate Works	Oligochaeta	n	Lymnaea	o
71	Bourn Brook, below Woodgate Works	Oligochaeta	c	Lymnaea	r
72	Bourn Brook, Swinford Road	Baetis	c	Tipulidae	r
		Lymnaea	c	Helophorus	r
		Chironomidae	o	Dytiscidae	r
		<u>E. octoculata</u>	r		

73	Bourn Brook, Harborne Lane	Oligochaeta	c	Lymnaea	r
		Asellus	o		
74	Tributary, Chad Valley, Harborne Road	Chironomidae	o	E. testacea	r
		Oligochaeta	r		
75	Edgbaston Road	Chironomidae	n		
76	Duddeston Mill Road	Chironomidae	o	Cyclops	r

Cole

77	Above 'Horse and Jockey'	Chironomidae	o	E. octoculata	r
		Oligochaeta	o		
78	'Horse and Jockey'	C. riparius	vn	Lymnaea	o
		Chironomidae	c	Asellus	r
		Oligochaeta	c	Gammarus	r
		Glossiphonia	o	Sialis	r
79	Tanners Green Lane	Chironomidae	c	Gammarus	o
		C. riparius	o	E. octoculata	o
		Baetis	o	Sialis	r
		Oligochaeta	o		
80	Lowbrook Bridge	Baetis	o	Helobdella	r
		Chironomidae	o	Hydropsyche	r
		Gammarus	o	Asellus	r
		Oligochaeta	o	Sialis	r
		E. octoculata	o		
81	Houndsfield Lane	Chironomidae	c	Gammarus	r
		Helobdella	c	Asellus	r
		Oligochaeta	o	Baetis	r
		E. octoculata	o	C. riparius	r
82	Tributary, Houndsfield Lane	C. riparius	n	Simulium	o
		Baetis	c	Oligochaeta	o
		Chironomidae	o	Helophorus	r

83	Trumans Heath Road	C. riparius	vn	Chironomidae	r
		Helobdella	r		
84	Peterbrook, Alcester Road	Gammarus	n	P. nigra	r
		Oligochaeta	c	Glossiphonia	r
		Chironomidae	o	Nepa	r
85	Peterbrook, Hollywood Road	Chironomidae	c	Gammarus	r
		Lymnaea	c	P. nigra	r
		Oligochaeta	o	Helophorus	r
		Asellus	r	Glossiphonia	r
		Baetis	r		
86	Peterbrook, Peterbrook Road	Baetis	c	Pisidium	r
		Gammarus	r	Glossiphonia	r
		Lymnaea	r	Helobdella	r
		Chironomidae	r	E. testacea	r
		Oligochaeta	r		
87	Aqueduct Road	C. riparius	n	Oligochaeta	r
		Chironomidae	c		
88	Slade Lane	Chironomidae	n	Oligochaeta	c
		C. riparius	c	E. testacea	r
89	Highfield Road	Oligochaeta	vn	Asellus	r
		Chironomidae	n	E. testacea	r
		C. riparius	c	E. octoculata	r
90	Chinn Brook, Bells Lane	Gammarus	c	Gasterosteus	o
		Chironomidae	c	Baetis	o
		Oligochaeta	c	E. testacea	r
		Potamopyrgus	c	Tipulidae	r
91	Chinn Brook, Yardley Wood Road	Chironomidae	o	Lymnaea	r
		Oligochaeta	o	Haemopsis	r
		Baetis	r		

92	Green Road	Oligochaeta	c	Baetis	r
		Chironomidae	o	Helobdella	r
		Asellus	r	<u>E. testacea</u>	r
93	Formans Road	Asellus	n	Sphaerium	r
		Oligochaeta	o	<u>E. octoculata</u>	r
		Chironomidae	o	Helobdella	r
94	Tyseley Brook	Oligochaeta	o		
27	Spark Brook	Nil			
95	Coventry Road	Oligochaeta	c	Lymnaea	c
		Chironomidae	c		
96	Stetchford Bridge	Oligochaeta	vn	Lymnaea	o
		Chironomidae	vn		
16	Cole Hall Lane	Oligochaeta	n	Lymnaea	o
		Chironomidae	c	Asellus	r
97	Lea Ford Road	Chironomidae	o	Oligochaeta	r
17	Bacons End	Oligochaeta	c	Chironomidae	o
18	Coleshill	Chironomidae	c	<u>C. riparius</u>	r
		Oligochaeta	c		
120	Shustoke	Oligochaeta	c	Chironomidae	o

<u>Kingshurst Brook</u>

106	Lyndon Brook, Mackadown Lane	Oligochaeta	c	Lymnaea	o
		Chironomidae	c	<u>E. octoculata</u>	r
		<u>C. riparius</u>	c		
103	Westley Brook, Fox Hollies Park	Chironomidae	c	Oligochaeta	r
		<u>C. riparius</u>	r		
104	Westley Brook, Gospel Lane	Baetis	o	Dytiscidae	o
		Oligochaeta	o	Helophorus	o
		Chironomidae	o	Simulium	r
		Lymnaea	o		
105	Westley Brook, Church Road	Chironomidae	c		

98	Hatchford Brook, Olton Park	Chironomidae	c		
99	Hatchford Brook, Wells Road	Oligochaeta	c	E. octoculata	o
		Asellus	o	Gasterosteus	o
		Potamopyrgus	o	Chironomidae	r
		Lymnaea	o		
100	Hatchford Brook, Rover Automobile Factory	Oligochaeta	c	Asellus	r
		Chironomidae	o	Lymnaea	r
		Gammarus	o	Cyclops	r
101	Hatchford Brook, Valley Road	Oligochaeta	c	Asellus	r
		Chironomidae	c	Sphaerium	r
		Lymnaea	c	Planorbis	r
		Cyclops	o		
102	Hatchford Brook, Coventry Road	Lymnaea	c	Potamopyrgus	r
		Asellus	o	E. octoculata	r
		Oligochaeta	o	Glossiphonia	r
		Chironomidae	o	Cyclops	r
107	Hatchford Brook, Eastern Bridge	Baetis	c	Potamopyrgus	r
		Oligochaeta	c	Asellus	r
		Lymnaea	o	Sphaerium	r
		Chironomidae	o	E. octoculata	r
108	Low Brook, Coventry Road (West Branch)	Potamopyrgus	c	Anabolia	r
		Gammarus	r	Chironomidae	r
109	Low Brook, Coventry Road (East Branch)	Gammarus	c	Ancylus	r
		Agapetus	c	Lymnaea	r
		Potamopyrgus	c	Glossiphonia	r
		Helmis	o	Cottus	r
		Baetis	o		

25 Low Brook, Marston Green	Baetis	c	Lymnaea	r
	Gammarus	o	P. tenuis	r
	Chironomidae	o	P. nigra	r
	Oligochaeta	o	E. octoculata	r
	Asellus	r	Helophorus	r

Blythe

110 Spring Brook	C. riparius	c	Sialis	o
	Chironomidae	o	Asellus	r
111 Chiswick Green	Gammarus	o	Gasterosteus	o
	Chironomidae	o	Cottus	r
	Baetis	o	Sialis	r
	Oligochaeta	o		
112 Tributary, Hay Lane	Chironomidae	c	Lymnaea	o
	Oligochaeta	c		
113 Widney Manor Road	Lymnaea	c	Potamopyrgus	r
	Chironomidae	o	E. octoculata	r
	Oligochaeta	o	Gasterosteus	r
	Gammarus	r		
20 Henwood Mill	Potamopyrgus	vn	Gasterosteus	o
	Pisidium	c	Tipulidae	o
	Asellus	o	Baetis	r
	Gammarus	o	Oligochaeta	r
	Ephemerella	o	Ancylus	r
	Chironomidae	o	Glossiphonia	r
	Lymnaea	o		

114	Cuttle Brook	Potamopyrgus	n	Helmis	o
		Gammarus	o	Glossiphonia	o
		Chironomidae	o	Sialis	r
		Lymnaea	o	Sphaerium	r
		Oligochaeta	o	Baetis	r
		Ephemerella	o	Cottus	r
		Ancylus	o		
115	Temple Balsall	Gammarus	c	Lymnaea	r
		Baetis	c	Helmis	r
		Chironomidae	o	E. octoculata	r
		Sphaerium	o	Glossiphonia	r
		Ephemerella	o	Sialis	r
		Oligochaeta	o	Planorbis	r
		Potamopyrgus	r	Nemacheilus	r
21	Hampton-in-Arden	Gammarus	c	Baetis	r
		Chironomidae	o	Oligochaeta	r
		Ephemerella	r	Polycentrobidae	r
		Helmis	r	Nemacheilus	r
		Ancylus	r		
116	Eastcote Brook	Asellus	c	Oligochaeta	c
		Simulium	c	Gammarus	o
		Chironomidae	c	Baetis	r
117	Eastcote Brook, before Blythe Confluence	Oligochaeta	n	Simulium	o
		Baetis	c	Asellus	r
		Chironomidae	o		
118	Stonebridge	Gammarus	c	Helmis	r
		Oligochaeta	c	Ephemerella	r
		Chironomidae	c	Glossiphonia	r
		Ancylus	o	Nemacheilus	r
		Baetis	r		

119	Shustoke	Lymnaea	c	Helmis	r
		Planorbis	c	Potamopyrgus	r
		Asellus	o	E. octoculata	r
		Ancylus	o	Oligochaeta	r
		Sphaerium	o	Leptoceridae	r
		Chironomidae	o	Nemacheilus	r
		Baetis	o		

Bourne

124	Didgley Brook	Gammarus	c	Rhithrogena	r
		Baetis	c	P. felina	r
		Sphaerium	r	Helmidae	r
125	Above Didgley Brook	Gammarus	c	Oligochaeta	r
		Baetis	o	Helmidae	r
		Chironomidae	r	Tabanidae	r
126	Below Didgley Brook	Gammarus	c	Rhithrogena	r
		Baetis	o		
127	Tributary below Arley Works	Gammarus	o	Oligochaeta	r
		Chironomidae	o		
128	Tributary, Tippers Hill Lane	Gammarus	c	Asellus	r
		Oligochaeta	r	Sialis	r
		Chironomidae	r	Glossiphonia	r
		Baetis	r	Dytiscidae	r
129	Furnace End	Gammarus	c	Lymnaea	r
		Baetis	o	Sphaerium	r
		Chironomidae	o	Helmis	r
		Oligochaeta	o	Dytiscidae	r
		Potamopyrgus	o		

130	Tributary, above Furnace End Works	Gammarus	c	Potamopyrgus	r
		Baetis	c	Oligochaeta	r
		Chironomidae	o	Hydropsyche	r
		Rhithrogena	r	Limnophilidae	r
		Helobdella	r		
24	Whitacre	Chironomidae	c	Gammarus	r
		Oligochaeta	c	Helobdella	r

<u>Langley Brook</u>

131	Tributary, Bodymoor Heath	Oligochaeta	c	Chironomidae	o
		Potamopyrgus	c	Sphaerium	r
		Glossiphonia	o	Hydropsyche	r
132	Collets Brook	Gammarus	c	Hydropsyche	r
		Simulium	o	Helmis	r
		Asellus	r	<u>P. nigra</u>	r
22	Above Langley Works	Gammarus	n	Potamopyrgus	r
		Baetis	o	<u>E. octoculata</u>	r
		Asellus	r	Gasterosteus	r
		Chironomidae	r	Dendrocoelum	r
		Oligochaeta	r		
23	Middleton	Gammarus	c	Oligochaeta	o
		Baetis	c	Agapetus	o
		Potamopyrgus	c	Sialis	r
		Helmis	c	Hydropsyche	r
		Chironomidae	o	Glossiphonia	r

8. APPENDIX 2. CHEMICAL SURVEY

Table 57. Results of analysis of samples from chemical survey

Ammonia	=	Ammoniacal Nitrogen
Ox.Nit	=	Oxidised Nitrogen
PV	=	Permanganate Value
BOD	=	Biochemical Oxygen Demand
Temp	=	Temperature ^{o}C
Dis. Oxy	=	Dissolved Oxygen
Fe	=	Iron
Cr	=	Chromium
Cu	=	Copper
Ni	=	Nickel
Zn	=	Zinc

All concentrations are given in mg/l.

The sampling stations are the same as those of corresponding number in the biological survey.

STATION 1. STREAM BELOW UPPER GORNAL.

Date	Ammonia	Ox.Nit	PV	BOD	pH	Temp	Dis.Oxy	Fe	Cr	Cu	Ni	Zn
Sep 68	0.7	37.0	5.0	6.6	6.9	15.0	8.26	1.17	0.03	0.10	0.00	0.18
Oct 68	2.7	20.3	4.1	17.8	7.5	12.2	7.40	0.69	0.05	0.10	0.13	0.14
Nov 68	7.7	13.7	6.5	16.0	7.6	10.0	7.62	0.12	0.01	0.18	0.06	0.10
Dec 68	3.4	13.0	27.0	43.6	7.3	5.8	4.50	26.00	0.05	0.31	0.05	0.66
Jan 69	2.4	8.8	13.0	19.2	7.2	7.6	6.82	0.00	0.08	0.25	0.04	0.17
Feb 69	6.2	13.7	6.8	16.8	7.5	5.0	7.20	1.80	0.02	0.22	0.00	0.52
Mar 69	6.4	10.7	10.8	34.6	7.5	5.2	10.00	0.52	0.02	0.10	0.00	0.18
Apl 69	4.1	12.2	13.7	25.8	7.1	9.8	8.26	2.40	0.06	0.09	0.00	0.15
May 69	2.0	9.3	11.5	30.2	7.2	12.6	7.48	2.00	0.00	0.16	0.00	0.14
Jne 69	1.3	10.6	10.0	15.6	7.3	14.8	7.60	1.10	0.06	0.09	0.00	0.09
Jly 69	7.5	7.0	13.5	13.6	7.7	19.8	4.00	1.30	0.04	0.16	0.04	0.15
Aug 69	2.5	13.0	6.0	7.3	7.7	18.0	7.30	0.45	0.12	0.05	0.04	0.13
Sep 69	2.5	19.5	10.0	7.1	7.3	13.6	6.00	1.88	0.03	0.10	0.05	0.17
Oct 69	10.0	20.0	15.5	24.2	7.4	14.2	5.30	1.00	0.04	0.14	0.04	0.10
Nov 69	5.0	12.0	12.5	8.6	7.5	6.5	9.70	4.75	0.13	0.20	0.90	0.38
Dec 69	9.5	11.5	7.5	10.0	7.4	7.5	8.60	1.55	0.07	0.05	0.17	0.11
Jan 70	4.0	12.0	4.9	10.0	7.4	7.5	8.80	1.35	0.00	0.05	0.03	0.09
Feb 70	3.0	12.5	3.0	5.2	7.7	7.0	9.21	1.77	0.01	0.05	0.06	0.10
Mar 70	2.0	10.5	4.8	5.6	7.5	8.0	9.80	0.83	0.01	0.07	0.11	0.08
Apl 70	3.0	9.0	10.0	15.4	7.9	8.5	9.90	1.20	0.04	0.11	0.04	0.13
May 70	6.0	7.5	16.0	25.0	7.7	14.6	6.56	2.18	0.01	0.14	0.04	0.22
Jne 70	3.2	20.0	14.5	10.6	8.2	19.0	8.08	1.62	0.03	0.11	0.07	0.16
Jly 70	6.0	22.5	15.5	20.4	7.5	17.5	6.88	1.40	0.05	0.11	0.24	0.16
Aug 70	3.6	14.5	13.9	15.0	7.5	17.0	6.08	0.81	0.01	0.10	0.05	0.10
Mean	4.4	14.2	10.7	16.8	7.5	11.5	7.56	2.41	0.04	0.13	0.09	0.18
Nov 70	2.5	6.5	15.5	8.0	7.4	8.0	9.08	6.69	0.03	0.10	0.11	0.47
Dec 70	2.0	9.7	4.7	5.5	7.6	8.0	8.40	0.91	0.03	0.07	0.03	0.10
Jan 71	4.0	14.2	7.0	9.0	7.7	6.7	8.40	1.00	0.03	0.10	0.08	0.07
Feb 71	5.0	9.5	6.0	12.0	7.2	7.0	10.00	1.11	0.00	0.03	0.06	0.06
Mar 71	3.5	13.5	6.4	6.0	7.7	9.0	8.20	0.82	0.02	0.24	0.06	0.21
Apl 71	3.5	8.8	5.0	11.5	7.6	12.0	8.76	0.46	0.02	0.03	0.04	0.07
Mean	3.4	10.4	7.4	8.7	7.5	8.4	8.81	1.83	0.02	0.10	0.06	0.16

STATION 2. STREAM BELOW GORGE ROAD.

Date	Ammonia	Ox.Nit	PV	BOD	pH	Temp	Dis.Oxy	Fe	Cr	Cu	Ni	Zn
Sep 68	8.9	22.4	10.5	13.0	7.2	15.2	5.80	3.12	0.03	0.15	0.00	0.08
Oct 68	0.0	27.5	4.2	3.0	7.7	12.4	9.42	0.39	0.06	0.06	0.20	0.08
Nov 68	0.0	25.5	4.5	5.4	7.8	9.6	9.56	0.44	0.01	0.06	0.11	0.09
Dec 68	2.0	23.7	26.5	41.4	7.5	5.4	8.45	13.75	0.02	0.27	0.05	0.73
Jan 69	3.3	12.3	8.4	16.6	7.2	7.5	6.64	1.20	0.07	0.23	0.00	0.12
Feb 69	3.2	19.3	19.5	29.4	7.7	4.5	9.58	2.30	0.02	0.25	0.00	0.54
Mar 69	8.0	20.5	7.5	6.6	7.9	5.4	10.63	1.20	0.03	0.08	0.00	0.13
Apl 69	6.0	24.5	21.5	39.0	7.2	9.0	6.40	4.90	0.02	0.13	0.00	0.29
May 69	0.7	13.5	62.0	100.0	7.3	12.2	2.54	8.30	0.06	0.48	0.00	0.63
Jne 69	6.0	23.5	10.4	9.0	7.2	14.4	8.40	1.50	0.03	0.09	0.00	0.09
Jly 69	0.0	40.0	9.9	4.8	7.6	18.0	7.82	0.84	0.00	0.17	0.06	0.14
Aug 69	3.0	21.0	4.7	2.1	7.9	16.9	7.90	0.46	0.00	0.01	0.05	0.09
Sep 69	0.0	28.5	9.0	2.2	7.2	14.6	8.00	1.80	0.04	0.06	0.03	0.16
Oct 69	0.0	32.0	7.7	2.4	7.2	14.2	8.00	0.80	0.06	0.13	0.07	0.06
Nov 69	1.5	14.0	10.8	5.2	7.4	6.9	10.50	2.00	0.04	0.08	0.21	0.16
Dec 69	0.0	20.0	3.8	3.0	7.0	7.0	11.08	0.75	0.10	0.06	0.11	0.11
Jan 70	1.5	17.5	3.0	4.9	7.5	8.0	11.00	0.65	0.00	0.03	0.02	0.07
Feb 70	1.3	24.2	11.6	8.5	7.5	8.0	9.89	2.52	0.04	0.10	0.09	0.16
Mar 70	0.5	19.0	7.6	6.4	7.8	8.0	8.92	5.41	0.02	0.10	0.10	0.13
Apl 70	0.5	17.0	8.0	6.6	8.0	8.0	9.98	1.27	0.04	0.11	0.05	0.11
May 70	0.5	24.0	15.1	13.2	7.8	13.2	8.08	2.08	0.00	0.09	0.02	0.15
Jne 70	3.3	41.0	32.7	20.5	7.6	17.0	5.60	7.39	0.03	0.22	0.20	0.44
Jly 70	5.5	29.5	18.0	20.8	7.2	16.4	7.74	3.02	0.04	0.09	0.11	0.21
Aug 70	7.9	18.5	11.8	17.6	7.4	16.5	6.76	0.37	0.03	0.11	0.07	0.12
Mean	2.6	23.3	13.7	15.9	7.5	11.2	8.28	2.77	0.03	0.13	0.06	0.20

Nov 70	0.5	17.2	10.0	8.6	7.2	8.5	9.98	3.61	0.02	0.04	0.06	0.26
Dec 70	0.5	17.7	8.3	10.7	7.8	8.5	10.00	0.87	0.05	0.08	0.05	0.08
Jan 71	6.5	17.0	4.5	7.9	7.8	7.1	8.42	0.81	0.02	0.07	0.06	0.06
Feb 71	7.5	20.7	10.2	16.8	7.8	7.5	9.30	1.88	0.00	0.09	0.06	0.12
Mar 71	3.5	7.8	6.4	7.2	7.6	8.5	9.20	1.89	0.02	0.07	0.05	0.09
Apl 71	7.0	23.6	15.2	10.4	7.7	12.0	6.64	1.48	0.00	0.09	0.06	0.18
Mean	4.2	17.3	9.1	10.3	7.6	8.7	8.92	1.76	0.02	0.07	0.06	0.13

STATION 3. TIPTON BROOK ABOVE TOLL END.

Date	Ammonia	Ox.Nit	PV	BOD	pH	Temp	Dis.Oxy	Fe	Cr	Cu	Ni	Zn
Sep 68	6.0	10.6	9.0	26.4	6.8	15.4	4.24	31.25	0.16	0.06	0.79	0.67
Oct 68	0.9	12.2	29.0	61.6	7.2	12.3	4.44	45.60	1.65	0.33	0.70	2.50
Nov 68	7.8	8.0	17.7	48.4	7.1	10.2	6.30	19.25	0.62	0.17	1.60	0.86
Dec 68	4.2	6.5	22.5	54.0	7.0	6.0	7.16	23.10	1.70	0.35	0.79	1.70
Jan 69	3.7	6.5	16.0	22.4	6.9	9.0	8.04	13.00	0.57	0.38	0.61	0.67
Feb 69	5.2	9.9	19.4	35.6	6.7	5.0	9.20	2.30	0.04	0.50	0.00	0.62
Mar 69	7.2	6.5	54.0	83.0	6.7	7.2	3.80	92.50	0.55	0.58	0.43	1.75
Apl 69	2.5	7.7	15.8	35.2	6.7	9.8	4.82	36.50	1.25	0.22	0.82	1.71
May 69	2.5	13.6	11.0	41.2	6.6	13.6	6.04	30.00	1.16	0.22	0.88	0.32
Jne 69	1.8	6.8	12.5	26.8	6.9	15.4	6.00	16.25	0.47	0.23	1.07	1.84
Jly 69	5.0	5.0	39.6	44.0	6.4	18.4	4.50	86.50	0.62	1.01	0.80	7.75
Aug 69	4.0	4.5	15.0	18.0	7.3	18.4	3.00	19.00	0.12	0.15	0.21	0.50
Sep 69	5.0	6.0	14.5	46.8	7.3	14.9	5.02	12.30	0.60	0.31	0.69	0.83
Oct 69	10.0	5.0	18.0	32.0	7.1	15.0	2.68	24.75	1.10	0.16	1.39	0.52
Nov 69	2.5	7.5	13.0	8.8	7.2	9.3	8.00	8.80	0.14	0.16	2.41	0.64
Dec 69	5.5	13.0	16.5	24.0	6.6	8.0	1.46	78.50	0.75	0.08	0.64	0.50
Jan 70	3.5	9.5	12.5	26.0	7.2	9.0	5.70	19.00	0.21	0.18	0.84	0.91
Feb 70	4.0	16.0	12.1	22.4	7.3	8.0	6.60	30.40	0.36	0.30	0.50	1.37
Mar 70	2.5	11.5	14.0	28.0	6.9	8.0	3.62	34.10	0.07	0.18	1.11	0.46
Apl 70	2.5	9.5	6.5	4.0	6.9	9.5	6.48	43.54	0.21	0.09	0.69	0.46
May 70	6.0	7.0	27.5	26.8	6.4	14.0	2.22	107.20	0.79	0.21	2.61	0.81
Jne 70	4.3	9.5	10.4	6.0	6.8	17.5	3.70	74.50	0.35	0.10	0.66	0.87
Jly 70	7.0	6.5	22.5	42.0	7.0	17.0	1.06	69.75	0.99	0.12	0.62	0.91
Aug 70	4.4	5.9	26.0	35.6	6.8	17.0	3.02	68.75	0.33	0.30	0.46	0.75
Mean	4.5	8.5	18.9	33.3	6.9	12.0	4.88	41.12	0.62	0.27	0.89	1.25

STATION 4. STREAM ABOVE LUNT ROAD.

Date	Ammonia	Ox.Nit	PV	BOD	pH	Temp	Dis.Oxy	Fe	Cr	Cu	Ni	Zn
Sep 68	2.6	5.0	3.5	4.9	7.0	19.6	6.80	3.00	0.14	0.55	0.65	1.25
Oct 68	1.4	4.3	3.5	6.4	7.3	17.0	6.32	1.27	0.07	0.57	0.10	0.42
Nov 68	0.8	2.8	3.5	23.2	7.2	14.0	7.60	0.79	0.03	0.06	0.11	0.50
Dec 68	0.5	2.7	5.8	21.8	7.2	11.5	5.80	4.00	0.01	0.36	0.06	1.20
Jan 69	0.0	3.3	6.0	14.6	7.1	11.2	7.61	4.00	0.09	0.53	0.09	0.63
Feb 69	2.0	4.4	3.0	8.1	7.2	12.6	7.70	28.00	0.50	0.03	0.00	1.80
Mar 69	0.0	0.0	4.5	30.2	7.2	9.8	8.05	2.30	0.03	0.50	0.06	0.45
Apl 69	0.0	2.7	4.5	5.0	7.1	15.0	6.50	2.50	0.06	0.31	0.00	0.96
May 69	0.0	3.9	5.6	12.8	7.0	17.4	7.40	2.44	0.07	0.18	0.19	1.03
Jne 69	0.7	3.6	5.7	18.4	7.0	18.6	7.14	2.00	0.10	0.38	0.07	0.56
Jly 69	0.0	3.0	6.0	13.4	7.3	20.0	6.60	1.48	0.08	0.47	0.07	0.53
Aug 69	0.0	3.5	4.5	7.2	7.1	20.0	6.54	1.55	0.13	0.22	28.50	1.01
Sep 69	0.0	3.5	1.5	5.9	7.3	18.0	6.20	4.26	0.01	0.22	0.03	0.31
Oct 69	0.0	2.5	4.2	14.5	7.2	18.0	6.20	1.92	0.06	0.17	0.04	0.37
Nov 69	0.0	3.0	7.0	17.4	7.1	10.1	7.62	3.45	0.06	0.29	0.44	0.64
Dec 69	0.0	4.0	4.0	2.4	7.0	13.0	7.70	1.50	0.04	0.19	0.30	0.52
Jan 70	1.0	5.0	1.8	7.8	7.4	14.5	8.20	1.87	0.00	0.29	0.01	0.43
Feb 70	2.5	5.5	1.0	4.6	7.3	13.5	6.34	3.62	0.12	0.33	0.16	0.39
Mar 70	0.5	6.0	3.8	8.0	7.5	15.5	8.78	8.05	0.00	0.32	0.12	0.26
Apl 70	0.5	5.5	1.0	2.0	7.3	13.5	7.22	0.06	0.02	0.24	0.06	0.37
May 70	0.0	3.0	4.5	21.6	7.3	18.0	6.94	1.87	0.07	0.92	0.05	0.39
Jne 70	3.8	6.5	2.0	4.5	7.6	21.0	6.30	2.72	0.06	0.32	0.06	1.24
Jly 70	4.5	5.0	3.0	4.5	7.0	20.5	7.44	1.29	0.09	0.27	0.12	1.25
Aug 70	0.3	3.7	4.0	8.6	7.1	19.0	7.64	1.49	0.05	0.22	0.05	1.04
Mean	0.9	3.8	3.9	11.1	7.2	15.9	7.11	3.56	0.08	0.33	1.31	0.73
Nov 70	0.5	3.4	11.0	12.6	7.1	16.0	7.92	10.12	0.04	0.35	0.08	3.37
Dec 70	0.5	6.0	2.5	9.5	7.3	16.0	7.12	2.06	0.01	0.20	0.06	2.00
Jan 71	1.0	6.0	2.2	6.5	7.6	13.5	4.82	1.07	0.02	0.20	0.08	1.33
Feb 71	5.5	8.5	3.0	16.4	7.3	15.0	7.10	5.61	1.00	0.42	0.71	4.05
Mar 71	2.0	5.0	7.5	25.7	7.2	14.0	7.30	10.27	0.13	0.45	1.36	5.12
Apl 71	8.0	5.0	9.0	18.2	7.2	17.0	5.90	1.93	0.05	0.58	0.10	5.70
Mean	2.9	5.6	5.9	14.8	7.3	15.2	6.69	5.18	0.21	0.37	0.40	3.63

STATION 5. STREAM BELOW LUNT ROAD.

Date	Ammonia	Ox.Nit	PV	BOD	pH	Temp	Dis.Oxy	Fe	Cr	Cu	Ni	Zn
Sep 68	11.4	3.7	9.0	41.2	7.0	18.2	3.04	2.55	0.36	0.26	0.45	0.89
Oct 68	17.5	5.3	13.8	34.4	7.5	15.0	2.40	2.50	0.14	0.25	0.25	0.83
Nov 68	16.7	1.8	13.2	34.8	7.5	10.8	4.32	1.86	0.10	0.11	0.31	0.80
Dec 68	13.0	1.8	20.5	57.6	7.3	7.4	3.85	6.37	0.13	0.24	0.37	2.20
Jan 69	14.0	2.4	20.6	46.4	7.3	10.0	3.90	4.50	0.11	0.14	0.38	1.51
Feb 69	20.5	2.2	19.7	54.0	7.5	9.0	3.84	3.39	0.10	0.35	0.09	0.86
Mar 69	22.7	2.7	31.0	61.6	7.5	13.0	2.90	3.70	0.11	0.26	0.29	1.36
Apl 69	17.9	1.7	25.7	58.0	7.5	11.6	3.30	1.90	0.09	0.14	1.35	0.71
May 69	18.8	1.1	21.0	102.0	7.2	15.2	3.60	5.84	0.24	0.18	0.19	2.54
Jne 69	10.7	3.1	16.5	30.8	7.2	15.8	3.68	6.25	0.08	0.23	0.10	1.25
Jly 69	17.5	0.0	22.7	48.4	7.5	20.2	1.22	3.40	0.10	0.35	0.22	1.24
Aug 69	12.0	2.5	14.0	20.6	7.4	19.2	2.87	3.70	0.08	0.19	4.75	1.70
Sep 69	19.0	2.0	19.0	28.8	7.5	16.0	2.40	6.80	0.00	0.22	0.24	2.82
Oct 69	21.0	0.0	20.7	56.0	7.6	16.6	2.42	3.80	0.09	0.16	0.40	1.21
Nov 69	13.0	5.5	19.0	30.0	7.0	8.5	6.02	4.30	0.14	0.25	0.70	1.24
Dec 69	13.5	6.0	12.1	15.6	7.0	11.0	4.86	2.12	0.17	0.12	1.30	0.64
Jan 70	16.0	6.0	18.5	44.8	7.0	10.8	5.52	3.27	0.19	0.30	0.11	1.97
Feb 70	13.0	8.0	10.7	18.8	7.5	9.5	5.12	5.95	0.09	0.24	0.25	0.81
Mar 70	16.5	4.5	25.5	73.2	7.5	11.0	6.28	5.80	0.11	0.32	0.25	1.76
Apl 70	13.0	6.5	12.5	26.4	7.5	11.5	5.72	1.74	0.05	0.17	0.10	0.46
May 70	19.0	1.0	18.1	46.4	7.7	16.5	4.74	4.38	0.06	0.20	0.11	1.14
Jne 70	20.0	1.0	20.0	36.8	7.7	20.5	2.80	3.31	0.15	0.16	0.12	3.10
Jly 70	22.0	6.0	19.0	43.2	7.3	19.0	2.28	4.65	0.16	0.14	0.40	1.69
Aug 70	10.4	5.0	18.3	29.2	7.4	18.0	3.28	2.12	0.06	0.19	0.10	0.89
Mean	16.2	3.3	18.4	43.3	7.4	13.9	3.76	3.92	0.12	0.21	0.53	1.40
Nov 70	12.2	4.9	30.6	102.4	7.2	12.5	6.70	4.69	1.42	0.25	0.13	1.37
Dec 70	15.5	10.0	19.5	52.0	7.5	12.5	5.28	3.00	0.16	0.18	0.12	1.25
Jan 71	19.5	6.7	19.2	44.0	7.5	10.5	5.00	3.72	0.11	0.18	0.27	1.50
Feb 71	20.0	9.5	22.0	55.2	8.1	12.5	4.52	3.50	0.22	0.19	0.49	1.80
Mar 71	13.5	4.6	20.0	57.6	7.4	11.5	6.02	6.69	0.12	0.23	0.81	3.75
Apl 71	23.0	7.6	21.5	46.2	7.6	14.2	3.10	2.87	0.11	0.16	0.25	3.62
Mean	17.3	7.2	22.1	59.6	7.5	12.3	5.10	6.08	0.36	0.20	0.34	2.21

STATION 6. TAME AT NOOSE LANE.

Date	Ammonia	Ox.Nit	PV	BOD	pH	Temp	Dis.Oxy	Fe	Cr	Cu	Ni	Zn
Sep 68	2.4	8.9	12.0	52.4	7.3	22.0	7.00	69.00	0.41	1.55	2.67	5.70
Oct 68	1.1	14.2	12.0	14.4	7.3	18.0	8.40	19.00	0.49	0.74	1.35	5.50
Nov 68	1.5	12.3	8.9	20.8	7.3	15.0	6.38	16.70	0.20	0.29	0.66	3.22
Dec 68	2.2	2.0	11.0	20.0	7.2	10.6	7.40	13.75	0.22	0.60	0.45	8.00
Jan 69	0.0	0.6	15.5	17.6	4.9	14.0	0.47	126.00	0.36	0.69	0.85	68.00
Feb 69	1.6	12.3	7.7	15.6	7.5	10.2	9.08	11.70	0.38	0.44	0.74	4.15
Mar 69	1.8	9.9	9.9	46.0	7.4	7.0	7.83	14.10	2.32	0.48	0.66	3.10
Apl 69	0.0	5.8	20.0	30.0	6.9	16.0	4.50	55.00	0.69	0.67	1.00	4.10
May 69	0.5	13.8	8.0	30.4	5.6	20.8	9.00	48.70	0.18	0.88	0.32	6.30
Jne 69	1.8	8.2	6.7	13.2	6.8	18.0	3.70	16.25	0.02	0.16	0.93	3.55
Jly 69	0.0	6.0	26.5	69.2	5.8	24.5	1.32	109.50	4.81	0.95	1.59	11.45
Aug 69	0.0	10.5	9.0	7.2	9.1	21.8	6.50	4.87	0.11	0.24	0.20	0.76
Sep 69	2.0	1.0	9.1	28.0	7.2	20.0	5.40	16.00	0.02	0.22	0.06	3.15
Oct 69	0.0	1.5	9.4	51.6	7.5	20.0	6.20	15.70	0.16	0.42	0.00	1.64
Nov 69	2.0	9.5	7.6	2.8	7.2	6.1	7.46	2.62	0.02	0.11	0.35	0.67
Dec 69	0.0	3.0	5.5	9.2	7.4	8.5	7.20	3.40	0.08	0.07	0.10	1.89
Jan 70	1.5	4.0	3.0	6.4	7.7	14.0	7.76	3.40	0.10	0.22	0.03	1.52
Feb 70	10.0	5.0	3.6	11.0	6.4	11.0	5.54	25.00	0.05	0.20	0.17	57.00
Mar 70	2.0	5.5	12.0	14.0	7.5	12.0	6.69	3.83	0.01	0.20	0.11	2.07
Apl 70	1.5	4.0	4.4	3.6	7.3	15.0	7.84	13.55	0.05	0.10	0.09	3.00
May 70	1.0	4.5	4.1	10.2	7.7	22.2	6.88	7.05	0.01	0.15	0.04	3.65
Jne 70	1.8	3.5	5.0	9.8	7.9	22.0	6.00	13.56	0.09	0.11	0.07	4.90
Jly 70	0.0	1.5	5.0	11.0	7.3	23.0	5.34	7.12	0.05	0.22	0.10	1.50
Aug 70	0.3	1.8	4.3	5.6	7.3	20.5	6.72	2.69	0.03	0.12	0.10	5.25
Mean	1.5	6.2	9.2	20.8	7.1	16.3	6.28	25.77	0.45	0.41	0.53	8.75

STATION 7. WADDENS BROOK AT NOOSE LANE.

Date	Ammonia	Ox.Nit	PV	BOD	pH	Temp	Dis.Oxy	Fe	Cr	Cu	Ni	Zn
Sep 68	15.4	12.7	23.3	57.2	7.0	18.4	0.70	3.40	0.05	0.16	0.02	0.33
Oct 68	6.8	20.8	8.5	19.6	7.4	14.6	2.64	1.57	0.03	0.08	0.02	0.24
Nov 68	4.8	21.0	6.8	13.0	7.4	10.2	6.10	2.60	0.01	0.15	0.21	0.32
Dec 68	10.6	18.0	13.0	20.4	7.4	6.5	6.90	3.50	0.01	0.16	0.03	0.74
Jan 69	3.2	15.0	7.7	11.6	6.9	9.0	7.03	3.04	0.06	0.33	0.09	0.83
Feb 69	8.3	20.0	9.0	15.6	7.5	6.0	6.90	2.60	0.03	0.14	0.05	0.50
Mar 69	7.2	21.3	12.7	8.6	7.5	7.0	5.50	1.79	0.07	0.09	0.00	0.39
Apl 69	1.4	17.4	23.6	17.6	7.1	10.6	6.70	7.70	0.00	0.08	0.00	0.51
May 69	3.8	18.8	8.2	11.4	7.1	14.6	5.76	36.10	0.16	0.98	0.00	1.91
Jne 69	3.7	17.8	10.5	12.8	7.0	17.0	4.30	4.62	0.00	0.16	0.00	0.34
Jly 69	2.0	20.0	10.0	10.8	7.3	21.0	3.40	1.56	0.03	0.15	0.04	0.22
Aug 69	3.0	16.5	9.5	7.2	7.7	21.0	1.90	1.70	0.00	0.08	0.07	0.19
Sep 69	3.0	21.0	10.3	8.6	7.4	15.5	2.56	1.62	0.00	0.06	0.03	0.25
Oct 69	7.5	23.0	15.3	12.4	7.3	16.0	2.40	2.38	0.03	0.10	0.00	0.17
Nov 69	2.0	11.0	8.6	3.2	7.3	6.6	8.20	2.37	0.02	0.12	0.31	0.49
Dec 69	7.0	17.5	10.3	6.8	7.5	9.0	6.56	4.05	0.09	0.06	0.11	0.29
Jan 70	2.0	12.0	4.4	3.0	7.6	8.5	8.40	1.50	0.03	0.05	0.01	0.23
Feb 70	3.5	18.0	6.5	5.4	7.5	8.0	8.00	3.52	0.03	0.06	0.12	0.33
Mar 70	4.0	15.0	8.0	6.8	7.6	8.0	7.80	1.82	0.01	0.06	0.12	0.17
Apl 70	3.0	13.0	9.0	5.5	7.7	11.0	10.45	1.22	0.02	0.07	0.10	0.43
May 70	19.0	25.0	14.7	12.2	7.7	15.2	6.00	2.75	0.01	0.07	0.07	0.23
Jne 70	20.7	30.0	15.8	6.8	7.7	19.5	4.40	3.00	0.02	0.11	0.07	0.31
Jly 70	2.5	26.5	11.3	8.2	7.3	18.2	3.96	1.94	0.00	0.06	0.04	0.24
Aug 70	1.5	18.1	9.2	9.8	7.4	17.5	3.36	0.62	0.02	0.08	0.07	0.12
Mean	6.1	18.7	11.1	12.3	7.4	12.9	5.41	4.04	0.03	0.14	0.07	0.41
Nov 70	2.2	12.6	11.0	9.8	7.5	9.8	7.62	5.19	0.03	0.12	0.09	0.78
Dec 70	1.5	18.0	8.9	10.2	7.6	9.8	7.80	2.19	0.06	0.12	0.12	0.18
Jan 71	4.0	24.7	9.1	14.4	7.4	9.0	6.82	5.00	0.04	0.12	0.08	0.25
Feb 71	5.0	21.7	9.5	8.2	7.6	11.0	7.78	3.17	0.01	0.07	0.14	0.18
Mar 71	2.5	17.0	10.5	6.0	7.7	11.0	7.38	2.50	0.02	0.12	0.12	0.80
Apl 71	4.5	28.8	12.0	10.6	7.4	13.2	4.40	3.72	0.06	0.10	0.11	0.41
Mean	3.3	20.5	10.2	9.9	7.5	10.6	6.97	3.63	0.04	0.11	0.11	0.63

STATION 8. TAME AT MOSELEY ROAD.

Date	Ammonia	Ox.Nit	PV	BOD	pH	Temp	Dis.Oxy	Fe	Cr	Cu	Ni	Zn
Sep 68	6.4	4.0	1.0	4.3	7.1	15.8	3.50	1.97	0.08	0.11	0.02	1.62
Oct 68	3.5	3.8	1.9	4.1	7.1	10.6	1.34	16.70	0.02	0.06	0.33	3.63
Nov 68	3.2	1.6	4.9	8.0	7.1	10.0	3.70	5.20	0.01	0.06	0.21	2.50
Dec 68	4.0	2.3	21.2	56.2	7.1	6.0	7.59	22.25	0.12	0.12	0.03	2.20
Jan 69	2.4	3.0	9.5	12.0	6.9	9.0	6.17	8.30	0.05	0.32	0.09	1.51
Feb 69	3.6	6.6	3.7	9.2	7.0	5.6	4.45	15.50	0.07	0.18	0.11	2.47
Mar 69	2.7	5.2	2.1	5.0	7.0	7.0	3.66	12.65	0.03	0.01	0.00	2.40
Apl 69	0.7	2.3	10.0	0.8	7.0	10.1	4.68	17.70	0.16	0.09	0.00	1.84
May 69	2.7	7.0	3.5	8.0	7.1	13.3	4.94	4.10	0.00	0.05	0.00	1.11
Jne 69	3.8	7.0	3.6	6.9	7.1	14.8	3.30	6.31	0.00	0.03	0.00	1.07
Jly 69	3.5	4.5	1.3	1.0	7.4	20.0	3.30	2.04	0.03	0.04	0.70	2.12
Aug 69	3.0	6.0	1.5	4.0	7.4	17.4	3.42	3.12	0.00	0.07	0.10	1.32
Sep 69	3.5	4.0	2.0	1.0	7.2	13.6	2.62	9.70	0.02	0.04	0.06	2.36
Oct 69	6.5	2.5	2.0	0.3	7.0	14.0	3.38	6.68	0.06	0.05	0.04	3.10
Nov 69	5.5	4.5	8.2	14.8	7.1	7.0	5.70	2.52	0.02	0.15	0.70	1.71
Dec 69	5.0	4.0	7.5	6.1	7.0	8.5	2.44	20.75	0.09	0.07	0.22	3.15
Jan 70	9.5	7.5	9.7	15.4	7.1	8.5	3.80	14.66	0.04	0.16	0.05	3.33
Feb 70	3.0	9.0	2.4	2.8	7.2	8.0	3.14	16.85	0.13	0.07	0.14	3.90
Mar 70	2.5	9.5	1.3	4.4	7.5	10.0	6.00	6.96	0.02	0.05	0.12	1.44
Apl 70	2.0	7.5	3.0	0.8	7.2	9.5	6.10	10.45	0.03	0.09	0.12	2.55
May 70	2.5	6.0	4.7	2.7	7.5	15.0	6.52	23.70	0.08	0.13	0.25	3.23
Jne 70	4.4	3.5	2.3	1.4	7.7	19.5	5.00	16.37	0.02	0.05	0.09	3.35
Jly 70	3.5	5.0	5.2	3.4	7.1	17.5	2.84	17.75	0.16	0.10	0.14	3.10
Aug 70	1.7	2.8	7.1	9.0	6.8	17.0	3.84	6.95	0.03	0.06	0.07	6.65
Mean	3.7	5.0	5.0	7.6	7.2	12.0	4.23	11.22	0.05	0.09	0.15	2.57

STATION 9. TAME AT SUMMERFORD ROAD.

Date	Ammonia	Ox.Nit	PV	BOD	pH	Temp	Dis.Oxy	Fe	Cr	Cu	Ni	Zn
Sep 68	9.8	12.1	12.0	18.0	7.2	18.5	1.84	0.88	0.06	0.42	0.77	3.10
Oct 68	5.6	21.9	10.0	21.8	7.3	14.0	2.50	6.66	0.19	0.27	0.14	1.07
Nov 68	5.0	17.1	8.4	32.4	7.2	10.0	4.50	7.40	0.07	0.11	0.21	0.86
Dec 68	6.3	6.8	15.9	34.4	7.4	6.5	6.55	23.00	0.10	0.22	0.05	2.00
Jan 69	2.7	10.1	11.0	27.2	6.9	9.0	5.90	9.60	0.11	0.38	0.13	1.69
Feb 69	6.3	17.8	8.1	12.8	7.4	5.6	6.70	3.37	0.06	0.20	0.05	0.96
Mar 69	5.4	16.1	10.0	19.8	7.4	6.0	5.28	5.00	0.81	0.12	0.19	1.07
Apl 69	1.4	3.2	11.0	18.2	7.0	11.2	5.30	5.70	0.04	0.10	0.10	0.71
May 69	2.5	12.1	5.4	19.2	7.1	15.0	4.47	12.10	0.10	0.19	0.13	1.11
Jne 69	3.4	11.5	8.1	8.6	7.1	16.8	2.62	3.20	0.00	0.09	0.21	0.56
Jly 69	2.5	17.0	9.0	9.8	7.4	22.0	2.92	4.30	0.24	0.19	0.13	1.20
Aug 69	3.5	14.5	8.5	9.0	7.4	20.0	2.20	1.62	0.03	0.10	0.00	0.72
Sep 69	3.0	16.5	10.0	11.4	7.4	15.8	2.52	3.72	0.03	0.06	0.03	0.75
Oct 69	5.5	20.5	11.0	7.2	7.4	16.6	1.86	3.84	0.11	0.09	0.00	0.44
Nov 69	2.5	9.0	9.5	9.0	7.0	6.0	7.30	3.45	0.04	0.11	0.37	0.86
Dec 69	5.5	15.0	13.0	10.4	6.9	8.5	5.66	4.90	0.14	0.08	0.19	0.62
Jan 70	2.0	10.5	6.9	4.8	7.5	8.5	6.54	4.73	0.03	0.08	0.02	0.71
Feb 70	4.0	15.0	13.5	8.8	7.2	8.0	6.42	17.50	0.08	0.18	0.16	8.10
Mar 70	2.5	13.0	5.8	6.8	7.3	9.0	5.50	2.72	0.01	0.06	0.24	0.66
Apl 70	2.5	14.0	6.8	3.2	7.5	10.0	7.82	2.12	0.04	0.07	0.09	0.65
May 70	1.5	17.0	11.0	15.6	7.6	16.0	5.74	5.25	0.05	0.09	0.07	1.06
Jne 70	2.8	24.0	17.2	11.2	7.8	20.5	2.28	8.15	0.03	0.10	0.12	1.54
Jly 70	3.0	22.0	8.5	6.0	7.3	19.0	4.08	2.19	0.00	0.08	0.07	0.51
Aug 70	1.5	13.3	10.0	7.2	7.2	17.5	4.16	2.81	0.03	0.10	0.11	1.07
Mean	3.8	14.6	10.0	13.9	7.3	12.9	4.61	6.01	0.10	0.14	0.15	1.33

STATION 10. STREAM BELOW BARNS LANE

Date	Ammonia	Ox.Nit	PV	BOD	pH	Temp	Dis.Oxy	Fe	Cr	Cu	Ni	Zn
Sep 68	6.9	13.5	9.5	15.6	6.4	18.1	3.82	3.05	0.03	0.15	0.05	0.88
Oct 68	3.7	12.8	9.8	12.5	7.5	12.0	5.86	1.19	0.04	0.16	0.08	0.31
Nov 68	3.4	7.7	11.1	17.4	7.4	7.6	6.80	1.51	0.06	0.20	0.21	0.46
Dec 68	5.3	9.8	6.3	14.0	7.5	3.0	8.50	0.69	0.19	0.12	0.07	0.30
Jan 69	1.4	9.7	7.4	18.4	7.2	7.0	6.30	1.70	0.09	0.32	0.09	0.45
Feb 69	4.9	9.1	8.2	15.8	7.4	3.6	8.83	1.70	0.03	0.25	0.11	0.72
Mar 69	7.8	10.5	9.5	17.8	7.5	5.5	7.68	0.60	0.03	0.12	0.10	0.62
Apl 69	0.6	5.2	6.9	7.4	7.5	10.6	8.16	0.70	0.00	0.08	0.00	0.21
May 69	1.6	5.7	6.8	13.2	7.1	15.0	6.38	1.20	0.02	0.09	0.00	0.37
Jne 69	4.0	11.6	4.0	16.4	7.2	16.5	6.30	2.20	0.02	0.13	0.10	0.19
Jly 69	6.5	17.5	19.5	18.2	7.3	22.0	4.80	1.48	0.10	0.37	0.07	0.61
Aug 69	1.0	8.0	11.6	11.2	7.8	22.0	7.22	0.88	0.04	0.10	0.15	0.19
Sep 69	6.0	9.0	9.1	8.3	7.4	14.4	2.44	2.82	0.04	0.09	0.10	0.40
Oct 69	6.0	17.0	11.0	10.4	7.3	16.0	5.00	1.40	0.08	0.10	0.00	0.35
Nov 69	1.5	4.0	8.4	2.6	7.1	4.2	8.88	1.50	0.04	0.14	0.27	0.60
Dec 69	5.0	10.5	6.1	8.2	7.6	5.0	8.40	0.80	0.04	0.10	0.10	0.57
Jan 70	2.0	5.5	4.1	5.0	7.4	6.5	6.80	0.83	0.02	0.09	0.04	0.53
Feb 70	7.0	8.5	7.0	14.0	7.6	5.5	7.82	0.35	0.05	0.16	0.11	0.42
Mar 70	4.0	7.0	6.7	16.0	7.3	7.0	6.72	0.85	0.01	0.16	0.11	0.49
Apl 70	3.5	9.0	10.3	20.0	7.7	10.5	10.15	0.81	0.04	0.14	0.10	0.37
May 70	5.0	10.0	13.0	12.0	7.7	17.2	9.00	1.12	0.04	0.18	0.06	0.30
Jne 70	8.5	16.5	15.5	7.2	7.8	22.0	3.30	1.15	0.03	0.14	0.06	0.39
Jly 70	7.0	19.5	12.5	8.8	7.2	18.5	3.46	1.27	0.04	0.19	0.13	0.40
Aug 70	2.6	11.2	19.5	7.1	7.4	17.5	2.90	1.77	0.02	0.10	0.05	0.20
Mean	4.4	10.4	9.7	12.4	7.4	12.0	6.48	1.31	0.04	0.15	0.09	0.43
Nov 70	3.1	8.5	7.4	8.8	7.4	7.5	7.48	1.29	0.02	0.10	0.15	0.54
Dec 70	3.0	10.0	6.6	8.0	7.5	7.5	7.32	0.66	0.03	0.07	0.06	0.47
Jan 71	7.0	9.5	8.0	18.1	7.5	7.0	4.68	2.31	0.04	0.17	0.06	0.56
Feb 71	9.5	13.5	12.5	18.0	7.6	9.0	6.62	4.11	0.05	0.21	0.07	0.47
Mar 71	5.5	8.8	11.0	12.8	7.5	9.5	8.80	1.30	0.02	0.15	0.07	0.62
Apl 71	8.0	21.4	14.5	17.6	7.6	11.5	5.52	2.62	0.04	0.14	0.16	0.37
Mean	6.0	11.9	10.0	13.9	7.5	8.7	6.74	2.50	0.03	0.16	0.09	0.60

STATION 11. GOSCOTE BROOK ABOVE GOSCOTE.

Date	Ammonia	Ox.Nit	PV	BOD	pH	Temp	Dis.Oxy	Fe	Cr	Cu	Ni	Zn
Sep 68	1.8	1.9	2.0	2.2	7.0	14.8	4.72	46.90	0.00	10.00	11.00	2.08
Oct 68	1.3	1.0	1.5	0.0	6.8	11.6	1.70	16.79	0.01	8.25	10.25	0.41
Nov 68	2.2	0.1	18.0	4.4	6.7	9.6	2.50	14.10	0.01	5.75	8.20	0.44
Dec 68	2.7	0.6	7.5	11.9	7.5	7.0	2.76	28.60	0.01	5.13	6.17	0.76
Jan 69	0.8	4.4	5.0	1.1	6.9	8.6	4.08	8.00	0.09	1.94	3.60	0.45
Feb 69	1.8	0.9	2.0	0.5	6.6	5.4	2.92	1.60	0.08	5.00	7.80	0.72
Mar 69	0.4	1.7	2.1	5.6	6.5	7.0	2.72	15.00	0.04	7.27	7.75	0.57
Apl 69	0.0	1.4	2.6	2.2	6.7	11.0	5.30	7.90	0.00	3.40	4.00	0.36
May 69	0.2	1.7	3.0	2.0	6.6	14.0	4.67	10.80	0.15	5.30	6.60	0.58
Jne 69	2.2	0.8	7.5	15.6	6.7	15.9	1.90	10.00	0.00	4.42	4.12	0.30
Jly 69	0.0	1.0	2.4	7.6	6.6	18.0	2.00	19.20	0.03	11.75	10.75	0.61
Aug 69	1.5	0.0	2.9	2.8	6.7	16.2	1.00	19.00	0.10	10.90	8.25	0.46
Sep 69	0.0	0.0	2.4	0.0	6.7	12.1	0.60	11.25	0.06	6.90	8.40	0.56
Oct 69	0.5	5.5	1.5	0.0	6.5	12.4	1.38	8.20	0.07	10.50	9.95	0.49
Nov 69	2.0	2.0	8.7	6.4	6.7	5.3	4.50	5.00	0.08	1.82	4.40	1.31
Dec 69	0.5	0.5	3.5	0.9	6.9	8.0	1.20	16.25	0.04	5.60	9.60	0.51
Jan 70	0.5	2.0	2.4	1.8	7.1	7.4	3.40	9.00	0.00	4.33	4.43	0.47
Feb 70	2.0	2.5	2.1	0.0	6.9	7.0	3.40	10.42	0.06	4.50	6.40	0.40
Mar 70	2.0	2.5	1.0	0.7	6.9	8.0	3.82	8.25	0.00	5.50	4.90	0.43
Apl 70	1.0	1.5	2.6	0.1	6.7	10.0	3.90	12.05	0.06	4.30	6.92	0.41
May 70	1.5	0.5	3.5	1.1	6.9	14.5	5.28	29.80	0.03	8.67	8.50	0.49
Jne 70	2.2	0.0	2.5	1.6	6.9	17.5	0.00	24.00	0.01	11.25	5.55	0.54
Jly 70	2.0	1.5	3.5	2.3	6.4	15.0	0.74	22.50	0.00	7.25	12.90	0.58
Aug 70	3.1	0.6	3.7	3.5	6.7	14.0	0.70	19.50	0.03	8.80	5.59	0.50
Mean	1.3	1.4	3.9	3.1	6.8	11.3	2.72	15.59	0.04	6.60	7.33	0.60
Nov 70	2.6	1.3	8.7	27.0	6.9	8.0	3.28	7.25	0.04	2.95	3.40	0.71
Dec 70	1.0	2.5	2.8	2.7	6.9	8.0	2.80	9.87	0.01	3.62	4.00	0.39
Jan 71	3.5	1.7	2.0	1.9	6.9	7.8	1.98	15.00	0.00	5.50	5.60	0.42
Feb 71	0.5	1.2	1.0	2.1	7.5	9.5	3.02	13.87	0.02	5.12	6.00	0.36
Mar 71	1.5	1.0	1.5	2.0	6.7	10.0	3.40	10.81	0.02	6.25	6.56	0.44
Apl 71	2.5	1.4	1.0	2.0	6.8	11.6	4.03	15.81	0.00	5.92	10.62	0.56
Mean	1.9	1.6	2.8	6.3	6.9	9.1	3.08	12.10	0.01	4.89	6.03	0.68

STATION 12. GOSCOTE BROOK BELOW GOSCOTE.

Date	Ammonia	Ox.Nit	PV	BOD	pH	Temp	Dis.Oxy	Fe	Cr	Cu	Ni	Zn
Sep 68	4.9	12.6	9.5	28.4	7.4	17.6	1.36	3.82	0.00	2.42	2.90	1.48
Oct 68	4.7	15.8	12.0	23.0	7.1	13.4	5.26	3.74	0.11	2.13	3.03	0.42
Nov 68	6.5	9.9	10.8	22.0	7.1	10.0	5.65	3.40	0.08	1.60	2.70	0.53
Dec 68	5.0	10.8	14.5	35.2	7.0	6.8	3.70	4.44	0.09	1.36	2.15	0.80
Jan 69	3.8	8.0	11.5	18.4	7.0	9.0	5.03	3.00	0.13	1.14	1.72	0.29
Feb 69	8.9	10.5	14.0	26.0	7.0	5.2	7.10	4.83	0.08	1.90	2.85	0.72
Mar 69	7.3	7.0	14.4	23.6	7.1	6.6	6.44	4.40	0.08	2.40	3.00	0.50
Apl 69	4.3	6.2	8.7	28.4	6.9	11.2	5.44	3.20	0.01	1.62	2.27	0.37
May 69	4.8	7.7	11.1	24.0	6.9	14.0	5.08	4.10	0.06	1.60	2.91	0.52
Jne 69	5.3	11.7	17.1	22.0	6.9	15.8	3.22	4.40	0.06	1.89	1.93	0.44
Jly 69	6.5	16.5	59.0	110.0	7.1	19.8	0.00	29.80	0.26	15.00	4.62	2.27
Aug 69	3.0	12.5	10.5	10.4	7.2	19.2	4.12	4.00	0.00	1.95	2.77	0.30
Sep 69	3.5	16.5	12.7	30.4	6.9	14.2	5.08	4.18	0.05	1.61	3.57	0.52
Oct 69	3.5	17.5	18.5	28.0	7.0	15.4	4.72	5.48	0.08	2.34	3.45	0.42
Nov 69	2.5	10.0	11.0	11.8	6.9	5.7	7.62	3.12	0.06	0.82	1.36	0.56
Dec 69	6.5	15.0	9.0	25.0	7.2	8.5	6.48	4.52	0.20	1.41	2.92	0.51
Jan 70	4.0	8.5	10.7	18.0	7.1	8.0	6.32	10.66	0.05	1.02	1.93	0.54
Feb 70	5.0	11.0	10.3	0.0	7.2	7.5	6.22	3.86	0.08	2.07	2.29	0.54
Mar 70	4.5	8.0	14.5	27.6	7.1	8.5	7.30	4.15	0.06	2.47	2.27	0.53
Apl 70	5.0	7.0	10.0	12.8	7.1	10.0	7.20	3.19	0.04	1.76	3.54	0.45
May 70	8.0	4.0	14.0	20.0	7.3	15.8	6.98	5.50	0.02	2.37	2.34	0.44
Jne 70	11.9	14.5	19.5	22.0	7.5	19.5	1.70	5.75	0.05	1.40	2.15	0.49
Jly 70	8.0	15.0	14.0	21.2	7.0	17.0	4.70	5.31	0.08	2.39	2.72	0.41
Aug 70	3.2	14.3	14.5	18.8	7.0	17.0	4.10	3.72	0.10	2.05	2.57	0.39
Mean	5.4	11.3	14.7	25.3	7.1	12.3	5.03	5.52	0.08	2.36	2.66	0.60
Nov 70	4.3	10.2	15.0	34.8	6.9	9.0	5.00	3.35	0.09	1.62	1.50	0.70
Dec 70	4.0	16.0	13.0	28.0	7.1	9.0	7.00	5.94	0.06	1.42	1.75	0.46
Jan 71	4.5	13.2	12.6	22.4	7.1	8.0	5.62	6.12	0.03	2.80	1.68	0.62
Feb 71	6.5	12.0	14.2	21.6	7.3	9.5	7.00	5.12	0.03	2.12	2.37	0.47
Mar 71	5.5	4.2	11.8	34.4	7.1	10.0	5.02	4.81	0.01	2.20	2.97	0.49
Apl 71	13.0	20.6	18.0	21.6	7.3	12.0	1.70	5.27	0.03	2.55	2.96	0.46
Mean	6.3	12.7	14.1	27.1	7.1	9.6	5.22	5.10	0.04	2.12	2.20	0.53

STATION 13. TAME AT WALSALL/WEST BROMWICH ROAD.

Date	Ammonia	Ox.Nit	PV	BOD	pH	Temp	Dis.Oxy	Fe	Cr	Cu	Ni	Zn
Sep 68	7.7	11.4	10.0	26.4	7.2	17.5	2.58	7.10	0.11	0.19	0.59	0.59
Oct 68	10.2	9.7	12.9	16.4	7.4	13.2	2.56	8.80	0.28	0.32	0.77	0.90
Nov 68	7.3	8.5	10.1	20.4	7.3	10.0	4.20	6.20	0.18	0.25	0.72	1.05
Dec 68	8.7	8.3	24.5	50.8	7.2	5.8	3.95	18.10	0.35	0.75	0.50	2.30
Jan 69	4.3	6.4	15.4	28.0	6.9	9.0	4.40	9.00	0.27	0.51	0.57	0.50
Feb 69	7.2	9.8	9.0	24.0	7.1	5.2	5.54	6.15	0.16	0.31	3.90	1.13
Mar 69	7.6	8.7	16.1	37.6	7.3	7.0	3.50	15.75	0.16	0.42	0.57	1.01
Apl 69	3.5	8.0	10.7	26.8	7.0	10.0	5.22	6.80	0.24	0.21	0.40	0.79
May 69	4.3	9.2	11.0	29.4	7.1	15.0	3.50	6.00	0.28	0.27	0.70	0.83
Jne 69	5.2	7.4	13.0	15.4	7.1	16.4	2.62	6.62	0.22	0.32	0.36	0.71
Jly 69	6.5	9.5	18.3	35.2	7.4	20.4	1.22	14.00	0.29	0.59	0.84	1.10
Aug 69	5.5	7.0	10.8	10.0	7.4	20.0	2.64	3.75	0.08	0.13	0.40	0.46
Sep 69	7.0	8.5	13.2	18.2	7.3	15.2	6.12	7.40	0.17	0.20	0.69	0.81
Oct 69	7.0	9.0	17.6	28.0	7.3	16.0	1.98	9.70	0.38	0.72	0.92	1.04
Nov 69	3.0	7.5	14.5	20.8	7.1	6.5	7.32	7.92	0.14	0.32	0.47	1.13
Dec 69	6.0	11.0	10.0	18.4	7.5	8.0	5.44	8.65	0.14	0.22	0.82	0.79
Jan 70	2.0	7.0	14.5	46.8	7.3	7.8	6.30	4.60	0.11	0.27	0.50	0.79
Feb 70	5.0	9.5	11.0	15.6	7.3	7.5	6.34	8.00	0.11	0.35	0.67	1.09
Mar 70	5.0	9.5	14.0	30.4	7.3	8.5	8.20	16.25	0.15	0.47	0.71	1.29
Apl 70	5.0	9.0	12.9	20.0	7.3	10.0	5.98	7.75	0.06	0.17	0.40	0.71
May 70	6.5	7.5	16.5	12.0	7.3	16.0	4.44	15.97	0.25	0.29	0.40	1.06
Jne 70	2.6	7.0	24.0	104.0	7.7	20.5	0.80	32.75	0.27	0.43	0.26	1.82
Jly 70	10.0	10.5	27.5	25.4	7.3	17.0	2.92	10.95	0.16	0.30	0.52	1.02
Aug 70	5.2	7.8	17.0	14.8	7.3	17.0	3.38	9.65	0.12	0.34	1.26	1.04
Mean	5.9	8.6	14.8	28.1	7.3	12.5	4.21	10.33	0.19	0.35	0.75	1.00
Nov 70	5.6	7.5	14.5	40.2	7.2	8.5	5.60	14.12	0.02	0.40	0.47	1.30
Dec 70	5.0	11.5	11.6	20.8	7.3	8.5	6.60	6.24	0.11	3.12	0.36	0.67
Jan 71	8.5	10.0	13.5	24.0	7.3	8.4	5.00	11.24	0.18	0.31	0.46	1.09
Feb 71	7.5	12.2	20.5	33.2	7.7	9.5	4.32	16.74	0.38	0.35	0.57	1.42
Mar 71	4.5	7.6	15.0	24.2	7.2	9.5	5.62	9.44	0.06	0.33	0.55	1.06
Apl 71	11.0	13.6	17.7	24.8	7.4	12.5	6.78	10.12	0.15	0.26	0.75	1.50
Mean	7.0	10.4	15.5	27.9	7.3	9.4	5.65	11.32	0.15	0.79	0.53	1.17

STATION 14. TAME AT NEWTON ROAD.

Date	Ammonia	Ox.Nit	PV	BOD	pH	Temp	Dis.Oxy	Fe	Cr	Cu	Ni	Zn
Sep 68	9.0	10.0	9.0	22.0	7.3	18.2	2.42	5.97	0.11	0.24	0.58	2.60
Oct 68	9.0	9.3	9.5	12.2	7.4	13.0	3.18	9.12	0.14	0.39	0.62	0.73
Nov 68	7.0	7.7	10.5	13.6	7.3	10.0	4.65	7.12	0.16	0.24	0.62	0.95
Dec 68	8.7	7.2	26.5	65.5	7.1	6.5	4.25	23.10	0.43	0.85	0.67	3.17
Jan 69	4.2	6.3	17.0	31.2	7.2	8.4	4.41	12.60	0.27	0.67	0.38	1.39
Feb 69	6.6	9.8	10.7	23.2	7.2	4.8	5.97	7.25	0.13	0.29	0.42	0.96
Mar 69	7.6	8.3	13.0	28.4	7.3	7.3	3.85	10.43	0.19	0.44	0.52	1.13
Apl 69	3.4	7.0	13.5	24.0	7.1	10.4	5.12	9.70	0.14	0.73	0.40	1.04
May 69	3.8	8.6	7.5	40.8	7.1	14.8	3.90	8.00	0.26	0.30	0.61	0.94
Jne 69	4.8	6.5	12.5	17.6	7.2	16.1	2.90	8.12	0.19	0.28	0.36	0.75
Jly 69	7.0	11.0	16.0	22.0	7.4	21.0	1.18	12.25	0.18	0.52	0.76	0.95
Aug 69	5.5	6.5	11.0	12.4	7.4	20.0	2.22	7.00	0.05	0.09	0.37	0.38
Sep 69	5.0	9.0	10.5	14.0	7.4	14.6	2.76	6.24	0.16	0.16	0.63	0.72
Oct 69	9.5	10.0	13.0	12.0	7.3	16.0	2.00	8.48	0.30	0.26	0.86	0.90
Nov 69	3.0	6.5	12.4	14.4	6.9	6.5	7.40	12.08	0.15	0.25	1.26	1.29
Dec 69	6.0	10.0	10.1	9.6	7.5	8.0	5.30	18.00	0.09	0.23	0.71	0.93
Jan 70	2.0	6.5	14.5	28.4	7.3	7.8	7.00	4.93	0.10	0.21	0.43	0.83
Feb 70	5.0	9.0	11.5	20.0	7.4	7.0	6.30	8.52	0.12	0.24	0.54	1.00
Mar 70	4.5	8.0	14.0	30.8	7.5	8.5	5.70	9.30	0.13	0.48	0.67	1.08
Apl 70	5.0	8.5	13.2	16.0	7.3	10.0	5.82	10.50	0.08	0.21	0.44	0.80
May 70	6.0	7.0	11.0	16.4	7.4	16.0	4.40	16.30	0.12	0.24	0.29	0.79
Jne 70	7.7	2.0	16.5	37.8	7.8	21.0	1.72	4.86	0.14	0.22	0.49	1.20
Jly 70	9.5	8.0	17.3	17.2	7.3	17.5	0.94	11.30	0.31	0.43	0.40	1.76
Aug 70	5.3	6.8	17.0	22.4	7.3	17.0	1.30	12.00	0.13	0.31	1.18	1.15
Mean	6.0	7.9	13.2	23.0	7.3	12.5	3.94	10.13	0.17	0.34	0.59	1.14

STATION 15. TAME AT PERRY BARR.

Date	Ammonia	Ox.Nit	PV	BOD	pH	Temp	Dis.Oxy	Fe	Cr	Cu	Ni	Zn
Sep 68	10.2	8.6	11.0	19.6	7.2	18.6	1.54	18.00	0.08	0.57	0.62	1.08
Oct 68	8.2	7.4	8.7	18.4	7.4	13.2	2.82	4.83	0.08	0.17	0.41	0.41
Nov 68	8.5	6.1	15.6	16.0	7.3	10.2	3.50	6.62	0.14	0.22	0.46	0.82
Dec 68	7.7	6.6	28.5	64.8	7.6	6.0	3.20	26.25	0.49	0.87	1.52	2.50
Jan 69	4.4	5.2	16.6	24.8	7.3	9.0	5.45	9.75	0.22	0.23	0.29	0.50
Feb 69	8.9	7.4	14.2	23.2	7.3	4.8	5.72	10.00	0.09	0.28	0.32	0.82
Mar 69	10.8	6.6	12.5	26.4	7.3	7.0	3.96	7.62	0.10	0.26	0.33	0.70
Apl 69	4.9	6.1	10.4	20.8	7.4	10.6	4.86	6.10	0.12	0.17	0.32	0.65
May 69	5.0	7.2	10.2	23.4	7.3	14.0	4.34	7.00	0.13	0.22	0.36	0.75
Jne 69	6.2	5.0	10.4	17.6	7.2	16.4	1.78	8.12	0.14	0.22	0.25	0.56
Jly 69	9.5	8.0	13.0	9.2	7.6	21.4	2.10	6.54	0.10	0.39	0.50	0.47
Aug 69	6.5	6.0	11.6	6.4	7.7	20.2	2.48	4.37	0.00	0.10	0.33	0.32
Sep 69	5.0	3.5	9.6	18.4	7.7	14.6	2.10	4.32	0.09	0.10	0.44	0.44
Oct 69	11.5	5.0	13.5	20.0	7.4	16.0	1.22	4.88	0.17	0.36	0.50	0.58
Nov 69	4.0	6.0	13.0	20.8	6.9	6.2	6.92	7.00	0.18	0.23	0.44	1.00
Dec 69	7.0	8.5	13.5	18.0	7.6	8.0	4.50	13.47	0.11	0.20	0.66	0.91
Jan 70	3.0	6.0	9.5	17.6	7.4	7.5	7.00	5.00	0.07	0.17	0.34	0.67
Feb 70	7.0	8.0	9.7	19.0	7.5	6.5	4.40	9.25	0.11	0.22	0.46	0.83
Mar 70	6.0	8.0	6.1	23.8	7.4	8.0	6.00	7.00	0.07	0.16	0.49	0.69
Apl 70	5.5	7.0	15.3	21.0	7.4	10.0	4.60	4.84	0.04	0.20	0.35	0.60
May 70	8.5	5.0	13.0	134.4	7.5	16.5	2.92	8.03	0.06	0.16	0.25	0.55
Jne 70	10.4	4.5	17.8	26.4	7.8	21.5	1.00	15.51	0.10	0.20	0.25	1.24
Jly 70	7.0	6.3	13.2	22.5	7.4	18.0	1.10	8.39	0.10	0.22	0.40	0.79
Aug 70	6.8	4.9	20.3	40.0	7.5	17.5	0.78	8.95	0.13	0.31	0.30	0.80
Mean	7.2	6.4	13.2	27.2	7.4	12.6	3.51	8.83	0.12	0.26	0.44	0.78

STATION 16. COLE AT COLE HALL LANE.

Date	Ammonia	Ox.Nit	PV	BOD	pH	Temp	Dis.Oxy	Fe	Cr	Cu	Ni	Zn
Sep 68	0.7	4.9	3.0	4.3	8.0	19.8	1.24	0.54	0.22	0.07	0.00	0.14
Oct 68	1.5	4.5	3.8	4.4	8.1	13.0	7.30	0.53	0.04	0.04	0.20	0.19
Nov 68	2.5	4.0	4.0	5.3	7.4	14.0	6.71	1.30	0.02	0.05	0.37	0.36
Dec 68	1.0	2.0	32.2	42.0	7.8	5.2	8.86	30.00	0.11	0.24	0.65	1.13
Jan 69	2.5	5.0	3.7	5.6	7.5	5.4	8.80	1.38	0.05	0.25	0.00	0.69
Feb 69	1.3	4.0	7.5	8.8	7.2	8.0	8.45	1.43	0.05	0.05	0.10	0.30
Mar 69	3.3	4.8	3.5	1.5	7.8	7.8	8.78	1.55	0.06	0.07	0.10	0.22
Apl 69	1.0	4.5	5.4	4.0	8.0	12.5	12.75	0.80	0.07	0.05	0.30	0.14
May 69	1.0	5.0	5.3	4.3	7.5	15.5	8.35	1.62	0.03	0.05	0.09	0.21
Jne 69	2.0	3.0	8.0	3.2	7.7	17.8	12.50	0.60	0.02	0.07	0.00	0.21
Jly 69	1.0	3.5	5.4	3.3	8.1	25.9	9.42	1.60	0.03	0.00	0.04	0.22
Aug 69	0.0	0.5	7.0	6.8	7.4	18.3	5.70	1.95	0.04	0.04	0.10	0.22
Sep 69	1.0	4.0	5.5	3.9	7.5	14.7	6.00	1.00	0.04	0.06	0.00	0.51
Oct 69	0.0	8.5	13.0	9.6	7.1	6.5	8.78	2.12	0.08	0.07	0.10	0.26
Nov 69	1.5	2.5	5.7	21.5	7.2	16.4	6.62	1.30	0.02	0.07	0.10	0.26
Dec 69	4.5	5.0	7.9	13.2	7.4	7.8	5.92	0.97	0.12	0.06	0.19	0.44
Jan 70	1.5	6.0	11.7	18.0	7.4	7.0	8.50	2.30	0.08	0.07	0.08	0.53
Feb 70	2.0	6.5	13.9	19.9	7.3	8.0	8.60	1.39	0.08	0.07	0.11	0.16
Mar 70	1.5	5.0	3.2	3.5	7.6	8.0	8.50	0.87	0.01	0.04	0.11	0.19
Apl 70	3.5	4.0	7.7	9.4	7.6	12.0	4.60	0.72	0.01	0.09	0.12	0.25
May 70	2.0	2.5	4.7	3.7	8.5	21.5	6.00	1.00	0.03	0.04	0.05	0.14
Jne 70	0.0	1.5	25.0	15.6	7.5	27.0	3.78	1.36	0.03	0.04	0.09	0.16
Jly 70	4.5	4.5	16.0	17.8	7.2	16.0	7.30	1.75	0.00	0.02	0.04	0.28
Aug 70	2.1	4.2	5.0	6.1	7.8	23.0	8.40	0.75	0.06	0.06	0.05	0.20
Mean	1.7	4.2	8.7	9.8	7.6	13.8	7.58	2.45	0.05	0.07	0.12	0.31

Date	Ammonia	Ox.Nit	PV	BOD	pH	Temp	Dis.Oxy	Fe	Cr	Cu	Ni	Zn
Nov 70	0.5	5.0	5.3	3.8	7.6	7.0	9.80	1.44	0.04	0.09	0.88	0.26
Dec 70	0.5	7.0	3.0	1.6	7.5	6.8	10.00	0.87	0.04	0.04	0.06	0.16
Jan 71	0.5	4.2	5.0	4.4	7.0	7.0	9.32	1.32	0.04	0.06	0.04	0.20
Feb 71	2.0	5.0	2.6	4.9	8.1	9.5	13.82	2.09	0.00	0.02	0.56	0.09
Mar 71	1.4	4.1	4.7	4.9	7.6	9.5	12.90	0.97	0.02	0.03	0.06	0.16
Apl 71	1.5	5.8	3.8	4.9	8.7	15.0	17.70	0.86	0.01	0.01	0.03	0.09
Mean	1.1	5.2	4.1	4.1	7.7	9.1	12.26	1.26	0.02	0.04	0.27	0.16

STATION 17. COLE AT BACONS END.

Date	Ammonia	Ox.Nit	PV	BOD	pH	Temp	Dis.Oxy	Fe	Cr	Cu	Ni	Zn
Sep 68	5.6	7.7	13.0	20.6	7.3	19.6	1.70	1.20	0.22	0.36	0.65	0.43
Oct 68	17.0	7.0	35.4	21.0	7.1	14.5	0.32	26.40	0.45	1.07	0.92	1.17
Nov 68	7.0	6.0	14.0	21.6	7.0	11.0	7.52	0.87	0.19	0.35	1.03	0.42
Dec 68	5.5	2.0	24.0	57.5	7.3	6.8	6.30	21.56	0.44	0.77	0.13	1.57
Jan 69	6.5	7.4	26.8	41.5	7.3	8.0	3.63	26.00	0.36	0.74	0.80	0.82
Feb 69	6.5	11.5	25.5	15.6	7.2	7.4	6.20	14.60	0.30	0.68	1.32	1.24
Mar 69	7.4	8.0	14.3	16.8	7.4	8.9	5.99	2.08	0.23	0.27	0.60	0.41
Apl 69	4.5	8.5	11.3	17.4	7.2	12.9	5.63	1.10	0.46	0.25	0.80	0.40
May 69	7.5	8.0	13.0	16.4	7.5	15.1	3.45	2.00	0.19	0.35	0.60	0.44
Jne 69	9.0	5.0	14.3	14.4	7.2	17.2	1.21	3.60	0.20	0.50	0.57	0.37
Jly 69	6.5	4.0	19.5	26.0	7.3	22.8	2.16	1.92	0.30	0.41	0.60	0.47
Aug 69	2.5	7.0	10.5	15.6	7.0	18.6	4.26	2.00	0.07	0.14	0.45	0.30
Sep 69	10.0	9.5	19.1	17.6	7.3	16.1	1.72	1.53	0.30	0.24	0.62	0.59
Oct 69	4.0	11.0	10.2	11.2	7.1	8.5	7.38	3.20	0.21	0.23	0.76	0.35
Nov 69	8.5	5.5	13.1	42.0	7.1	17.4	1.12	1.35	0.11	0.25	0.57	0.37
Dec 69	7.0	8.5	15.5	32.8	7.2	10.0	3.10	2.50	0.16	0.21	0.62	0.46
Jan 70	4.0	7.5	12.9	20.6	7.3	8.0	6.30	1.62	0.29	0.14	0.42	0.34
Feb 70	3.5	8.5	22.5	27.2	7.2	8.2	6.69	10.50	0.16	0.24	0.40	0.46
Mar 70	4.0	8.0	8.7	14.2	7.3	9.0	7.30	1.62	0.33	0.29	0.56	0.35
Apl 70	9.0	6.5	17.6	30.2	7.6	12.0	3.00	1.97	0.18	0.30	0.52	0.61
May 70	9.0	3.5	18.6	24.4	7.5	19.0	6.92	1.60	0.08	0.24	0.40	0.34
Jne 70	10.5	11.0	15.5	20.0	7.5	23.8	3.02	1.87	0.10	0.19	0.34	0.44
Jly 70	3.0	1.5	9.5	12.4	7.0	16.0	4.90	2.02	0.13	0.14	0.14	0.37
Aug 70	13.5	11.3	14.0	21.8	7.4	21.0	3.98	2.56	0.30	0.29	0.69	0.52
Mean	7.1	7.3	16.6	23.3	7.3	13.8	4.32	5.65	0.24	0.36	0.60	0.55
Nov 70	7.2	8.8	9.6	14.2	7.4	9.0	7.00	1.21	0.19	0.25	0.50	0.41
Dec 70	5.0	13.0	9.0	16.2	7.3	8.8	8.12	0.87	0.18	0.15	0.37	0.34
Jan 71	6.0	8.7	9.0	12.6	7.3	8.3	6.70	1.39	0.12	0.20	0.34	0.38
Feb 71	10.0	9.5	11.0	21.8	7.9	10.0	6.62	2.03	0.19	0.31	0.92	0.33
Mar 71	7.2	8.2	10.5	13.2	7.1	10.5	7.50	1.16	0.13	0.34	0.64	0.34
Apl 71	10.5	10.4	14.5	30.8	7.5	14.0	5.20	1.75	0.33	0.29	1.04	0.37
Mean	7.6	9.8	10.6	18.1	7.4	10.1	6.86	1.40	0.19	0.26	0.63	0.36

STATION 18. COLE AT COLESHILL.

Date	Ammonia	Ox.Nit	PV	BOD	pH	Temp	Dis.Oxy	Fe	Cr	Cu	Ni	Zn
Sep 68	3.8	7.3	7.0	11.4	7.6	18.9	8.64	0.62	0.20	0.22	0.31	0.20
Oct 68	4.0	7.0	5.9	6.0	7.3	13.0	5.50	0.87	0.11	0.17	0.40	0.24
Nov 68	5.5	7.0	6.6	9.2	7.2	9.0	3.88	1.01	0.15	0.16	0.46	0.28
Dec 68	5.0	5.0	16.5	9.6	7.5	6.5	6.03	9.06	0.21	0.30	0.68	0.47
Jan 69	3.2	5.4	26.0	43.2	7.2	8.1	7.00	10.29	0.21	0.38	0.45	0.67
Feb 69	4.5	8.5	6.5	10.8	7.5	5.5	7.90	2.58	0.12	0.36	0.62	0.63
Mar 69	5.0	5.6	10.0	8.0	7.5	7.1	5.60	1.74	0.14	0.20	0.34	0.26
Apl 69	3.5	6.5	6.5	6.6	7.5	11.4	6.77	0.80	0.10	0.14	0.35	0.21
May 69	4.5	8.5	6.5	4.8	7.6	14.2	6.00	2.48	0.11	0.13	0.35	0.24
Jne 69	6.0	6.0	9.7	6.4	7.5	16.5	8.70	1.10	0.06	0.23	0.44	0.24
Jly 69	8.0	2.5	12.6	9.0	7.8	24.4	6.30	1.04	0.21	0.41	0.50	0.30
Aug 69	2.5	8.5	16.5	7.6	7.2	18.0	4.50	3.40	0.04	0.14	0.29	0.22
Sep 69	10.5	5.5	12.5	7.4	7.5	15.0	2.62	0.85	0.16	0.28	0.00	0.38
Oct 69	3.0	9.0	8.2	6.2	7.3	6.2	8.32	1.00	0.16	0.23	0.46	0.19
Nov 69	7.5	3.5	9.0	20.0	7.2	16.2	3.10	1.00	0.06	0.17	0.34	0.21
Dec 69	6.5	5.0	10.4	16.4	7.0	7.9	3.50	3.97	0.14	0.14	0.39	0.36
Jan 70	1.5	7.0	9.2	5.0	7.4	7.3	8.20	1.80	0.33	0.11	0.25	0.25
Feb 70	2.5	6.0	5.0	9.6	7.2	6.0	6.88	2.47	0.09	0.12	0.26	0.21
Mar 70	2.5	7.5	6.5	7.0	7.5	7.7	7.70	0.97	0.06	0.18	0.36	0.23
Apl 70	5.5	4.0	11.0	8.8	7.5	10.4	3.76	2.10	0.09	0.18	0.35	0.41
May 70	7.0	3.5.	9.3	10.8	7.7	16.5	2.70	1.25	0.08	0.12	0.26	0.22
Jne 70	6.5	6.5	11.2	12.0	7.9	24.0	12.70	1.15	0.07	0.11	0.26	0.21
Jly 70	5.0	1.5	20.5	34.2	6.9	15.8	2.62	5.35	0.18	0.18	0.26	0.58
Aug 70	5.0	9.0	8.0	10.4	7.7	21.0	6.62	0.85	0.14	0.17	0.51	0.27
Mean	4.9	6.1	10.5	11.7	7.4	12.8	6.06	2.41	0.13	0.20	0.37	0.31
Nov 70	3.7	6.8	7.1	3.8	7.5	7.8	7.30	2.11	0.08	0.12	0.32	0.31
Dec 70	3.5	9.2	7.7	10.2	7.4	7.0	8.62	0.84	0.07	0.12	0.24	0.22
Jan 71	3.0	6.4	5.4	4.2	7.5	8.5	7.70	1.48	0.07	0.14	0.17	0.25
Feb 71	7.5	7.0	12.4	13.9	7.8	10.5	6.30	2.02	0.17	0.21	0.47	0.23
Mar 71	4.5	6.8	10.9	8.0	7.4	8.4	6.90	1.09	0.20	0.17	0.29	0.31
Apl 71	8.5	7.4	9.2	4.8	7.9	14.8	10.00	2.25	0.11	0.16	0.66	0.25
Mean	5.1	7.3	8.8	7.5	7.6	9.5	7.80	1.63	0.12	0.15	0.36	0.26

STATION 19. BLYTHE AT BLYTHE BRIDGE.

Date	Ammonia	Ox.Nit	PV	BOD	pH	Temp	Dis.Oxy	Fe	Cr	Cu	Ni	Zn
Sep 68	0.0	5.9	3.0	1.4	8.0	17.5	9.60	0.54	0.02	0.06	0.00	0.05
Oct 68	0.0	6.5	4.1	1.9	7.7	11.5	12.50	0.75	0.02	0.04	0.02	0.04
Nov 68	6.0	7.5	3.5	1.8	7.6	7.0	12.83	0.62	0.02	0.08	0.11	0.10
Dec 68	1.0	6.0	3.8	1.0	7.8	3.8	10.50	0.81	0.00	0.04	0.45	0.05
Jan 69	0.8	6.5	4.2	3.5	7.5	6.5	9.96	3.56	0.04	0.18	0.06	0.16
Feb 69	1.0	6.5	3.2	1.4	7.7	7.5	11.99	1.78	0.06	0.29	0.00	0.72
Mar 69	1.3	6.0	2.5	1.6	7.9	5.1	11.82	1.15	0.02	0.06	0.05	0.09
Apl 69	0.0	6.0	3.5	2.4	7.9	9.8	11.40	0.60	0.00	0.03	0.00	0.04
May 69	0.5	7.0	4.5	4.6	7.8	13.5	9.89	1.22	0.02	0.01	0.00	0.07
Jne 69	0.0	4.0	4.4	2.5	7.8	16.1	8.31	0.60	0.13	0.00	0.00	0.10
Jly 69	0.0	5.5	4.0	1.0	8.4	23.3	8.90	0.50	0.05	0.00	0.04	0.05
Aug 69	0.0	5.0	6.3	4.5	7.3	17.8	4.30	1.30	0.00	0.09	0.04	0.03
Sep 69	0.0	7.0	3.8	0.9	7.9	14.0	8.72	0.58	0.03	0.02	0.00	0.07
Oct 69	0.0	10.0	6.1	0.8	7.4	4.5	10.68	0.52	0.04	0.05	0.00	0.04
Nov 69	0.0	8.5	3.3	2.0	7.7	14.8	9.68	1.70	0.01	0.05	0.05	0.06
Dec 69	1.0	7.5	4.4	2.4	7.7	4.8	11.60	0.62	0.02	0.05	0.19	0.09
Jan 70	0.5	7.5	5.5	2.8	7.5	6.0	10.30	1.05	0.01	0.01	0.04	0.06
Feb 70	0.2	6.0	4.6	2.4	7.7	15.9	10.51	0.87	0.03	0.03	0.04	0.06
Mar 70	1.0	6.5	2.0	0.4	7.6	6.4	11.38	0.56	0.00	0.03	0.10	0.06
Apl 70	0.0	6.5	2.8	1.5	8.1	10.0	11.54	0.27	0.02	0.00	0.02	0.05
May 70	0.5	5.0	3.5	2.6	8.9	17.0	6.60	0.42	0.00	0.02	0.02	0.05
Jne 70	0.0	7.0	5.2	4.8	8.4	23.1	12.10	0.47	0.02	0.03	0.02	0.06
Jly 70	0.5	5.5	6.4	12.2	8.1	17.0	9.00	0.75	0.00	0.02	0.04	0.12
Aug 70	0.3	9.1	4.8	2.4	8.0	20.0	9.30	0.44	0.02	0.08	0.01	0.10
Mean	0.6	6.6	4.1	2.6	7.8	12.2	10.14	0.90	0.02	0.05	0.05	0.10
Nov 70	0.0	6.3	4.4	2.0	7.7	6.0	11.20	1.00	0.06	0.06	0.02	0.07
Dec 70	0.5	9.2	4.8	2.5	7.7	5.7	11.60	0.84	0.01	0.00	0.05	0.04
Jan 71	0.5	7.9	3.0	2.7	7.7	6.0	10.70	0.89	0.03	0.06	0.04	0.07
Feb 71	0.5	7.0	2.4	1.4	8.2	6.5	14.40	2.12	0.03	0.03	0.06	0.06
Mar 71	0.5	6.0	5.5	3.3	7.5	7.5	9.82	0.50	0.03	0.01	0.06	0.07
Apl 71	0.6	8.0	3.4	3.2	8.4	13.0	18.10	0.37	0.00	0.02	0.05	0.07
Mean	0.4	7.4	3.9	2.5	7.9	7.4	12.64	0.95	0.03	0.03	0.05	0.06

STATION 20. BLYTHE AT HENWOOD MILL.

Date	Ammonia	Ox.Nit	PV	BOD	pH	Temp	Dis.Oxy	Fe	Cr	Cu	Ni	Zn
Sep 68	0.0	3.8	4.5	2.0	7.8	16.7	7.84	0.71	0.00	0.03	0.00	0.04
Oct 68	5.5	4.0	4.4	1.2	7.7	10.5	7.48	0.56	0.01	0.03	0.01	0.04
Nov 68	5.0	3.5	5.0	1.7	7.5	7.0	8.26	0.87	0.01	0.06	0.06	0.09
Dec 68	2.0	3.0	8.0	3.8	7.9	4.3	10.20	2.31	0.00	0.05	0.03	0.13
Jan 69	0.7	4.5	4.6	1.7	7.5	5.9	10.67	0.88	0.01	0.04	0.05	0.06
Feb 69	1.0	4.0	3.0	2.1	7.6	2.7	11.80	1.97	0.04	0.33	0.00	0.80
Mar 69	1.0	3.5	2.5	2.5	7.8	5.0	11.05	0.61	0.00	0.03	0.03	0.05
Apl 69	1.0	4.5	3.7	2.0	7.8	9.3	10.00	0.80	0.00	0.01	0.00	0.04
May 69	1.0	5.5	4.7	2.3	7.7	13.1	9.38	0.82	0.00	0.02	0.00	0.06
Jne 69	0.0	4.0	4.0	1.5	7.6	14.5	6.96	0.55	0.02	0.04	0.07	0.04
Jly 69	0.0	4.0	6.0	1.4	7.8	21.7	7.86	0.92	0.04	0.02	0.06	0.06
Aug 69	0.0	3.0	4.4	1.0	7.0	17.2	6.38	1.20	0.00	0.06	0.04	0.06
Sep 69	0.0	4.5	3.5	1.1	7.8	13.5	7.60	0.89	0.04	0.04	0.00	0.09
Oct 69	3.0	10.0	6.1	1.2	7.2	5.0	10.72	0.54	0.00	0.05	0.00	0.01
Nov 69	0.0	4.0	3.0	2.6	7.6	14.2	7.60	1.80	0.00	0.12	0.15	0.06
Dec 69	1.5	6.0	4.9	1.8	7.7	5.2	9.90	0.35	0.00	0.04	0.16	0.11
Jan 70	0.5	6.5	5.7	2.3	7.5	5.5	10.32	0.95	0.00	0.03	0.02	0.09
Feb 70	2.5	6.5	7.0	1.6	7.3	4.8	11.18	1.75	0.01	0.03	0.07	0.14
Mar 70	1.0	5.0	2.0	1.1	7.7	6.2	11.30	0.73	0.01	0.04	0.12	0.08
Apl 70	0.0	4.5	2.6	2.5	8.1	10.2	11.42	0.22	0.04	0.03	0.02	0.07
May 70	0.7	3.0	4.0	4.4	9.2	17.5	13.52	1.00	0.02	0.05	0.04	0.07
Jne 70	0.0	3.0	4.0	7.5	8.0	20.8	9.00	0.85	0.01	0.02	0.02	0.06
Jly 70	0.5	2.5	7.1	13.4	7.7	15.5	7.92	0.86	0.00	0.00	0.02	0.07
Aug 70	0.1	2.8	3.4	2.0	7.7	18.0	6.92	1.05	0.03	0.09	0.01	0.10
Mean	1.1	4.4	4.5	2.7	7.7	11.0	9.39	0.97	0.01	0.05	0.04	0.10

STATION 21. BLYTHE AT HAMPTON-IN-ARDEN

Date	Ammonia	Ox.Nit	PV	BOD	pH	Temp	Dis.Oxy	Fe	Cr	Cu	Ni	Zn
Sep 68	0.0	11.2	6.0	3.4	7.5	18.1	9.02	0.62	0.00	0.09	0.00	0.07
Oct 68	0.0	9.5	4.4	1.8	7.3	12.0	8.98	0.46	0.02	0.06	0.06	0.07
Nov 68	1.0	7.0	4.5	2.5	7.3	8.1	9.05	0.57	0.02	0.04	0.06	0.10
Dec 68	1.0	7.5	5.2	2.8	7.3	4.8	10.00	0.62	0.00	0.04	0.00	0.06
Jan 69	1.2	7.9	4.3	2.0	7.4	7.1	9.36	1.10	0.04	0.16	0.04	0.11
Feb 69	1.5	10.0	4.5	9.7	7.6	4.5	10.60	1.20	0.00	0.41	0.00	0.96
Mar 69	2.9	6.4	4.0	8.0	7.9	5.8	11.00	0.74	0.03	0.03	0.08	0.07
Apl 69	1.0	7.5	4.9	3.0	7.9	10.0	12.65	0.60	0.06	0.02	0.00	0.06
May 69	1.0	8.5	5.6	4.0	7.6	13.7	10.34	0.60	0.00	0.02	0.05	0.07
Jne 69	1.0	9.5	5.8	2.2	7.5	15.4	9.63	0.70	0.03	0.00	0.00	0.06
Jly 69	0.0	9.5	6.8	3.0	7.8	20.6	10.80	0.50	0.08	0.07	0.04	0.09
Aug 69	0.0	4.5	6.1	4.8	7.2	17.6	4.38	1.45	0.00	0.04	0.00	0.06
Sep 69	0.0	9.5	4.5	3.3	7.7	14.2	7.60	0.61	0.01	0.03	0.00	0.09
Oct 69	2.0	11.5	5.5	0.8	7.2	5.5	9.84	0.55	0.06	0.08	0.04	0.04
Nov 69	0.8	9.5	6.0	2.6	7.2	15.6	8.72	0.80	0.02	0.01	0.57	0.03
Dec 69	3.0	10.5	6.0	3.6	7.7	6.1	10.72	0.72	0.00	0.05	0.12	0.12
Jan 70	0.5	8.0	4.9	2.5	7.5	7.0	10.10	0.83	0.00	0.03	0.02	0.06
Feb 70	2.0	8.5	6.1	1.5	7.2	5.5	11.90	3.00	0.01	0.04	0.09	0.11
Mar 70	2.5	6.5	2.4	2.9	7.2	7.2	10.60	0.73	0.02	0.04	0.10	0.06
Apl 70	0.5	7.0	4.1	3.5	8.0	10.5	11.86	0.56	0.09	0.03	0.04	0.09
May 70	2.0	5.0	6.1	10.0	9.5	16.5	7.48	0.65	0.05	0.17	0.07	0.15
Jne 70	3.0	9.0	6.7	7.0	7.7	22.0	8.72	0.50	0.01	0.03	0.06	0.11
Jly 70	5.0	9.0	8.9	24.0	7.4	15.9	8.60	0.55	0.00	0.05	0.02	0.09
Aug 70	0.8	13.0	6.1	4.2	7.5	19.0	8.28	0.56	0.02	0.09	0.02	0.12
Mean	1.4	8.6	5.4	4.7	7.6	11.8	9.59	0.80	0.02	0.07	0.06	0.12

STATION 22. LANGLEY BROOK AT LANGLEY.

Date	Ammonia	Ox.Nit	PV	BOD	pH	Temp	Dis.Oxy	Fe	Cr	Cu	Ni	Zn
Sep 68	0.2	9.3	2.0	7.8	7.6	14.6	7.38	0.90	0.00	0.08	0.00	0.37
Oct 68	0.0	8.0	2.3	2.6	7.5	10.3	8.80	2.40	0.02	0.05	0.02	0.10
Nov 68	1.0	7.0	3.0	1.4	7.6	7.6	6.30	0.62	0.01	0.04	0.11	0.09
Dec 68	0.0	7.5	4.0	3.0	7.6	5.1	7.20	1.41	0.00	0.05	0.00	0.10
Jan 69	1.0	9.4	8.0	4.8	7.5	6.9	10.00	4.87	0.08	0.19	0.04	0.25
Feb 69	3.5	9.5	2.5	2.9	7.8	5.4	10.60	1.38	0.00	0.40	0.00	0.60
Mar 69	3.9	8.3	2.0	1.1	8.0	4.5	11.90	2.17	0.02	0.04	0.04	0.07
Apl 69	1.5	8.0	6.5	1.2	7.8	8.2	11.60	3.30	0.00	0.02	0.00	0.07
May 69	2.5	11.0	3.2	2.9	7.6	11.4	6.80	0.52	0.00	0.04	0.05	0.07
Jne 69	6.0	9.0	3.0	2.7	7.7	12.4	8.13	0.80	0.05	0.00	0.00	0.02
Jly 69	0.5	9.5	2.8	7.8	7.8	16.1	6.42	0.62	0.02	0.08	0.07	0.05
Aug 69	0.0	10.0	5.7	2.4	7.5	16.5	5.76	1.04	0.03	0.05	0.04	0.06
Sep 69	0.5	9.5	4.0	3.5	7.8	17.9	6.02	1.90	0.04	0.06	0.03	0.14
Oct 69	0.0	15.0	3.6	0.8	7.4	6.8	10.86	0.60	0.06	0.05	0.07	0.03
Nov 69	0.0	9.5	2.9	1.6	7.4	13.2	6.10	0.09	0.03	0.04	0.07	0.06
Dec 69	0.5	11.0	3.2	0.9	7.8	6.4	11.00	10.55	0.00	0.05	0.11	0.11
Jan 70	0.5	13.5	6.5	1.3	7.6	6.0	10.60	2.33	0.02	0.04	0.01	0.12
Feb 70	2.0	11.5	4.3	0.4	7.2	5.6	11.22	1.30	0.01	0.05	0.10	0.11
Mar 70	1.5	10.0	2.3	1.6	7.6	6.5	6.20	1.00	0.00	0.11	0.11	0.16
Apl 70	0.5	5.5	2.9	1.6	7.7	8.7	10.78	0.75	0.03	0.02	0.06	0.09
May 70	2.0	7.5	3.8	5.4	8.0	11.5	13.90	6.05	0.00	0.08	0.14	0.17
Jne 70	1.5	9.0	2.3	17.1	8.2	11.8	9.00	0.97	0.03	0.02	0.05	0.09
Jly 70	1.0	1.5	6.9	11.6	7.3	13.6	7.60	0.81	0.00	0.04	0.02	0.12
Aug 70	0.1	8.8	2.6	1.6	8.0	15.0	11.60	0.66	0.02	0.07	0.01	0.10
Mean	1.3	9.1	3.8	3.7	7.7	10.1	8.99	1.96	0.02	0.07	0.05	0.13

STATION 23. LANGLEY BROOK AT MIDDLETON.

Date	Ammonia	Ox.Nit	PV	BOD	pH	Temp	Dis.Oxy	Fe	Cr	Cu	Ni	Zn
Sep 68	0.0	9.6	3.8	1.6	7.8	15.5	6.78	1.44	0.00	0.11	0.00	0.05
Oct 68	0.0	8.5	2.1	2.6	7.8	10.0	9.70	0.55	0.02	0.04	0.02	0.04
Nov 68	0.0	7.0	3.9	1.3	7.7	7.1	9.02	0.56	0.01	0.05	0.06	0.07
Dec 68	0.0	10.5	2.7	1.1	7.9	4.2	11.20	0.69	0.01	0.04	0.02	0.05
Jan 69	0.8	11.5	3.0	1.4	7.6	6.6	10.50	1.00	0.06	0.13	0.04	0.08
Feb 69	0.0	11.0	3.0	1.8	8.0	4.5	11.90	1.42	0.03	0.33	0.00	0.63
Mar 69	0.7	10.0	2.4	2.6	8.1	4.5	11.00	0.60	0.03	0.05	0.02	0.05
Apl 69	0.0	9.0	3.4	1.4	7.9	8.3	12.16	0.50	0.00	0.04	0.00	0.06
May 69	0.5	12.0	4.3	3.0	7.8	12.6	9.47	0.68	0.00	0.04	0.00	0.07
Jne 69	1.5	10.0	3.0	1.9	8.0	13.9	10.42	0.50	0.04	0.03	0.00	0.04
Jly 69	0.0	10.0	4.4	1.8	7.9	17.7	8.26	0.60	0.02	0.19	0.04	0.04
Aug 69	0.0	7.5	5.7	2.8	7.8	17.2	7.20	0.58	0.05	0.05	0.04	0.03
Sep 69	0.0	11.0	2.8	1.2	8.0	13.1	9.12	0.80	0.10	0.03	0.00	0.11
Oct 69	0.0	16.0	3.2	0.7	7.2	5.2	10.30	0.30	0.03	0.03	0.00	0.00
Nov 69	0.0	11.0	4.1	2.6	7.7	14.0	8.52	0.90	0.03	0.04	0.10	0.06
Dec 69	1.0	12.0	4.2	1.4	8.0	5.6	11.50	0.50	0.03	0.05	0.07	0.09
Jan 70	0.5	13.0	6.1	1.9	7.8	5.5	11.10	0.66	0.01	0.03	0.00	0.05
Feb 70	2.5	12.5	5.9	4.9	7.3	5.0	12.02	1.94	0.00	0.04	0.10	0.15
Mar 70	1.0	10.0	2.3	2.2	8.0	6.5	12.28	1.37	0.01	0.04	0.12	0.08
Apl 70	0.0	8.0	4.3	2.6	9.1	9.0	10.66	0.69	0.03	0.06	0.04	0.09
May 70	0.4	7.5	2.4	1.6	8.6	13.5	13.00	0.32	0.02	0.03	0.03	0.07
Jne 70	0.0	11.5	4.0	5.5	8.1	17.6	8.62	1.15	0.02	0.03	0.02	0.09
Jly 70	0.5	12.5	13.6	7.9	7.6	14.0	8.40	5.02	0.00	0.00	0.16	0.14
Aug 70	0.2	9.0	3.5	1.2	7.8	16.0	9.88	0.62	0.04	0.08	0.02	0.10
Mean	0.4	10.4	4.1	2.4	7.9	10.3	10.12	0.97	0.02	0.06	0.04	0.09

STATION 24. BOURNE.

Date	Ammonia	Ox.Nit	PV	BOD	pH	Temp	Dis.Oxy	Fe	Cr	Cu	Ni	Zn
Sep 68	0.4	7.5	2.0	1.5	8.0	16.5	8.80	1.42	0.00	0.06	0.00	0.07
Oct 68	1.0	6.5	2.5	4.1	7.8	11.0	8.90	0.67	0.01	0.04	0.10	0.04
Nov 68	0.0	5.5	2.1	2.9	7.7	7.6	9.90	0.31	0.01	0.06	0.06	0.07
Dec 68	5.5	7.5	8.3	7.0	7.9	5.8	8.86	3.81	0.00	0.15	0.23	0.40
Jan 69	0.9	8.5	2.9	2.4	7.8	7.0	10.85	0.29	0.06	0.16	0.04	0.08
Feb 69	0.5	8.5	1.5	2.3	7.9	4.0	11.00	3.46	0.06	0.35	0.00	0.72
Mar 69	0.0	8.1	1.5	4.6	8.0	6.0	9.80	1.27	0.02	0.04	0.03	0.05
Apl 69	0.0	9.0	4.8	4.3	8.0	10.2	11.54	0.80	0.00	0.04	0.00	0.04
May 69	0.5	10.0	2.2	4.6	7.8	12.9	9.69	0.48	0.00	0.04	0.05	0.06
Jne 69	1.0	6.0	1.9	1.0	8.0	15.4	9.50	1.20	0.01	0.03	0.00	0.06
Jly 69	0.0	4.5	4.0	1.9	8.0	21.6	9.40	0.75	0.01	0.08	0.04	0.05
Aug 69	0.5	7.0	2.1	3.2	7.8	16.1	7.90	0.54	0.03	0.02	0.04	0.03
Sep 69	0.0	7.5	2.4	0.5	8.0	13.5	7.82	1.18	0.04	0.05	0.03	0.09
Oct 69	0.0	12.5	4.1	2.1	7.8	5.9	7.32	2.08	0.07	0.04	0.00	0.00
Nov 69	0.0	6.0	1.7	2.9	7.9	14.5	9.62	0.60	0.02	0.03	0.09	0.01
Dec 69	1.5	10.0	2.3	1.3	7.9	5.3	9.80	4.05	0.01	0.06	0.06	0.11
Jan 70	0.5	10.0	3.6	2.7	7.9	6.0	11.16	0.98	0.01	0.03	0.02	0.05
Feb 70	2.0	10.0	8.0	1.4	7.4	4.5	12.04	4.27	0.03	0.04	0.14	0.08
Mar 70	1.0	10.0	1.8	2.6	8.1	6.5	11.40	0.75	0.02	0.03	0.09	0.07
Apl 70	0.0	9.5	1.4	1.0	8.3	9.4	12.00	0.35	0.03	0.02	0.02	0.07
May 70	0.6	8.0	3.4	0.4	8.8	15.5	5.80	0.23	0.02	0.03	0.06	0.07
Jne 70	1.0	8.0	3.3	9.9	7.9	21.0	9.52	0.90	0.00	0.02	0.04	0.09
Jly 70	2.0	6.5	6.7	13.3	7.8	14.5	10.00	3.22	0.00	0.09	0.07	0.07
Aug 70	1.2	8.3	3.0	2.8	8.2	18.5	11.02	0.40	0.03	0.03	0.05	0.10
Mean	0.8	8.1	3.2	3.4	7.9	11.2	9.73	1.42	0.02	0.06	0.05	0.10

STATION 25. LOW BROOK AT MARSTON GREEN.

Date	Ammonia	Ox.Nit	PV	BOD	pH	Temp	Dis.Oxy	Fe	Cr	Cu	Ni	Zn
Nov 70	0.5	6.8	16.0	5.5	7.4	9.1	9.0	1.37	0.01	0.03	0.04	0.08
Nov 70	0.5	7.5	12.0	11.5	7.5	7.6	8.8	1.24	0.04	0.02	0.04	0.07
Dec 70	3.7	8.0	3.5	19.5	7.8	8.5	9.8	0.44	0.01	0.01	0.04	0.04
Dec 70	0.5	2.7	3.5	1.5	7.4	7.5	10.1	0.30	0.02	0.27	0.03	0.16
Dec 70	0.5	3.8	2.5	6.5	7.7	2.2	12.7	0.36	0.02	0.19	0.04	0.14
Feb 71	0.5	5.3	4.5	4.5	---	6.3	11.6	0.54	0.04	0.00	0.04	0.06
Feb 71	0.5	5.5	---	3.0	7.9	5.7	12.4	0.40	0.00	0.03	0.02	0.09
Mar 71	0.5	4.0	---	5.0	7.9	7.8	11.5	0.34	0.03	0.03	0.02	0.05
Apl 71	0.5	6.0	---	0.5	8.1	8.0	14.6	0.22	0.02	0.02	0.01	0.05
Apl 71	0.5	3.8	---	12.0	7.9	9.0	14.9	0.32	0.00	0.00	0.04	0.05
Mean	0.8	5.3	7.0	6.9	7.7	7.2	11.5	0.55	0.02	0.06	0.03	0.08

STATION 26. LOW BROOK AT ELMDON.

Date	Ammonia	Ox.Nit	PV	BOD	pH	Temp	Dis.Oxy	Fe	Cr	Cu	Ni	Zn
Nov 70	0.5	6.8	15.5	2.5	7.4	8.7	8.5	1.39	0.02	0.03	0.02	0.07
Nov 70	0.5	9.0	19.0	6.5	7.8	7.4	8.8	1.03	0.02	0.06	0.04	0.07
Dec 70	0.5	6.5	2.0	21.5	7.7	8.0	9.4	0.41	0.03	0.01	0.04	0.04
Dec 70	0.5	4.0	3.0	1.5	7.5	7.5	10.5	0.30	0.01	0.03	0.03	0.04
Dec 70	0.5	5.0	2.0	1.0	7.6	2.0	12.1	0.40	0.03	0.05	0.01	0.03
Feb 71	0.5	9.0	5.0	5.7	---	7.0	11.2	0.76	0.02	0.00	0.03	0.02
Feb 71	0.5	4.0	---	8.0	7.9	5.5	11.6	0.46	0.00	0.02	0.02	0.06
Mar 71	0.5	3.0	---	4.5	7.8	8.0	11.2	0.47	0.04	0.03	0.08	0.08
Apl 71	0.5	3.5	---	4.2	8.0	7.5	11.5	0.46	0.00	0.00	0.02	0.03
Apl 71	0.5	3.2	---	5.0	7.7	9.0	11.5	0.47	0.00	0.00	0.04	0.07
Mean	0.5	5.4	7.7	6.0	7.7	7.1	10.6	0.61	0.02	0.02	0.03	0.05

STATION 27. SPARK BROOK.

Date	Ammonia	Ox.Nit	PV	BOD	pH	Temp	Dis.Oxy	Fe	Cr	Cu	Ni	Zn
Nov 70	0.5	3.9	13.0	6.0	7.3	10.0	8.0	1.52	0.02	0.03	0.04	0.26
Nov 70	0.5	4.6	12.0	7.0	7.5	8.6	7.3	1.36	0.04	0.06	0.06	0.60
Dec 70	0.5	5.0	1.5	13.0	7.6	9.5	6.4	0.34	0.04	0.01	0.04	0.34
Dec 70	2.7	8.2	4.5	9.7	7.4	8.8	6.1	0.61	0.03	0.06	0.04	0.27
Dec 70	3.1	3.7	4.0	5.5	7.5	4.1	6.3	0.57	0.05	0.07	0.06	0.38
Feb 71	0.5	13.3	4.0	13.5	---	8.5	8.1	0.31	0.02	0.00	0.03	0.22
Feb 71	0.5	11.2	---	4.0	7.4	7.2	6.3	0.51	0.00	0.02	0.02	0.63
Mar 71	0.5	4.5	---	9.5	7.4	8.0	7.8	0.84	0.03	0.04	0.04	0.45
Apl 71	2.1	6.9	---	35.5	7.5	8.5	6.0	0.28	0.01	0.00	0.02	0.25
Apl 71	0.5	10.8	---	6.5	7.3	11.0	7.5	0.28	0.00	0.02	0.04	0.24
Mean	1.1	7.2	6.3	11.0	7.4	8.4	7.0	0.66	0.02	0.03	0.04	0.36

STATION 28. STREAM ABOVE UPPER GORNAL.

Date	Ammonia	Ox.Nit	PV	BOD	pH	Temp	Dis.Oxy	Fe	Cr	Cu	Ni	Zn
Nov 70	0.5	6.8	7.5	3.0	7.6	9.0	10.6	0.65	0.01	0.02	0.05	0.04
Nov 70	0.5	7.5	7.5	1.2	7.5	8.0	10.7	0.78	0.03	0.01	0.04	0.09
Dec 70	0.5	11.2	2.5	22.5	7.6	8.6	10.8	0.50	0.07	0.01	0.03	0.05
Dec 70	0.5	9.0	2.5	1.5	7.5	7.7	11.3	0.94	0.04	0.03	0.04	0.07
Dec 70	0.5	9.0	1.5	3.5	7.5	4.4	12.1	0.69	0.05	0.03	0.04	0.07
Feb 71	0.5	11.8	2.0	3.5	---	7.8	11.8	1.00	0.02	0.00	0.06	0.37
Feb 71	0.5	10.2	---	20.0	8.0	8.5	6.9	0.51	0.00	0.02	0.02	0.06
Mar 71	0.5	9.2	---	6.5	7.7	9.0	11.8	0.53	0.05	0.02	0.02	0.07
Apl 71	0.5	8.2	---	4.0	8.0	8.0	11.9	0.34	0.00	0.02	0.02	0.03
Apl 71	0.5	8.6	---	3.5	7.7	10.0	11.9	0.37	0.00	0.00	0.04	0.04
Mean	0.5	9.1	3.9	6.9	7.7	8.1	11.0	0.63	0.03	0.02	0.04	0.09

STATION 29. STREAM AT TURLSHILL ROAD BELOW GORGE ROAD.

Date	Ammonia	Ox.Nit	PV	BOD	pH	Temp	Dis.Oxy	Fe	Cr	Cu	Ni	Zn
Nov 70	3.3	14.5	12.5	34.5	7.4	10.2	9.5	0.62	0.01	0.05	0.05	0.11
Nov 70	3.1	18.6	15.5	4.5	7.4	9.0	9.3	1.00	0.03	0.06	0.06	0.10
Dec 70	0.5	22.6	2.0	19.0	7.6	10.0	9.3	0.53	0.02	0.03	0.04	0.09
Dec 70	1.2	22.8	7.0	5.5	7.5	9.6	9.1	0.12	0.04	0.06	0.03	0.09
Dec 70	11.2	0.5	13.0	51.0	7.5	6.0	7.8	0.74	0.09	0.10	0.05	0.10
Feb 71	0.5	22.6	7.0	12.5	---	9.0	10.6	1.12	1.20	1.07	0.06	0.86
Feb 71	9.5	35.5	---	18.0	7.6	9.0	7.5	0.84	0.00	0.08	0.02	0.13
Mar 71	1.5	24.8	---	25.0	7.6	10.0	9.8	0.76	0.04	0.11	0.02	0.15
Apl 71	5.0	32.2	---	39.5	7.5	11.0	8.0	0.87	0.00	0.07	0.05	0.15
Apl 71	0.5	30.0	---	35.0	7.3	11.7	9.4	2.40	0.01	0.06	0.05	0.17
Mean	3.6	22.4	9.5	24.4	7.5	9.5	9.0	0.90	0.14	0.17	0.04	0.19

STATION 30. STREAM AT BROAD LANES, BILSTON.

Date	Ammonia	Ox.Nit	PV	BOD	pH	Temp	Dis.Oxy	Fe	Cr	Cu	Ni	Zn
Nov 70	2.5	7.2	15.0	23.0	7.7	22.2	6.1	2.94	0.02	0.22	0.11	7.50
Nov 70	3.1	7.5	15.0	14.5	7.4	20.0	5.8	2.61	0.05	0.25	0.09	8.32
Dec 70	0.5	14.0	2.0	16.5	7.7	22.0	6.4	0.69	0.02	0.10	0.03	2.17
Dec 70	0.5	9.0	3.0	5.0	7.5	22.0	5.1	0.69	0.05	0.05	0.05	1.80
Dec 70	3.7	0.5	11.5	22.5	7.5	18.3	6.8	4.25	0.04	0.35	0.12	8.05
Feb 71	0.5	13.3	4.0	10.2	---	20.2	6.4	1.09	0.06	0.04	0.05	2.87
Feb 71	0.5	9.2	---	7.0	7.8	21.8	5.2	1.59	0.00	0.39	0.07	1.55
Mar 71	2.5	7.2	---	16.5	7.4	21.0	5.5	1.53	0.03	0.07	0.04	6.10
Apl 71	0.5	8.8	---	12.0	7.8	21.0	5.6	1.00	0.00	0.03	0.02	1.97
Apl 71	4.0	11.8	---	6.5	7.6	21.7	4.6	0.96	0.00	0.07	0.06	8.25
Mean	1.8	8.8	8.4	13.4	7.6	21.0	5.7	1.73	0.03	0.16	0.06	4.86

STATION 31. STREAM AT BANKFIELD ROAD, BILSTON.

Date	Ammonia	Ox.Nit	PV	BOD	pH	Temp	Dis.Oxy	Fe	Cr	Cu	Ni	Zn
Nov 70	1.5	4.0	12.0	7.0	7.6	15.5	6.6	4.54	0.02	0.11	0.09	4.70
Nov 70	3.1	5.8	6.0	4.5	7.4	19.4	5.3	2.87	0.04	0.16	0.04	4.20
Dec 70	0.5	9.0	1.5	16.5	7.7	19.0	6.0	1.94	0.02	0.10	0.04	2.87
Dec 70	0.5	3.3	4.0	1.0	7.6	18.9	5.6	1.19	0.08	0.05	0.06	2.42
Dec 70	2.0	7.3	6.5	19.0	7.9	18.2	6.9	2.19	0.05	0.08	0.06	3.32
Feb 71	0.5	9.8	2.5	7.2	---	13.8	6.2	1.51	0.02	0.05	0.06	1.85
Feb 71	0.5	7.0	---	11.0	7.7	13.0	6.8	5.01	0.00	0.07	0.06	5.75
Mar 71	8.5	7.0	---	40.0	7.4	14.7	5.0	3.51	0.04	0.17	0.08	30.50
Apl 71	6.2	7.7	---	67.5	7.8	19.3	5.2	3.32	0.01	0.03	0.04	4.07
Apl 71	0.5	8.2	---	11.5	7.5	17.0	6.1	2.76	0.00	0.10	0.06	3.30
Mean	2.4	6.9	5.4	18.5	7.6	16.9	6.0	2.88	0.03	0.09	0.06	6.30

STATION 32. TAME AT BESCOT.

Date	Ammonia	Ox.Nit	PV	BOD	pH	Temp	Dis.Oxy	Fe	Cr	Cu	Ni	Zn
Nov 70	5.1	4.0	15.0	14.0	7.1	10.6	4.8	3.42	0.07	0.20	0.22	1.10
Nov 70	6.0	5.3	6.5	24.0	7.1	10.2	4.3	3.06	0.11	0.12	0.18	1.28
Dec 70	5.2	6.8	2.0	33.5	7.3	11.0	3.9	5.50	0.17	0.09	0.19	0.93
Dec 70	6.8	4.0	11.0	22.0	7.2	11.0	1.6	4.27	0.24	0.67	0.33	1.80
Dec 70	7.8	5.3	9.5	31.5	7.1	7.1	3.4	4.27	0.12	0.12	0.34	1.40
Feb 71	5.3	6.7	8.5	22.5	---	10.2	3.4	5.05	0.10	0.14	0.22	1.50
Feb 71	7.8	5.3	---	29.0	7.1	10.9	2.0	6.36	0.14	0.20	0.37	1.01
Mar 71	6.0	5.2	---	27.0	7.2	11.0	3.8	6.12	0.18	0.13	0.33	1.35
Apl 71	8.5	4.2	---	38.0	7.2	11.5	1.7	4.69	0.08	0.12	0.27	1.20
Apl 71	8.2	6.0	---	39.0	6.9	13.0	3.0	3.75	0.28	0.14	0.31	1.00
Mean	6.7	5.3	8.7	28.0	7.1	10.6	3.2	4.65	0.15	0.19	0.28	1.26

STATION 33. DARLASTON BROOK AT WILLENHALL.

Date	Ammonia	Ox.Nit	PV	BOD	pH	Temp	Dis.Oxy	Fe	Cr	Cu	Ni	Zn
Nov 70	9.0	5.2	17.0	32.0	7.3	11.5	5.8	2.44	0.11	0.14	0.24	1.20
Nov 70	9.0	5.5	15.0	7.0	7.1	11.6	5.1	4.00	0.08	0.17	0.21	2.00
Dec 70	10.5	6.8	10.5	38.5	7.4	11.9	4.1	3.19	0.21	0.20	0.25	1.50
Dec 70	12.0	3.6	15.0	40.5	7.2	12.3	3.7	3.25	0.16	0.38	0.29	2.00
Dec 70	14.2	4.7	18.0	52.5	7.1	8.6	4.6	3.19	0.13	0.17	0.45	3.32
Feb 71	10.7	7.5	12.0	46.5	---	11.3	3.7	5.86	0.12	0.18	0.25	2.25
Feb 71	12.5	6.8	---	1.0	7.3	12.4	3.3	8.75	0.12	0.25	0.20	2.17
Mar 71	10.0	6.2	---	28.0	7.3	12.2	4.3	5.44	0.19	0.17	0.26	3.05
Apl 71	14.0	5.5	---	Exhaust	7.4	13.1	5.4	2.25	0.06	0.12	0.16	2.50
Apl 71	11.8	7.0	---	43.0	7.1	14.5	4.2	2.22	0.05	0.11	0.16	2.25
Mean	11.4	5.9	14.6	32.1	7.2	11.9	4.4	4.06	0.12	0.19	0.25	2.22

STATION 34. WADDENS BROOK AT LICHFIELD ROAD.

Date	Ammonia	Ox.Nit	PV	BOD	pH	Temp	Dis.Oxy	Fe	Cr	Cu	Ni	Zn
Nov 70	0.5	4.0	14.0	5.5	7.5	9.8	9.5	0.44	0.05	0.04	0.05	0.10
Nov 70	3.1	9.3	10.0	---	7.5	8.8	9.2	0.50	0.03	0.05	0.09	0.18
Dec 70	0.5	11.2	1.0	15.5	7.5	8.8	9.8	0.37	0.02	0.03	0.03	0.11
Dec 70	0.5	3.3	2.5	1.5	7.4	8.5	10.1	0.44	0.08	0.03	0.06	0.12
Dec 70	0.5	12.0	2.5	4.5	7.3	5.6	11.0	0.44	0.03	0.06	0.06	0.13
Feb 71	0.5	11.5	3.5	3.5	---	7.8	11.1	0.56	0.04	0.04	0.04	0.22
Mar 71	0.5	7.0	---	---	7.4	8.2	10.3	0.66	0.04	0.02	0.02	0.13
Apl 71	0.5	6.0	---	9.5	8.0	12.0	11.9	0.47	0.02	0.02	0.11	0.11
Apl 71	0.5	6.9	---	8.0	7.6	11.2	10.4	0.37	0.00	0.00	0.02	0.09
Mean	0.7	7.9	5.6	6.9	7.5	9.0	10.4	0.47	0.03	0.03	0.05	0.12

* No sample on 25th February, 1971.

STATION 35. GOSCOTE BROOK AT WOLVERHAMPTON ROAD.

Date	Ammonia	Ox.Nit	PV	BOD	pH	Temp	Dis.Oxy	Fe	Cr	Cu	Ni	Zn
Nov 70	0.5	1.2	11.0	5.0	7.2	8.6	5.9	0.81	0.05	0.06	0.05	0.19
Nov 70	1.6	3.2	14.5	1.0	7.0	7.0	6.4	0.71	0.01	0.03	0.04	0.25
Dec 70	0.5	5.5	1.5	20.5	7.4	8.0	6.2	0.25	0.02	0.05	0.06	0.14
Dec 70	0.5	2.3	2.5	4.5	7.4	7.3	5.9	0.42	0.12	0.02	0.06	0.16
Dec 70	0.5	3.7	2.5	2.0	7.3	1.0	8.3	0.88	0.01	0.10	0.05	0.09
Feb 71	0.5	5.0	4.5	5.0	---	7.0	6.0	0.94	0.06	0.07	0.09	0.22
Feb 71	0.5	3.8	---	2.5	7.5	7.0	9.3	0.55	0.00	0.04	0.07	0.14
Mar 71	0.5	6.0	---	2.5	7.5	8.9	9.2	0.49	0.03	0.03	0.03	0.20
Apl 71	0.5	2.8	---	8.2	7.6	10.7	8.2	0.37	0.00	0.01	0.02	0.09
Apl 71	0.5	3.8	---	12.0	7.2	11.8	5.8	0.66	0.01	0.04	0.04	0.12
Mean	0.6	3.7	6.1	6.3	7.3	7.7	7.1	0.61	0.03	0.04	0.05	0.16

STATION 36. STREAM ABOVE BARNS LANE.

Date	Ammonia	Ox.Nit	PV	BOD	pH	Temp	Dis.Oxy	Fe	Cr	Cu	Ni	Zn
Nov 70	0.5	4.5	12.5	2.5	7.1	9.0	6.7	0.62	0.06	0.06	0.07	0.15
Nov 70	1.6	4.6	4.5	3.5	7.3	8.0	4.7	0.57	0.02	0.02	0.04	0.25
Dec 70	0.5	3.7	1.0	21.5	7.4	8.1	5.3	0.19	0.01	0.02	0.04	0.05
Dec 70	0.5	0.5	2.5	2.0	7.3	8.2	5.7	0.99	0.09	0.04	0.07	0.12
Dec 70	0.5	0.5	1.5	3.0	7.2	2.0	7.3	0.39	0.00	0.03	0.04	0.04
Feb 71	0.5	2.0	2.0	7.0	---	8.0	9.1	0.38	0.03	0.00	0.04	0.06
Feb 71	0.5	1.5	---	0.5	7.4	9.0	5.5	0.51	0.00	0.01	0.03	0.06
Mar 71	0.5	2.8	---	0.5	7.4	10.2	10.6	0.66	0.03	0.04	0.02	0.09
Apl 71	0.5	0.5	---	15.7	7.7	12.0	17.2	0.56	0.00	0.02	0.02	0.07
Apl 71	0.5	3.2	---	7.5	7.3	12.0	13.7	0.78	0.00	0.00	0.04	0.07
Mean	0.6	2.4	6.0	6.4	7.3	8.6	8.6	0.56	0.02	0.02	0.04	0.10

STATION 37. STREAM ABOVE ROWAY LANE.

Date	Ammonia	Ox.Nit	PV	BOD	pH	Temp	Dis.Oxy	Fe	Cr	Cu	Ni	Zn
Jan 70	3.0	6.5	10.0	9.0	5.5	9.8	4.90	40.00	0.08	0.10	0.06	3.23
Feb 70	3.0	6.0	12.4	3.4	6.9	8.0	0.78	82.50	1.92	0.13	1.04	1.48
Mar 70	2.5	8.0	7.3	3.6	6.6	9.0	8.04	41.10	0.05	0.39	0.24	4.60
Apl 70	3.0	6.0	29.4	10.0	2.8	8.0	1.66	161.00	0.20	0.25	0.49	2.80
May 70	5.5	3.0	9.5	12.0	6.1	14.0	2.90	77.60	0.70	0.15	0.29	5.40
Jne 70	7.3	1.0	4.7	3.0	6.6	17.5	2.20	54.25	0.14	0.08	0.16	4.15
Jly 70	4.5	3.0	128.0	28.0	1.4	16.5	0.72	640.00	0.89	13.90	10.80	33.00
Aug 70	3.3	1.7	44.4	27.6	6.8	16.0	4.94	12.00	0.16	0.15	0.15	1.94
Sep 70	2.0	2.5	4.2	10.4	7.0	18.0	5.82	25.85	0.18	0.10	0.15	1.06
Nov 70	0.0	2.1	16.0	20.8	6.9	8.5	8.48	21.00	0.03	0.21	0.07	0.80
Dec 70	1.5	5.0	7.6	12.6	6.6	8.5	6.82	32.81	0.06	0.12	0.13	1.01
Jan 71	2.5	6.0	5.5	10.8	6.8	7.7	6.22	28.90	0.04	0.20	0.14	0.51
Feb 71	4.0	5.0	6.0	6.2	8.8	7.0	4.20	15.25	0.01	0.08	0.09	0.49
Mar 71	1.5	4.6	7.0	4.0	6.9	8.5	9.02	11.12	0.02	0.08	0.09	1.26
Apl 71	6.0	3.0	11.0	2.8	6.2	13.5	1.34	150.00	0.05	0.79	0.12	1.75
Mean	3.3	4.2	20.2	10.9	6.1	12.7	4.54	92.89	0.30	1.11	0.94	4.23

* No sample October, 1970.

Table 58. Concentration, proportion of threshold value and toxicity index at selected stations for the main two year period

Date	Chromium		Copper		Nickel		Zinc		Sum of	T.I.
	Conc	Prop	Conc	Prop	Conc	Prop	Conc	Prop	Prop	
Station 19. Blythe at Blythe Bridge										
Sep 68	0.02	0.8	0.06	0.8	0.00	0.0	0.05	0.3	1.9	0.5
Oct 68	0.02	0.8	0.04	0.5	0.02	0.3	0.04	0.3	1.9	0.5
Nov 68	0.02	0.8	0.08	1.1	0.11	1.8	0.10	0.7	4.4	1.1
Dec 68	0.00	0.0	0.04	0.5	0.45	7.5	0.05	0.3	8.3	2.1
Jan 69	0.04	1.6	0.18	2.4	0.06	1.0	0.16	1.1	6.1	1.5
Feb 69	0.06	2.4	0.29	3.9	0.00	0.0	0.72	4.8	11.1	2.8
Mar 69	0.02	0.8	0.06	0.8	0.05	0.8	0.09	0.6	3.0	0.8
Apl 69	0.00	0.0	0.03	0.4	0.00	0.0	0.04	0.3	0.7	0.2
May 69	0.02	0.8	0.01	0.1	0.00	0.0	0.07	0.5	1.4	0.4
Jne 69	0.13	5.2	0.00	0.0	0.00	0.0	0.10	0.7	5.9	1.5
Jly 69	0.05	2.0	0.00	0.0	0.04	0.7	0.05	0.3	3.0	0.8
Aug 69	0.00	0.0	0.09	1.2	0.04	0.7	0.03	0.2	2.1	0.5
Sep 69	0.03	1.2	0.02	0.3	0.00	0.0	0.07	0.5	2.0	0.5
Oct 69	0.04	1.6	0.05	0.7	0.00	0.0	0.04	0.3	2.6	0.7
Nov 69	0.01	0.4	0.05	0.7	0.05	0.8	0.06	0.4	2.3	0.6
Dec 69	0.02	0.8	0.05	0.7	0.19	3.2	0.09	0.6	5.3	1.3
Jan 70	0.01	0.4	0.01	0.1	0.04	0.7	0.06	0.4	1.6	0.4
Feb 70	0.03	1.2	0.03	0.4	0.04	0.7	0.06	0.4	2.7	0.7
Mar 70	0.00	0.0	0.03	0.4	0.10	1.7	0.06	0.4	2.5	0.6
Apl 70	0.02	0.8	0.00	0.0	0.02	0.3	0.05	0.3	1.4	0.4
May 70	0.00	0.0	0.02	0.3	0.02	0.3	0.05	0.3	0.9	0.2
Jne 70	0.02	0.8	0.03	0.4	0.02	0.3	0.06	0.4	1.9	0.5
Jly 70	0.00	0.0	0.02	0.3	0.04	0.7	0.12	0.8	1.8	0.5
Aug 70	0.02	0.8	0.08	1.1	0.01	0.2	0.10	0.7	2.8	0.7
Station 20. Blythe at Henwood Mill										
Sep 68	0.00	0.0	0.03	0.4	0.00	0.0	0.04	0.3	0.7	0.2
Oct 68	0.01	0.4	0.03	0.4	0.01	0.2	0.04	0.3	1.3	0.3
Nov 68	0.01	0.4	0.06	0.8	0.06	1.0	0.09	0.6	2.8	0.7
Dec 68	0.00	0.0	0.05	0.7	0.03	0.5	0.13	0.9	2.1	0.5
Jan 69	0.01	0.4	0.04	0.5	0.05	0.8	0.06	0.4	2.1	0.5
Feb 69	0.04	1.6	0.33	4.4	0.00	0.0	0.80	5.3	11.3	2.8
Mar 69	0.00	0.0	0.03	0.4	0.03	0.5	0.05	0.3	1.2	0.3
Apl 69	0.00	0.0	0.01	0.1	0.00	0.0	0.04	0.3	0.4	0.1
May 69	0.00	0.0	0.02	0.3	0.00	0.0	0.06	0.4	0.7	0.2
Jne 69	0.02	0.8	0.04	0.5	0.07	1.2	0.04	0.3	2.8	0.7
Jly 69	0.04	1.6	0.02	0.3	0.06	1.0	0.06	0.4	3.3	0.8
Aug 69	0.00	0.0	0.06	0.8	0.04	0.7	0.06	0.4	1.9	0.5
Sep 69	0.04	1.6	0.04	0.5	0.00	0.0	0.09	0.6	2.7	0.7
Oct 69	0.00	0.0	0.05	0.7	0.00	0.0	0.01	0.1	0.8	0.2
Nov 69	0.00	0.0	0.12	1.6	0.15	2.5	0.06	0.4	4.5	1.1
Dec 69	0.00	0.0	0.04	0.5	0.16	2.7	0.11	0.7	3.9	1.0
Jan 70	0.00	0.0	0.03	0.4	0.02	0.3	0.09	0.6	1.3	0.3
Feb 70	0.01	0.4	0.03	0.4	0.07	1.2	0.14	0.9	2.9	0.7
Mar 70	0.01	0.4	0.04	0.5	0.12	2.0	0.08	0.5	3.4	0.9
Apl 70	0.04	1.6	0.03	0.4	0.02	0.3	0.07	0.5	2.8	0.7
May 70	0.02	0.8	0.05	0.7	0.04	0.7	0.07	0.5	2.7	0.7
Jne 70	0.01	0.4	0.02	0.3	0.02	0.3	0.06	0.4	1.4	0.4
Jly 70	0.00	0.0	0.00	0.0	0.02	0.3	0.07	0.5	0.8	0.2
Aug 70	0.03	1.2	0.09	1.2	0.01	0.2	0.10	0.7	3.3	0.8

continued:-

Date	Chromium Conc	Chromium Prop	Copper Conc	Copper Prop	Nickel Conc	Nickel Prop	Zinc Conc	Zinc Prop	Sum of Prop	T.I.
Station 21. Blythe at Hampton-in-Arden										
Sep 68	0.00	0.0	0.09	1.2	0.00	0.0	0.07	0.5	1.7	0.4
Oct 68	0.02	0.8	0.06	0.8	0.06	1.0	0.07	0.5	3.1	0.8
Nov 68	0.02	0.8	0.04	0.5	0.06	1.0	0.10	0.7	3.0	0.8
Dec 68	0.00	0.0	0.04	0.5	0.00	0.0	0.06	0.4	0.9	0.2
Jan 69	0.04	1.6	0.16	2.1	0.04	0.7	0.11	0.7	5.1	1.3
Feb 69	0.00	0.0	0.41	5.5	0.00	0.0	0.96	6.4	11.9	3.0
Mar 69	0.03	1.2	0.03	0.4	0.08	1.3	0.07	0.5	3.4	0.9
Apl 69	0.06	2.4	0.02	0.3	0.00	0.0	0.06	0.4	3.1	0.8
May 69	0.00	0.0	0.02	0.3	0.05	0.8	0.07	0.5	1.6	0.4
Jne 69	0.03	1.2	0.00	0.0	0.00	0.0	0.06	0.4	1.6	0.4
Jly 69	0.08	3.2	0.07	0.9	0.04	0.7	0.09	0.6	5.4	1.4
Aug 69	0.00	0.0	0.04	0.5	0.00	0.0	0.06	0.4	0.9	0.2
Sep 69	0.01	0.4	0.03	0.4	0.00	0.0	0.09	0.6	1.4	0.4
Oct 69	0.06	2.4	0.08	1.1	0.04	0.7	0.04	0.3	4.5	1.1
Nov 69	0.02	0.8	0.01	0.1	0.57	9.5	0.03	0.2	10.6	2.7
Dec 69	0.00	0.0	0.05	0.7	0.12	2.0	0.12	0.8	3.5	0.9
Jan 70	0.00	0.0	0.03	0.4	0.02	0.3	0.06	0.4	1.1	0.3
Feb 70	0.01	0.4	0.04	0.5	0.09	1.5	0.11	0.7	3.1	0.8
Mar 70	0.02	0.8	0.04	0.5	0.10	1.7	0.06	0.4	3.4	0.9
Apl 70	0.09	3.6	0.03	0.4	0.04	0.7	0.09	0.6	5.3	1.3
May 70	0.05	2.0	0.17	2.3	0.07	1.2	0.15	1.0	6.5	1.6
Jne 70	0.01	0.4	0.03	0.4	0.06	1.0	0.12	0.7	2.5	0.6
Jly 70	0.00	0.0	0.05	0.7	0.02	0.3	0.09	0.6	1.6	0.4
Aug 70	0.02	0.8	0.09	1.2	0.02	0.3	0.12	0.8	3.1	0.8

Date	Chromium Conc	Chromium Prop	Copper Conc	Copper Prop	Nickel Conc	Nickel Prop	Zinc Conc	Zinc Prop	Sum of Prop	T.I.
Station 22. Langley Brook above Langley Works										
Sep 68	0.00	0.0	0.08	1.1	0.00	0.0	0.37	2.5	3.6	0.9
Oct 68	0.02	0.8	0.05	0.7	0.02	0.3	0.10	0.7	2.5	0.6
Nov 68	0.01	0.4	0.04	0.5	0.11	1.8	0.09	0.6	3.3	0.8
Dec 68	0.00	0.0	0.05	0.7	0.00	0.0	0.10	0.7	1.4	0.4
Jan 69	0.08	3.2	0.19	2.5	0.04	0.7	0.25	1.7	9.1	2.3
Feb 69	0.00	0.0	0.40	5.3	0.00	0.0	0.60	4.0	9.3	2.3
Mar 69	0.02	0.8	0.04	0.5	0.04	0.7	0.07	0.5	2.5	0.6
Apl 69	0.00	0.0	0.02	0.3	0.00	0.0	0.07	0.5	0.8	0.2
May 69	0.00	0.0	0.04	0.5	0.05	0.8	0.07	0.5	1.8	0.5
Jne 69	0.05	2.0	0.00	0.0	0.00	0.0	0.02	0.1	2.1	0.5
Jly 69	0.02	0.8	0.08	1.1	0.07	1.2	0.05	0.3	3.4	0.9
Aug 69	0.03	1.2	0.05	0.7	0.04	0.7	0.06	0.4	3.0	0.8
Sep 69	0.04	1.6	0.06	0.8	0.03	0.5	0.14	0.9	3.8	0.9
Oct 69	0.06	2.4	0.05	0.7	0.07	1.2	0.03	0.2	4.5	1.1
Nov 69	0.03	1.2	0.04	0.5	0.07	1.2	0.06	0.4	3.3	0.8
Dec 69	0.00	0.0	0.05	0.7	0.11	1.8	0.11	0.7	3.2	0.8
Jan 70	0.02	0.8	0.04	0.5	0.01	0.2	0.12	0.8	2.3	0.6
Feb 70	0.01	0.4	0.05	0.7	0.10	1.7	0.11	0.7	3.5	0.9
Mar 70	0.00	0.0	0.11	1.5	0.11	1.8	0.16	1.1	4.4	1.1
Apl 70	0.03	1.2	0.02	0.3	0.06	1.0	0.09	0.6	3.1	0.8
May 70	0.00	0.0	0.08	1.1	0.14	2.3	0.17	1.1	4.5	1.1
Jne 70	0.03	1.2	0.02	0.3	0.05	0.8	0.09	0.6	2.9	0.7
Jly 70	0.00	0.0	0.04	0.5	0.02	0.3	0.12	0.8	1.6	0.4
Aug 70	0.02	0.8	0.07	0.9	0.01	0.2	0.10	0.7	2.6	0.7

continued:-

Station 23. Langley Brook at Middleton

Date	Chromium		Copper		Nickel		Zinc		Sum of	T.I.
	Conc	Prop	Conc	Prop	Conc	Prop	Conc	Prop	Prop	
Sep 68	0.00	0.0	0.11	1.3	0.00	0.0	0.05	0.3	1.6	0.4
Oct 68	0.02	0.8	0.04	0.5	0.02	0.3	0.04	0.3	1.9	0.5
Nov 68	0.01	0.4	0.05	0.7	0.06	1.0	0.07	0.5	2.6	0.7
Dec 68	0.01	0.4	0.04	0.5	0.02	0.3	0.05	0.3	1.5	0.4
Jan 69	0.06	2.4	0.13	1.7	0.04	0.7	0.08	0.5	5.3	1.3
Feb 69	0.03	1.2	0.33	4.4	0.00	0.0	0.63	4.2	9.8	2.5
Mar 69	0.03	1.2	0.05	0.7	0.02	0.3	0.05	0.3	2.5	0.6
Apl 69	0.00	0.0	0.04	0.5	0.00	0.0	0.06	0.4	0.9	0.2
May 69	0.00	0.0	0.04	0.5	0.00	0.0	0.07	0.5	1.0	0.3
Jne 69	0.04	1.6	0.03	0.4	0.00	0.0	0.04	0.3	2.3	0.6
Jly 69	0.02	0.8	0.19	2.5	0.04	0.7	0.04	0.3	4.3	1.1
Aug 69	0.05	2.0	0.05	0.7	0.04	0.7	0.03	0.2	3.6	0.9
Sep 69	0.10	4.0	0.03	0.4	0.00	0.0	0.11	0.7	5.1	1.3
Oct 69	0.03	1.2	0.03	0.4	0.00	0.0	0.00	0.0	1.6	0.4
Nov 69	0.03	1.2	0.04	0.5	0.10	1.7	0.06	0.4	3.8	0.9
Dec 69	0.03	1.2	0.05	0.7	0.07	1.2	0.09	0.6	3.7	0.9
Jan 70	0.01	0.4	0.03	0.4	0.00	0.0	0.05	0.3	1.1	0.3
Feb 70	0.00	0.0	0.04	0.5	0.10	1.7	0.15	1.0	3.2	0.8
Mar 70	0.01	0.4	0.04	0.5	0.12	2.0	0.08	0.5	3.4	0.9
Apl 70	0.03	1.2	0.06	0.8	0.04	0.7	0.09	0.6	3.3	0.8
May 70	0.02	0.8	0.03	0.4	0.03	0.5	0.07	0.5	2.2	0.6
Jne 70	0.02	0.8	0.03	0.4	0.02	0.3	0.09	0.6	2.1	0.5
Jly 70	0.00	0.0	0.00	0.0	0.16	2.7	0.14	0.9	3.6	0.9
Aug 70	0.04	1.6	0.08	1.1	0.02	0.3	0.10	0.7	3.7	0.9

Station 24. Bourne at Whitacre

Date	Chromium		Copper		Nickel		Zinc		Sum of	T.I.
	Conc	Prop	Conc	Prop	Conc	Prop	Conc	Prop	Prop	
Sep 68	0.00	0.0	0.06	0.8	0.00	0.0	0.07	0.5	1.3	0.3
Oct 68	0.01	0.4	0.04	0.5	0.10	1.7	0.04	0.3	2.9	0.7
Nov 68	0.01	0.4	0.06	0.8	0.06	1.0	0.07	0.5	2.7	0.7
Dec 68	0.01	0.4	0.15	2.0	0.23	3.8	0.40	2.7	9.1	2.3
Jan 69	0.06	2.4	0.16	2.1	0.04	0.7	0.08	0.5	5.7	1.4
Feb 69	0.06	2.4	0.35	4.7	0.00	0.0	0.72	4.8	11.9	3.0
Mar 69	0.02	0.8	0.04	0.5	0.03	0.5	0.05	0.3	2.1	0.5
Apl 69	0.00	0.0	0.04	0.5	0.00	0.0	0.04	0.3	0.8	0.2
May 69	0.00	0.0	0.04	0.5	0.05	0.8	0.06	0.4	1.7	0.4
Jne 69	0.01	0.4	0.03	0.4	0.00	0.0	0.06	0.4	1.2	0.3
Jly 69	0.01	0.4	0.08	1.1	0.04	0.7	0.05	0.3	2.5	0.6
Aug 69	0.03	1.2	0.02	0.3	0.04	0.7	0.03	0.2	2.4	0.6
Sep 69	0.04	1.6	0.05	0.7	0.03	0.5	0.09	0.6	3.4	0.9
Oct 69	0.07	2.8	0.04	0.5	0.00	0.0	0.00	0.0	3.3	0.8
Nov 69	0.02	0.8	0.03	0.4	0.09	1.5	0.01	0.1	2.8	0.7
Dec 69	0.01	0.4	0.06	0.8	0.06	1.0	0.11	0.7	2.9	0.7
Jan 70	0.01	0.4	0.03	0.4	0.02	0.3	0.05	0.3	1.4	0.4
Feb 70	0.03	1.2	0.04	0.5	0.14	2.3	0.08	0.5	4.5	1.1
Mar 70	0.02	0.8	0.03	0.4	0.09	1.5	0.07	0.5	3.2	0.8
Apl 70	0.03	1.2	0.02	0.3	0.02	0.3	0.07	0.5	2.3	0.8
May 70	0.02	0.8	0.03	0.4	0.06	1.0	0.07	0.5	2.7	0.7
Jne 70	0.00	0.0	0.02	0.3	0.04	0.7	0.09	0.6	1.6	0.4
Jly 70	0.00	0.0	0.09	1.2	0.07	1.2	0.07	0.5	2.9	0.7
Aug 70	0.03	1.2	0.03	0.4	0.05	0.8	0.10	0.7	3.1	0.8

continued:-

Date	Chromium Conc	Chromium Prop	Copper Conc	Copper Prop	Nickel Conc	Nickel Prop	Zinc Conc	Zinc Prop	Sum of Prop	T.I.
Station 1. Jessons Bridge below Upper Gornal Works										
Sep 68	0.03	1.2	0.10	1.3	0.00	0.0	0.18	1.2	3.7	0.9
Oct 68	0.05	2.0	0.10	1.3	0.13	2.2	0.14	0.9	6.4	1.6
Nov 68	0.01	0.4	0.18	2.4	0.06	1.0	0.10	0.7	4.5	1.1
Dec 68	0.05	2.0	0.31	4.1	0.05	0.8	0.66	4.4	11.3	2.8
Jan 69	0.08	3.2	0.25	3.3	0.04	0.7	0.17	1.1	8.3	2.1
Feb 69	0.02	0.8	0.22	2.9	0.00	0.0	0.52	3.5	7.2	1.8
Mar 69	0.02	0.8	0.10	1.3	0.00	0.0	0.18	1.2	3.3	0.8
Apl 69	0.06	2.4	0.09	1.2	0.00	0.0	0.15	1.0	4.6	1.1
May 69	0.00	0.0	0.16	2.1	0.00	0.0	0.14	0.9	3.0	0.7
Jne 69	0.06	2.4	0.09	1.2	0.00	0.0	0.09	0.6	4.2	1.0
Jly 69	0.04	1.6	0.16	2.1	0.04	0.7	0.15	1.0	5.4	1.3
Aug 69	0.12	4.8	0.05	0.7	0.04	0.7	0.13	0.9	7.1	1.8
Sep 69	0.03	1.2	0.10	1.3	0.05	0.8	0.17	1.1	4.4	1.1
Oct 69	0.04	1.6	0.14	1.9	0.04	0.7	0.10	0.7	4.9	1.2
Nov 69	0.13	5.2	0.20	2.7	0.90	15.0	0.38	2.5	25.4	6.3
Dec 69	0.07	2.8	0.05	0.7	0.17	2.8	0.11	0.7	7.0	1.7
Jan 70	0.00	0.0	0.05	0.7	0.03	0.5	0.09	0.6	1.8	0.5
Feb 70	0.01	0.4	0.05	0.7	0.06	1.0	0.10	0.7	2.8	0.7
Mar 70	0.01	0.4	0.07	0.9	0.11	1.8	0.08	0.5	3.6	0.9
Apl 70	0.04	1.6	0.11	1.5	0.04	0.7	0.13	0.9	4.7	1.2
May 70	0.01	0.4	0.14	1.9	0.04	0.7	0.22	1.5	4.5	1.1
Jne 70	0.03	1.2	0.11	1.5	0.07	0.7	0.16	1.1	4.5	1.1
Jly 70	0.05	2.0	0.11	1.5	0.24	4.0	0.16	1.1	8.6	2.2
Aug 70	0.01	0.4	0.10	1.3	0.05	0.8	0.10	0.7	3.2	0.8
Station 2. Jessons Bridge below Gorge Road Works										
Sep 68	0.03	1.2	0.15	2.0	0.00	0.0	0.08	0.5	3.7	0.9
Oct 68	0.06	2.4	0.06	0.8	0.20	3.3	0.08	0.5	7.0	1.8
Nov 68	0.01	0.4	0.06	0.8	0.11	1.8	0.09	0.6	3.6	0.9
Dec 68	0.02	0.8	0.27	3.6	0.05	0.8	0.73	4.9	10.1	2.5
Jan 69	0.07	2.8	0.23	3.1	0.00	0.0	0.12	0.8	6.7	1.7
Feb 69	0.02	0.8	0.25	3.3	0.00	0.0	0.54	3.6	7.7	1.9
Mar 69	0.03	1.2	0.08	1.1	0.00	0.0	0.13	0.9	3.2	0.8
Apl 69	0.02	0.8	0.13	1.7	0.00	0.0	0.29	1.9	4.4	1.1
May 69	0.06	2.4	0.48	6.4	0.00	0.0	0.63	4.2	13.0	3.2
Jne 69	0.03	1.2	0.09	1.2	0.00	0.0	0.09	0.6	3.6	0.9
Jly 69	0.00	0.0	0.17	2.3	0.06	1.0	0.14	0.9	4.2	1.0
Aug 69	0.00	0.0	0.01	0.1	0.05	0.8	0.09	0.6	1.5	0.4
Sep 69	0.04	1.6	0.06	0.8	0.03	0.5	0.16	1.1	4.0	1.0
Oct 69	0.06	2.4	0.13	1.7	0.07	1.2	0.06	0.4	5.7	1.4
Nov 69	0.04	1.6	0.08	1.1	0.21	3.5	0.16	1.1	7.3	1.8
Dec 69	0.10	4.0	0.06	0.8	0.11	1.8	0.11	0.7	7.3	1.8
Jan 70	0.00	0.0	0.03	0.5	0.02	0.3	0.07	0.5	1.3	0.3
Feb 70	0.04	1.6	0.10	1.3	0.09	1.5	0.16	1.1	5.5	1.4
Mar 70	0.02	0.8	0.10	1.3	0.10	1.7	0.13	0.9	4.7	1.2
Apl 70	0.04	1.6	0.11	1.5	0.05	0.8	0.11	0.7	4.6	1.2
May 70	0.00	0.0	0.09	1.2	0.02	0.3	0.15	1.0	2.5	0.6
Jne 70	0.03	1.2	0.22	2.9	0.20	3.3	0.44	2.9	10.3	2.6
Jly 70	0.04	1.6	0.09	1.2	0.11	1.8	0.21	1.4	6.0	1.5
Aug 70	0.03	1.2	0.11	1.5	0.07	1.2	0.12	0.8	4.7	1.2

continued:-

Date	Chromium Conc	Chromium Prop	Copper Conc	Copper Prop	Nickel Conc	Nickel Prop	Zinc Conc	Zinc Prop	Sum of Prop	T.I.
Station 7.	Waddens Brook at Noose Lane									
Sep 68	0.05	2.0	0.16	2.1	0.02	0.3	0.33	2.2	6.6	1.6
Oct 68	0.03	1.2	0.08	1.1	0.02	0.3	0.24	1.6	4.2	1.1
Nov 68	0.01	0.4	0.15	2.0	0.21	3.5	0.32	2.1	8.0	2.0
Dec 68	0.01	0.4	0.16	2.1	0.03	0.5	0.74	4.9	7.9	2.0
Jan 69	0.06	2.4	0.33	4.4	0.09	1.5	0.83	5.5	13.8	3.4
Feb 69	0.03	1.2	0.14	1.9	0.05	0.8	0.50	3.3	7.2	1.8
Mar 69	0.07	2.8	0.09	1.2	0.00	0.0	0.39	2.6	6.6	1.6
Apl 69	0.00	0.0	0.08	1.1	0.00	0.0	0.57	3.4	4.5	1.1
May 69	0.16	6.4	0.98	13.0	0.00	0.0	1.91	12.7	32.1	8.0
Jne 69	0.00	0.0	0.16	2.1	0.00	0.0	0.34	2.3	4.4	1.1
Jly 69	0.03	1.2	0.15	2.0	0.04	0.7	0.22	1.5	5.4	1.3
Aug 69	0.00	0.0	0.08	1.1	0.07	1.2	0.19	1.3	3.6	0.9
Sep 69	0.00	0.0	0.06	0.8	0.03	0.5	0.25	1.7	3.0	0.7
Oct 69	0.03	1.2	0.10	1.3	0.00	0.0	0.17	1.1	3.6	0.9
Nov 69	0.02	0.8	0.12	1.6	0.31	5.2	0.49	4.3	11.9	3.0
Dec 69	0.09	3.6	0.06	0.8	0.11	1.8	0.29	1.9	8.1	2.0
Jan 70	0.03	1.2	0.05	0.7	0.01	0.2	0.23	1.5	3.6	0.8
Feb 70	0.03	1.2	0.06	0.8	0.12	2.0	0.33	2.2	6.2	1.5
Mar 70	0.01	0.4	0.06	0.8	0.12	2.0	0.17	1.1	4.3	1.1
Apl 70	0.02	0.8	0.07	0.9	0.10	1.7	0.43	2.9	6.3	1.6
May 70	0.01	0.4	0.07	0.9	0.07	1.2	0.23	1.5	4.0	1.0
Jne 70	0.02	0.8	0.11	1.5	0.07	1.2	0.31	2.1	5.6	1.4
Jly 70	0.00	0.0	0.06	0.8	0.04	0.7	0.24	1.6	3.1	0.8
Aug 70	0.02	0.8	0.08	1.1	0.07	1.2	0.12	0.8	3.9	1.0
Station 16.	Cole at Cole Hall Lane									
Sep 68	0.22	8.8	0.07	0.9	0.00	0.0	0.14	0.9	10.6	2.6
Oct 68	0.04	1.6	0.04	0.5	0.20	3.3	0.19	1.3	6.7	1.7
Nov 68	0.02	0.8	0.05	0.7	0.37	6.2	0.36	2.4	10.1	2.5
Dec 68	0.11	4.4	0.24	3.2	0.65	10.8	1.13	7.5	25.9	6.5
Jan 69	0.05	2.0	0.25	3.3	0.00	0.0	0.69	4.6	9.9	2.5
Feb 69	0.05	2.0	0.05	0.7	0.10	1.7	0.30	2.0	6.4	1.6
Mar 69	0.06	2.4	0.07	0.9	0.10	1.7	0.22	1.5	6.5	1.6
Apl 69	0.07	2.8	0.05	0.7	0.30	5.0	0.14	0.9	9.4	2.3
May 69	0.03	1.2	0.05	0.7	0.09	1.5	0.21	1.4	4.8	1.2
Jne 69	0.02	0.8	0.07	0.9	0.00	0.0	0.21	1.4	3.1	0.8
Jly 69	0.03	1.2	0.00	0.0	0.04	0.7	0.22	1.5	3.4	0.8
Aug 69	0.04	1.6	0.04	0.5	0.10	1.7	0.22	1.5	5.3	1.3
Sep 69	0.04	1.6	0.06	0.8	0.00	0.0	0.51	3.4	5.8	1.4
Oct 69	0.08	3.2	0.07	0.9	0.10	1.7	0.26	1.7	7.5	1.9
Nov 69	0.02	0.8	0.07	0.9	0.10	1.7	0.26	1.7	5.1	1.3
Dec 69	0.12	4.8	0.06	0.8	0.19	3.2	0.44	2.9	11.7	2.9
Jan 70	0.08	3.2	0.07	0.9	0.08	1.3	0.53	3.5	8.9	2.2
Feb 70	0.08	3.2	0.07	0.9	0.11	1.8	0.16	1.1	7.0	1.7
Mar 70	0.01	0.4	0.04	0.5	0.11	1.8	0.19	1.3	4.0	1.0
Apl 70	0.01	0.4	0.09	1.2	0.12	2.0	0.25	1.7	5.3	1.3
May 70	0.03	1.2	0.04	0.5	0.05	0.8	0.14	0.9	3.4	0.9
Jne 70	0.03	1.2	0.04	0.5	0.09	1.5	0.16	1.1	4.3	1.1
Jly 70	0.00	0.0	0.02	0.3	0.04	0.7	0.28	1.9	2.9	0.7
Aug 70	0.06	2.4	0.06	0.8	0.05	0.9	0.20	1.3	5.4	1.3

9. APPENDIX 3. LABORATORY EXPERIMENTS

Table 59. Abbreviations used in analysis of experimental results in the Appendix.

v	Concentration of chemical in experimental dish
n	Number of animals tested at each concentration
r	Number of animals dead at each concentration
p^1	Observed percentage mortality
p	Corrected percentage mortality, allowing for control mortality
e	Expected percentage mortality, obtained from provisional straight line
Y	Probit of expected percentage mortality
w	Weighting coefficient
x	Logarithm of concentration 'v'
y	Working probit

Experiments for 48 hours at a water hardness of 100 mg/l

Table 60. Copper: 10 Gammarus/1,000ml solution/dish. 100 hardness

Mortality after 48 hours

Conc (mg/l)	Expt 1	Expt 2	Expt 3	Expt 4	Expt 5	Expt 6	Total Tested	Total Dead
Control	0	0	0	0	0	0	140	3
	0	1	0	1		0		
		0	0	1				
0.22	4	1			1	2	100	17
	2	2			2	2		
		1				0		
0.27		2			3	3	100	28
		2			5	3		
		4			3	1		
					2			
0.33		2	4	5	2		100	34
		4	3	4				
		2	5	3				
0.39		6	4	5	2		100	34
		1	5	4				
		3	5	3				
0.47	7	3	3	3			110	47
	5	5	6	0				
		7	5	3				
0.56		6	5	4		7	100	50
		5	7	3				
		3	6	4				
0.68			5	2	4	9	100	49
			6	3	4	6		
			7	3				
0.82			6	4	3	7	100	62
			7	5	10	7		
			7	6				
1.0	8				6	7	100	78
	10				7	9		
					5	9		
					8	9		

Table 61. Zinc: 10 Gammarus/1,000ml solution/dish. 100 hardness.

Mortality after 48 hours

Conc (mg/l)	Expt 1	Expt 2	Total Tested	Total Dead
Control	0 0 0	0 1	50	1
1.8	2	0 0 0 2	50	4
2.2		0 2 1 2 1	50	6
2.7	4 1 4	5 4	50	18
3.3	6 3	7 5 7	50	28
3.9	8 8 8	5 8	50	37
4.7	8 8	8 8 9	50	41
5.6	10 9 10 10 8		50	47
6.8	10 10		20	20

Table 62. Chromium: 10 Gammarus/1,000ml solution/dish. 100 hardness

Mortality after 48 hours

Conc (mg/l)	Expt 1	Expt 2	Expt 3	Total Tested	Total Dead
Control	0 1	0 0 0		50	1
0.39		1 0 1 0 0		50	2
0.56			1 1 0 2 1	50	5
0.68		1 1 1 0 2		50	5
0.82			4 2 0 2 2	50	10
1.0			6 1 2 2 6	50	17
1.2	7 6 4	1 2		50	20
1.5	10 8	5 3 6		50	32
1.8	10 8 9	5 8		50	40

Table 63. Nickel: 10 Gammarus/800ml solution/dish. 100 hardness

Mortality after 48 hours

Conc (mg/l)	Expt 1		Total Tested	Total Dead
Control	0 0 0	1 0	50	1
180	1 0 0	0 3	50	4
220	0 0 1	2 0	50	3
270	0 1 1	2 1	50	5
330	1 1 2	1 0	50	5
390	3 4 0	5 1	50	13
470	1 4 4	3 3	50	15
560	2 4 2	1 1	50	10
680	3 6 5	6 4	50	24
820	3 5 9	7 4	50	28
1000	6 6 7	4 3	50	26
1200	4 6 8	7 6	50	31

Table 64. Lead: 10 Gammarus/1,000ml solution/dish. 100 hardness

Mortality after 48 hours

Conc (mg/l)	Expt 1	Expt 2	Expt 3	Expt 4	Total Tested	Total Dead
Control	0 0	0 0 0 0	0 1	1 0	100	2
0.47	0 1 1	0 0		0 0 0 0 0	100	2
0.68	0 0	0	0 0	1 0 0 1 0	100	2
1.0	0 1 0	0 0		0 2 1 0 1	100	5
1.8		0 0	0 1 0		50	1
3.3		1 0	0 0 1		50	2
5.6		1 0	1 2 0		50	4
10.0		0 1	2 3 2		50	8
18.0		4 0	4 4 4		50	16

Table 65. Cadmium: 10 Gammarus/1,000ml solution/dish. 100 hardness

Mortality after 48 hours

Conc (mg/l)	Expt 1	Expt 2	Expt 3	Total Tested	Total Dead
Control	0	0		50	1
	0	1			
		0			
0.15			4	50	9
			3		
			0		
			1		
			1		
0.22			3	50	13
			3		
			2		
			2		
			3		
0.33			1	50	8
			1		
			3		
			2		
			1		
0.39	0	2		50	11
	2	3			
	4				
0.47	4	4		50	22
	3	5			
		6			
0.56	5	5		50	20
	3	6			
	1				
0.68	6	3		50	21
	5	4			
		3			
0.82	6	2		50	19
	4	3			
	4				
1.0	6	7		50	34
	8	6			
		7			
1.2	8	9		50	34
	3	9			
	5				

Table 66. Ammonia: 10 Gammarus/800ml solution/dish. 100 hardness

Mortality after 48 hours. Concentration as mg/l nitrogen

Conc (mg/l)	Expt 1		Total Tested	Total Dead
Control	0	0	50	0
	0	0		
	0			
68	4	2	50	18
	4	6		
	2			
82	5	5	50	30
	5	9		
	6			
100	9	9	50	36
	5	6		
	7			
120	7	9	50	40
	9	6		
	9			
150	10	10	50	49
	9	10		
	10			
180	9	10	50	49
	10	10		
	10			
220	10	10	50	50
	10	10		
	10			
270	10	10	50	50
	10	10		
	10			

Table 67. Phenol: 10 Gammarus/1,000ml solution/dish. 100 hardness

Mortality after 48 hours

Conc (mg/l)	Expt 1		Total Tested	Total Dead
Control	0	0	50	2
	1	0		
	1			
47	1	1	50	4
	1	0		
	1			
56	1	1	50	4
	0	1		
	1			
68	2	0	50	5
	2	1		
	0			
82	3	2	50	15
	2	5		
	3			
100	5	6	50	39
	9	10		
	9			
120	10	8	50	40
	8	5		
	9			
150	4	9	50	36
	8	8		
	7			
180	8	10	50	41
	7	7		
	9			
220	9	9	50	45
	10	9		
	8			

Table 68. Cyanide: 10 Gammarus/800ml solution/dish. 100 hardness

Mortality after 48 hours

Conc (mg/l)	Expt 1		Total Tested	Total Dead
Control	0	0	50	2
	1	1		
	0			
0.33	1	1	50	6
	2	0		
	2			
0.39	6	1	50	13
	2	2		
	2			
0.47	2	3	50	15
	2	8		
	0			
0.56	8	7	50	36
	6	5		
	10			
0.68	9	8	50	38
	8	6		
	7			
0.82	8	10	50	44
	7	9		
	10			
1.0	10	10	50	50
	10	10		
	10			
1.2	10	10	50	50
	10	10		
	10			
1.5	10	10	50	50
	10	10		
	10			

Table 69. Copper: 15 Gammarus/800ml solution/dish. 100 hardness

Mortality in each dish and total for each concentration at given times

Time(hrs)	7		13		24		35		48		72		96		127	
Conc(mg/l)	No	Tot	No	Tot	No	Tot	No	Tot	No	Tot	No	Tot	No	Tot	No	Tot
Control	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	2
	0		0		0		0		0		1		1		1	
	0		0		0		0		0		0		0		0	
0.033	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	3
	0		0		0		0		0		0		1		1	
	0		0		0		0		0		0		1		1	
0.047	0	0	0	0	0	0	0	1	0	1	1	3	1	3	1	4
	0		0		0		0		0		1		1		2	
	0		0		0		1		1		1		1		1	
0.068	0	0	0	0	0	0	0	0	0	0	1	2	1	2	1	2
	0		0		0		0		0		0		0		0	
	0		0		0		0		0		1		1		1	
0.10	0	0	0	0	0	0	0	0	1	1	1	2	1	3	1	4
	0		0		0		0		0		1		1		1	
	0		0		0		0		0		0		1		2	
0.15	0	0	0	0	1	1	1	1	1	1	3	4	3	6	4	9
	0		0		0		0		0		1		2		2	
	0		0		0		0		0		0		1		3	
0.22	0	1	0	1	1	4	1	6	1	6	2	8	3	11	3	14
	1		1		3		4		4		4		5		6	
	0		0		0		1		1		2		3		5	
0.33	0	0	1	1	4	9	4	11	4	12	5	14	6	16	7	18
	0		0		4		6		6		7		8		8	
	0		0		1		1		2		2		2		3	
0.47	1	1	2	2	3	11	4	17	4	20	5	23	7	27	10	30
	0		0		3		6		6		7		9		9	
	0		0		5		7		10		11		11		11	
0.68	0	0	5	7	7	14	9	17	11	21	12	29	13	33	13	40
	0		1		1		2		4		10		12		14	
	0		1		6		6		6		7		8		13	
1.0	0	1	0	6	10	20	11	25	12	28	13	31	13	37	15	42
	1		3		4		8		8		10		15		15	
	0		3		6		6		8		8		9		12	
1.5	0	2	5	9	9	22	10	27	11	29	12	33	13	35	15	44
	0		1		7		9		10		11		12		14	
	2		3		6		8		8		10		10		15	
2.2	1	1	6	17	7	25	9	34	10	38	13	43	14	44	14	44
	0		4		7		12		14		15		15		15	
	0		7		11		13		14		15		15		15	
3.3	1	5	8	20	14	34	14	38	15	42	15	45	15	45	15	45
	2		6		10		12		13		15		15		15	
	2		6		10		12		14		15		15		15	
4.7	2	7	5	23	10	35	12	39	13	42	15	44	15	45	15	45
	2		10		13		14		14		14		15		15	
	3		8		12		13		15		15		15		15	
6.8	3	15	8	30	12	39	13	41	13	42	15	45	15	45	15	45
	6		14		14		15		15		15		15		15	
	6		8		13		13		14		15		15		15	

Copper: continued

Time(hrs)	168		218		242		272		336		415		510		600	
Conc(mg/l)	No	Tot	No	Tot	No	Tot	No	Tot	No	Tot	No	Tot	No	Tot	No	Tot
Control	1	3	2	6	2	8	3	10	3	12	6	17	6	19	6	22
	1		2		3		4		4		6		6		8	
	1		2		2		3		5		5		7		8	
0.033	1	4	1	4	2	7	2	8	3	11	5	15	7	20	7	21
	1		1		2		3		4		5		6		7	
	2		2		3		3		4		5		7		7	
0.047	2	5	4	9	4	10	4	12	5	14	5	18	8	25	8	26
	2		2		3		4		4		7		9		10	
	1		3		3		4		5		6		8		8	
0.068	2	4	3	5	3	7	5	9	6	13	7	18	10	23	11	24
	0		0		1		1		3		6		7		7	
	2		2		3		3		4		5		6		6	
0.10	1	6	1	9	2	10	2	11	4	14	4	15	7	21	8	25
	2		3		3		4		5		5		7		9	
	3		5		5		5		5		6		7		8	
0.15	5	10	5	12	5	13	5	13	5	17	6	22	9	27	9	28
	2		3		4		4		6		9		10		10	
	3		4		4		4		6		7		8		9	
0.22	3	16	5	20	5	21	8	25	9	28	10	30	10	37	11	41
	7		7		7		7		7		7		12		15	
	6		8		9		10		12		13		15		15	
0.33	9	23	14	33	14	34	14	36	15	39	15	40	15	41	15	41
	9		11		11		13		14		14		14		14	
	5		8		9		9		10		11		12		12	
0.47	11	35	11	39	11	39	13	41	13	41	13	41	13	41	13	43
	11		14		14		14		14		14		14		15	
	13		14		14		14		14		14		14		15	
0.68	13	41	14	42	14	43	14	43	15	45	15	45	15	45	15	45
	14		14		15		15		15		15		15		15	
	14		14		14		14		15		15		15		15	
1.0	15	42	15	42	15	43	15	43	15	44	15	45	15	45	15	45
	15		15		15		15		15		15		15		15	
	12		12		13		13		14		15		15		15	
1.5	15	45	100% Mortality													
	15															
	15															
2.2	15	45	100% Mortality													
	15															
	15															
3.3	15	45	100% Mortality													
	15															
	15															
4.7	15	45	100% Mortality													
	15															
	15															
6.8	15	45	100% Mortality													
	15															
	15															

Copper: continued

Time: 7 hours

v	n	r	p^1	p	e	Y	w	x	y
Cont	45	0	0	-	-	-	-	-	-
0.22	45	1	2	2	-	-	-	-	-
0.33	45	0	0	0	-	-	-	-	-
0.47	45	1	2	2	-	-	-	-	-
0.68	45	0	0	0	-	-	-	-	-
1.0	45	1	2	2	1	2.7	0.076	0.000	3.03
1.5	45	2	4	4	2	2.9	0.110	0.176	3.40
2.2	45	1	2	2	5	3.4	0.237	0.342	3.09
3.3	45	5	11	11	11	3.8	0.370	0.518	3.77
4.7	45	7	16	16	18	4.1	0.471	0.672	4.08
6.8	45	15	33	33	30	4.5	0.581	0.832	4.56

Time: 13 hours

v	n	r	p^1	p	e	Y	w	x	y
Cont	45	0	0	-	-	-	-	-	-
0.22	45	1	2	2	1	2.7	0.076	-0.658	3.03
0.33	45	1	2	2	3	3.1	0.154	-0.481	2.97
0.47	45	2	4	4	5	3.4	0.237	-0.328	3.27
0.68	45	7	16	16	9	3.7	0.336	-0.167	4.07
1.0	45	6	13	13	15	4.0	0.439	0.000	3.88
1.5	45	9	20	20	23	4.3	0.531	0.176	4.17
2.2	45	17	38	38	33	4.6	0.600	0.342	4.70
3.3	45	20	44	44	44	4.8	0.627	0.518	4.85
4.7	45	23	51	51	54	5.1	0.634	0.672	5.02
6.8	45	30	67	67	65	5.4	0.600	0.832	5.44

Time: 24 hours

v	n	r	p^1	p	e	Y	w	x	y
Cont	45	0	0	-	-	-	-	-	-
0.10	45	0	0	0	3	3.1	0.154	-1.000	2.66
0.15	45	1	2	2	5	3.4	0.237	-0.824	3.09
0.22	45.	4	9	9	9	3.7	0.336	-0.658	3.66
0.33	45	9	20	20	14	3.9	0.405	-0.481	4.19
0.47	45	11	24	24	21	4.2	0.503	-0.328	4.30
0.68	45	14	31	31	30	4.5	0.581	-0.167	4.50
1.0	45	20	44	44	40	4.7	0.616	0.000	4.85
1.5	45	22	49	49	51	5.0	0.637	0.176	4.97
2.2	45	25	56	56	62	5.3	0.616	0.342	5.15
3.3	45	34	76	76	73	5.6	0.558	0.518	5.70
4.7	45	35	78	78	81	5.9	0.471	0.672	5.76
6.8	45	39	87	87	87	6.1	0.405	0.832	6.13

Copper: continued

Time: 35 hours

v	n	r	p^1	p	e	Y	w	x	y
Cont	45	0	0	-	-	-	-	-	-
0.047	45	1	2	2	2	2.9	0.110	-1.328	2.95
0.068	45	0	0	0	3	3.1	0.154	-1.167	2.66
0.10	45	0	0	0	5	3.4	0.237	-1.000	2.91
0.15	45	1	2	2	9	3.7	0.336	-0.824	3.25
0.22	45	6	13	13	14	3.9	0.405	-0.658	3.87
0.33	45	11	24	24	22	4.2	0.503	-0.481	4.30
0.47	45	17	38	38	30	4.5	0.581	-0.328	4.70
0.68	45	17	38	38	40	4.7	0.616	-0.167	4.69
1.0	45	25	56	56	50	5.0	0.637	0.000	5.15
1.5	45	27	60	60	62	5.3	0.616	0.176	5.25
2.2	45	34	76	76	72	5.6	0.558	0.342	5.70
3.3	45	38	84	84	81	5.9	0.471	0.518	5.99
4.7	45	39	87	87	87	6.1	0.405	0.672	6.13
6.8	45	41	91	91	92	6.4	0.302	0.832	6.34

Time: 48 hours

v	n	r	p^1	p	e	Y	w	x	y
Cont	45	0	0	-	-	-	-	-	-
0.047	45	1	2	2	2	2.9	0.110	-1.328	2.95
0.068	45	0	0	0	3	3.1	0.154	-1.167	2.66
0.10	45	1	2	2	5	3.4	0.237	-1.000	3.09
0.15	45	1	2	2	9	3.7	0.336	-0.824	3.25
0.22	45	6	13	13	14	3.9	0.405	-0.658	3.87
0.33	45	12	27	27	23	4.3	0.531	-0.481	4.39
0.47	45	20	44	44	32	4.5	0.581	-0.328	4.87
0.68	45	21	47	47	43	4.8	0.627	-0.167	4.93
1.0	45	28	62	62	55	5.1	0.634	0.000	5.30
1.5	45	29	64	64	67	5.4	0.600	0.176	5.36
2.2	45	38	84	84	77	5.7	0.531	0.342	5.96
3.3	45	42	93	93	86	6.1	0.405	0.518	6.40
4.7	45	42	93	93	91	6.3	0.336	0.672	6.46
6.8	45	42	93	93	95	6.6	0.237	0.832	6.46

Copper: continued

Time: 72 hours

v	n	r	p^1	p	e	Y	w	x	y
Cont	45	1	2	-	-	-	-	-	-
0.033	45	0	0	(-2)	-	-	-	-	-
0.047	45	3	7	5	1	2.7	0.026	-1.328	4.09
0.068	45	2	4	2	3	3.1	0.090	-1.167	2.97
0.10	45	2	4	2	6	3.4	0.173	-1.000	3.09
0.15	45	4	9	7	12	3.8	0.315	-0.824	3.57
0.22	45	8	18	16	20	4.2	0.458	-0.658	4.02
0.33	45	14	31	30	32	4.5	0.545	-0.481	4.48
0.47	45	23	51	50	45	4.9	0.607	-0.328	5.00
0.68	45	29	64	63	58	5.2	0.606	-0.167	5.33
1.0	45	31	69	68	71	5.6	0.543	0.000	5.46
1.5	45	33	73	72	82	5.9	0.460	0.176	5.54
2.2	45	43	96	96	90	6.3	0.328	0.342	6.63
3.3	45	45	100	100	95	6.6	0.233	0.518	7.09
4.7	45	44	98	98	97	6.9	0.151	0.672	7.03
6.8	45	45	100	100	99	7.3	0.074	0.832	7.68

Time: 96 hours

v	n	r	p^1	p	e	Y	w	x	y
Cont	45	1	2	-	-	-	-	-	-
0.033	45	2	4	2	-	-	-	-	-
0.047	45	3	7	5	1	2.7	0.026	-1.328	4.09
0.068	45	2	4	2	3	3.1	0.090	-1.167	2.97
0.10	45	3	7	5	8	3.6	0.241	-1.000	3.40
0.15	45	6	13	11	16	4.0	0.389	-0.824	3.80
0.22	45	11	24	22	28	4.4	0.518	-0.658	4.24
0.33	45	16	36	35	44	4.8	0.598	-0.481	4.62
0.47	45	27	60	59	59	5.2	0.606	-0.328	5.23
0.68	45	33	73	72	73	5.6	0.543	-0.167	5.58
1.0	45	37	82	82	85	6.0	0.428	0.000	5.91
1.5	45	35	78	78	93	6.5	0.263	0.176	5.32
2.2	45	44	98	98	97	6.9	0.151	0.342	7.03
3.3	45	45	100	100	99	7.3	0.074	0.518	7.68
4.7	45	45	100	100	-	-	-	-	-
6.8	45	45	100	100	-	-	-	-	-

Copper: continued

Time: 127 hours

v	n	r	p^1	p	e	Y	w	x	y
Cont	45	2	4	-	-	-	-	-	-
0.033	45	3	7	3	-	-	-	-	-
0.047	45	4	9	5	2	2.9	0.033	-1.328	3.63
0.068	45	2	4	0	4	3.2	0.083	-1.167	2.74
0.10	45	4	9	5	10	3.7	0.235	-1.000	3.43
0.15	45	9	20	17	21	4.2	0.420	-0.824	4.06
0.22	45	14	31	28	36	4.6	0.536	-0.658	4.42
0.33	45	18	40	37	54	5.1	0.589	-0.481	4.67
0.47	45	30	67	66	69	5.5	0.548	-0.328	5.41
0.68	45	40	89	88	83	6.0	0.418	-0.167	6.16
1.0	45	42	93	93	92	6.4	0.289	0.000	6.47
1.5	45	44	98	98	97	6.9	0.148	0.176	7.03
2.2	45	44	98	98	99	7.3	0.073	0.342	6.97
3.3	45	45	100	100	-	-	-	-	-
4.7	45	45	100	100	-	-	-	-	-
6.8	45	45	100	100	-	-	-	-	-

Time: 168 hours

v	n	r	p^1	p	e	Y	w	x	y
Cont	45	3	7	-	-	-	-	-	-
0.033	45	4	9	2	-	-	-	-	-
0.047	45	5	11	4	2	2.9	0.021	-1.328	3.40
0.068	45	4	9	2	4	3.2	0.058	-1.167	3.00
0.10	45	6	13	6	10	3.7	0.189	-1.000	3.48
0.15	45	10	22	16	22	4.2	0.371	-0.824	4.02
0.22	45	16	36	31	38	4.7	0.515	-0.658	4.51
0.33	45	23	51	47	58	5.2	0.555	-0.481	4.92
0.47	45	35	78	76	74	5.6	0.505	-0.328	5.70
0.68	45	41	91	90	86	6.1	0.372	-0.167	6.26
1.0	45	42	93	93	94	6.6	0.220	0.000	6.46
1.5	45	45	100	100	98	7.1	0.102	0.176	7.51
2.2	45	45	100	100	-	-	-	-	-
3.3	45	45	100	100	-	-	-	-	-

Copper: continued

Time: 218 hours

v	n	r	p^1	p	e	Y	w	x	y
Cont	45	6	13	-	-	-	-	-	-
0.033	45	4	9	(-4)	-	-	-	-	-
0.047	45	9	20	8	2	2.9	0.012	-1.328	4.31
0.068	45	5	11	(-2)	5	3.4	0.064	-1.167	2.73
0.10	45	9	20	8	12	3.8	0.161	-1.000	3.62
0.15	45	12	27	16	25	4.3	0.329	-0.824	4.04
0.22	45	20	44	36	43	4.8	0.463	-0.658	4.64
0.33	45	33	73	69	64	5.4	0.489	-0.481	5.49
0.47	45	39	87	85	80	5.8	0.422	-0.328	6.01
0.68	45	42	93	92	90	6.3	0.288	-0.167	6.40
1.0	45	42	93	92	97	6.9	0.134	0.000	6.12
1.5	45	45	100	100	99	7.3	0.066	0.176	7.68
2.2	45	45	100	100	-	-	-	-	-
3.3	45	45	100	100	-	-	-	-	-

Time: 242 hours

v	n	r	p^1	p	e	Y	w	x	y
Cont	45	8	18	-	-	-	-	-	-
0.033	45	7	16	(-2)	-	-	-	-	-
0.047	45	10	22	5	1	2.7	0.004	-1.328	4.09
0.068	45	7	16	(-2)	3	3.1	0.018	-1.167	2.36
0.10	45	10	22	5	8	3.6	0.081	-1.000	3.40
0.15	45	13	29	13	21	4.2	0.247	-0.824	3.92
0.22	45	21	47	34	40	4.7	0.391	-0.658	4.59
0.33	45	34	76	71	63	5.3	0.455	-0.481	5.54
0.47	45	39	87	84	80	5.8	0.393	-0.328	5.98
0.68	45	43	96	95	92	6.4	0.244	-0.167	6.60
1.0	45	43	96	95	97	6.9	0.126	0.000	6.58
1.5	45	45	100	100	99	7.3	0.062	0.176	7.68
2.2	45	45	100	100	-	-	-	-	-
3.3	45	45	100	100	-	-	-	-	-

Copper: continued

Time: 272 hours

v	n	r	p^1	p	e	Y	w	x	y
Cont	45	10	22	-	-	-	-	-	-
0.033	45	8	18	(-5)	-	-	-	-	-
0.047	45	12	27	6	-	-	-	-	-
0.068	45	9	20	(-2)	2	2.9	0.007	-1.167	2.04
0.10	45	11	24	2	6	3.4	0.039	-1.000	3.09
0.15	45	13	29	9	18	4.1	0.186	-0.824	3.75
0.22	45	25	56	44	38	4.7	0.354	-0.658	4.85
0.33	45	36	80	74	64	5.4	0.420	-0.481	5.63
0.47	45	41	91	88	82	5.9	0.350	-0.328	6.14
0.68	45	43	96	95	93	6.5	0.207	-0.167	6.63
1.0	45	43	96	95	98	7.1	0.086	0.000	6.37
1.5	45	45	100	100	-	-	-	-	-
2.2	45	45	100	100	-	-	-	-	-
3.3	45	45	100	100	-	-	-	-	-

Time: 336 hours

v	n	r	p^1	p	e	Y	w	x	y
Cont	45	12	27	-	-	-	-	-	-
0.033	45	11	24	(-4)	-	-	-	-	-
0.047	45	14	31	5	-	-	-	-	-
0.068	45	13	29	3	2	2.9	0.005	-1.167	3.18
0.10	45	14	31	5	8	3.6	0.054	-1.000	3.40
0.15	45	17	38	15	22	4.2	0.183	-0.824	3.99
0.22	45	28	62	48	43	4.8	0.333	-0.658	4.95
0.33	45	39	87	82	68	5.5	0.379	-0.481	5.86
0.47	45	41	91	88	85	6.0	0.305	-0.328	6.16
0.68	45	45	100	100	95	6.6	0.171	-0.167	7.09
1.0	45	44	98	97	99	7.3	0.055	0.000	6.62
1.5	45	45	100	100	-	-	-	-	-

Copper: continued

Time: 415 hours

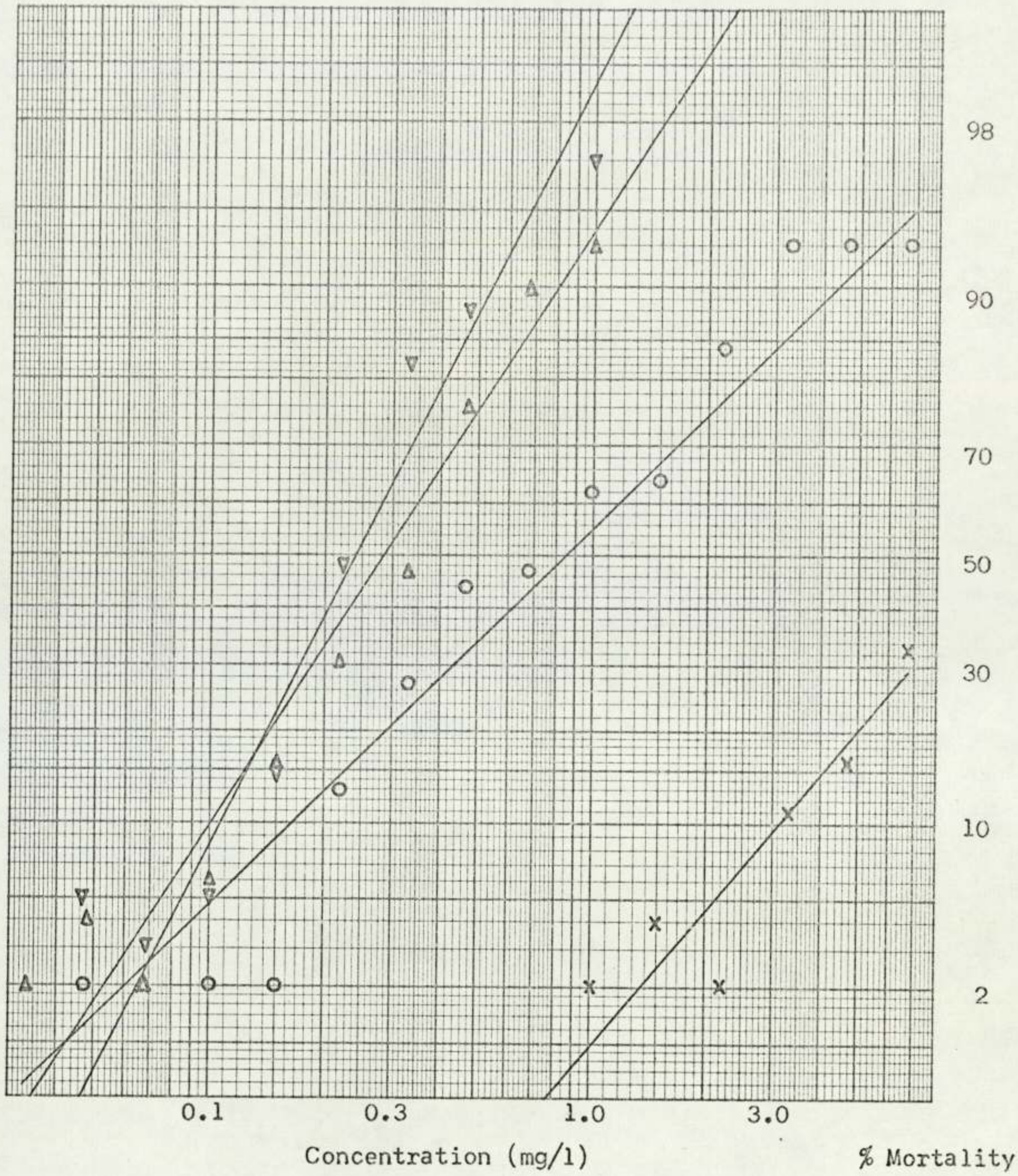
v	n	r	p^1	p	e	Y	w	x	y
Cont	45	17	38	-	-	-	-	-	-
0.033	45	15	33	(-8)	-	-	-	-	-
0.047	45	18	40	3	1	2.7	0.001	-1.328	3.38
0.068	45	18	40	3	3	3.1	0.007	-1.167	3.12
0.10	45	15	33	(-8)	10	3.7	0.046	-1.000	2.67
0.15	45	22	49	18	28	4.4	0.172	-0.824	4.12
0.22	45	30	67	47	50	5.0	0.286	-0.658	4.92
0.33	45	40	89	82	75	5.7	0.294	-0.481	5.90
0.47	45	41	91	85	90	6.3	0.200	-0.328	5.99
0.68	45	45	100	100	97	6.9	0.095	-0.167	7.34
1.0	45	45	100	100	-	-	-	-	-
1.5	45	45	100	100	-	-	-	-	-

Time: 510 hours

v	n	r	p^1	p	e	Y	w	x	y
Cont	45	19	42	-	-	-	-	-	-
0.033	45	20	44	3	1	2.7	0.001	-1.481	3.38
0.047	45	25	56	24	4	3.2	0.008	-1.328	5.78
0.068	45	23	51	16	10	3.7	0.040	-1.167	4.07
0.10	45	21	47	9	22	4.2	0.114	-1.000	3.78
0.15	45	27	60	31	40	4.7	0.213	-0.824	4.51
0.22	45	37	82	69	62	5.3	0.284	-0.658	5.49
0.33	45	41	91	84	80	5.8	0.262	-0.481	5.98
0.47	45	41	91	84	91	6.3	0.186	-0.328	5.93
0.68	45	45	100	100	97	6.9	0.088	-0.167	7.34
1.0	45	45	100	100	-	-	-	-	-
1.5	45	45	100	100	-	-	-	-	-

Time: 600 hours

v	n	r	p^1	p	e	Y	w	x	y
Cont	45	22	49	-	-	-	-	-	-
0.033	45	21	47	(-4)	-	-	-	-	-
0.047	45	26	58	18	3	3.1	0.004	-1.328	5.41
0.068	45	24	53	8	9	3.7	0.031	-1.167	3.60
0.10	45	25	56	14	23	4.3	0.107	-1.000	3.97
0.15	45	28	62	25	45	4.9	0.205	-0.824	4.37
0.22	45	41	91	82	68	5.5	0.243	-0.658	5.80
0.33	45	41	91	82	86	6.1	0.192	-0.481	5.90
0.47	45	43	96	92	90	6.3	0.163	-0.328	6.40
0.68	45	45	100	100	99	7.3	0.038	-0.167	7.68
1.0	45	45	100	100	-	-	-	-	-
1.5	45	45	100	100	-	-	-	-	-



x 7 hours
o 48 hours
Δ 168 hours
∇ 336 hours

Fig. 43a. Toxicity of copper to Gammarus at 100 hardness

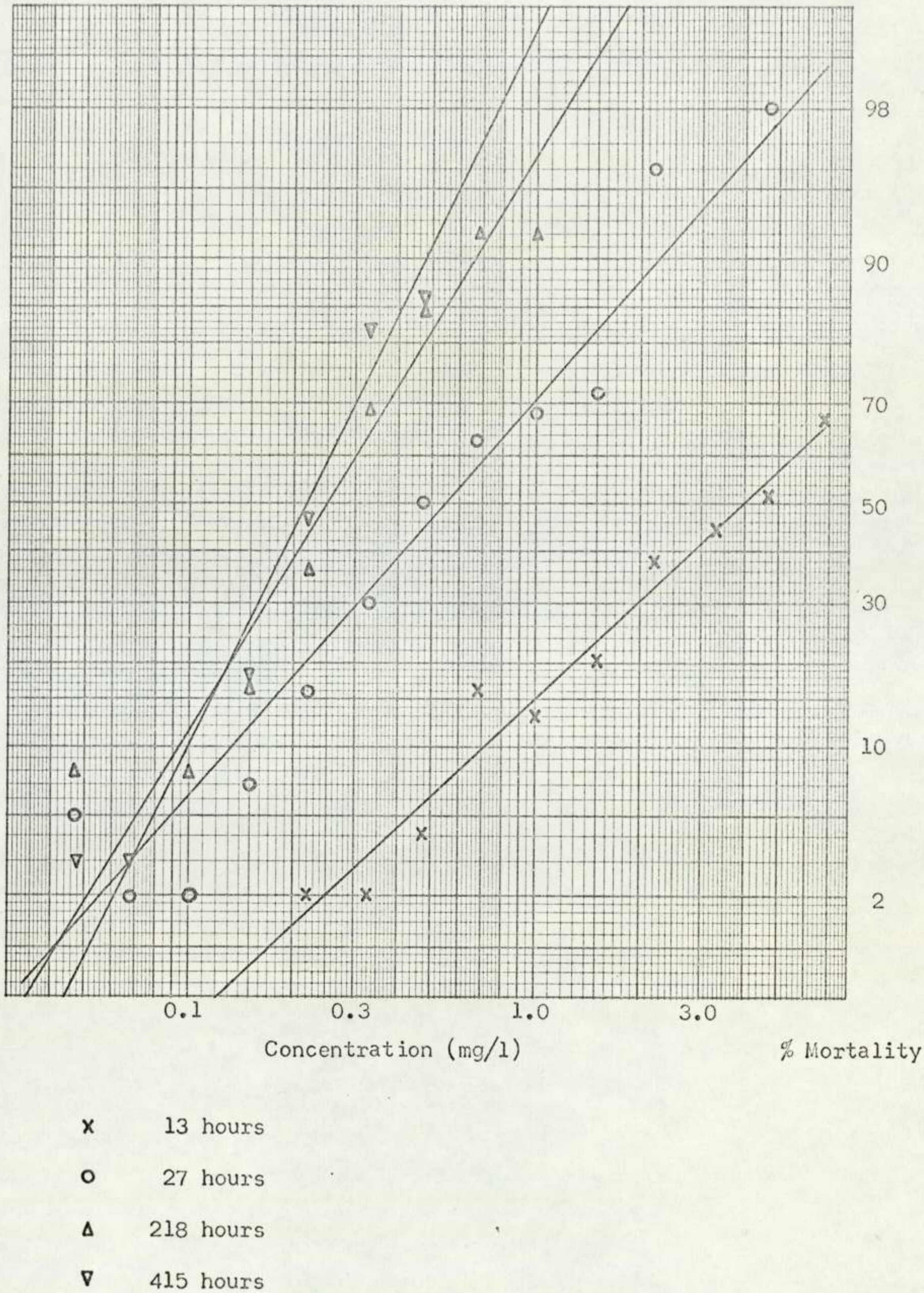


Fig. 43b. Toxicity of copper to Gammarus at 100 hardness

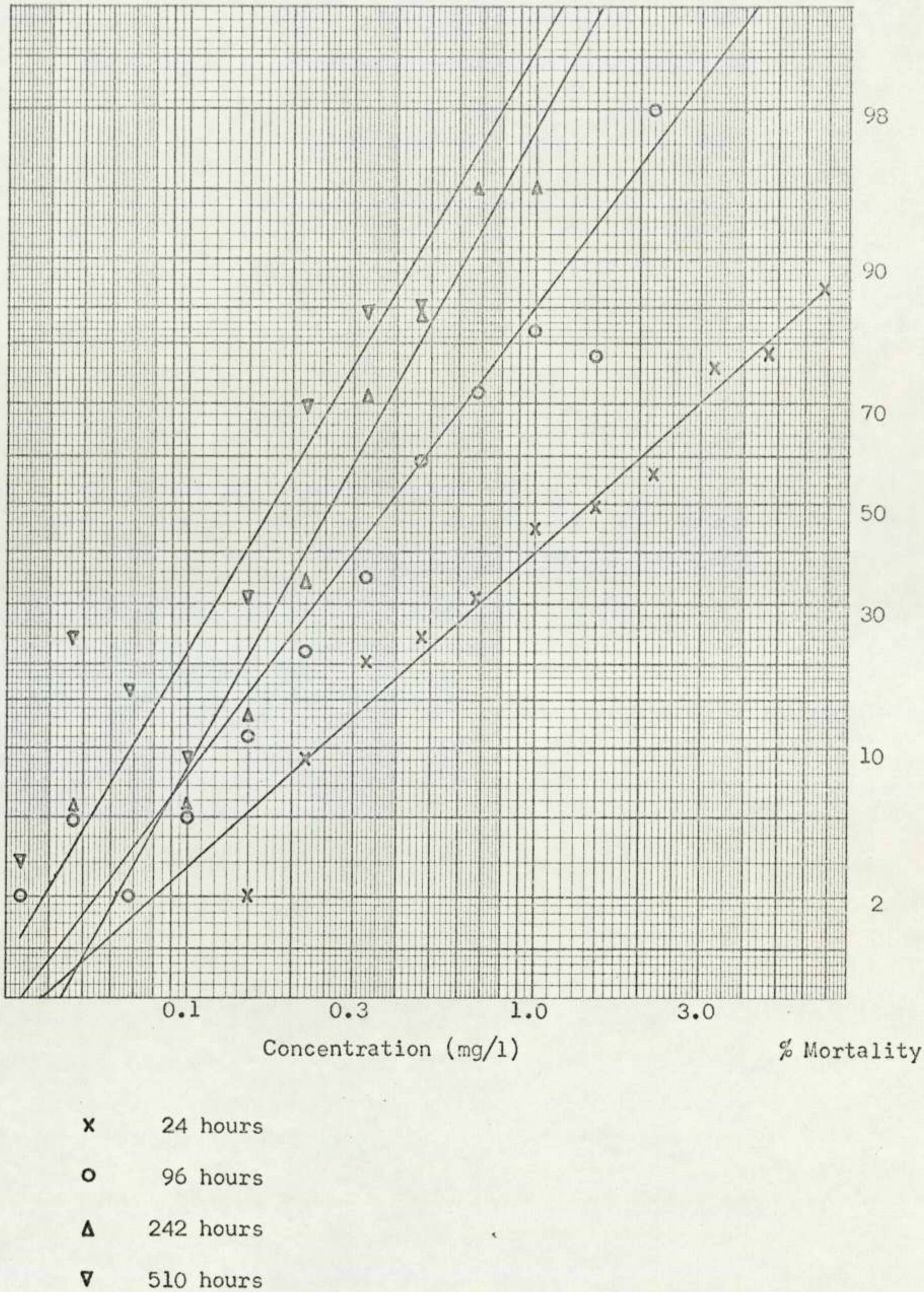
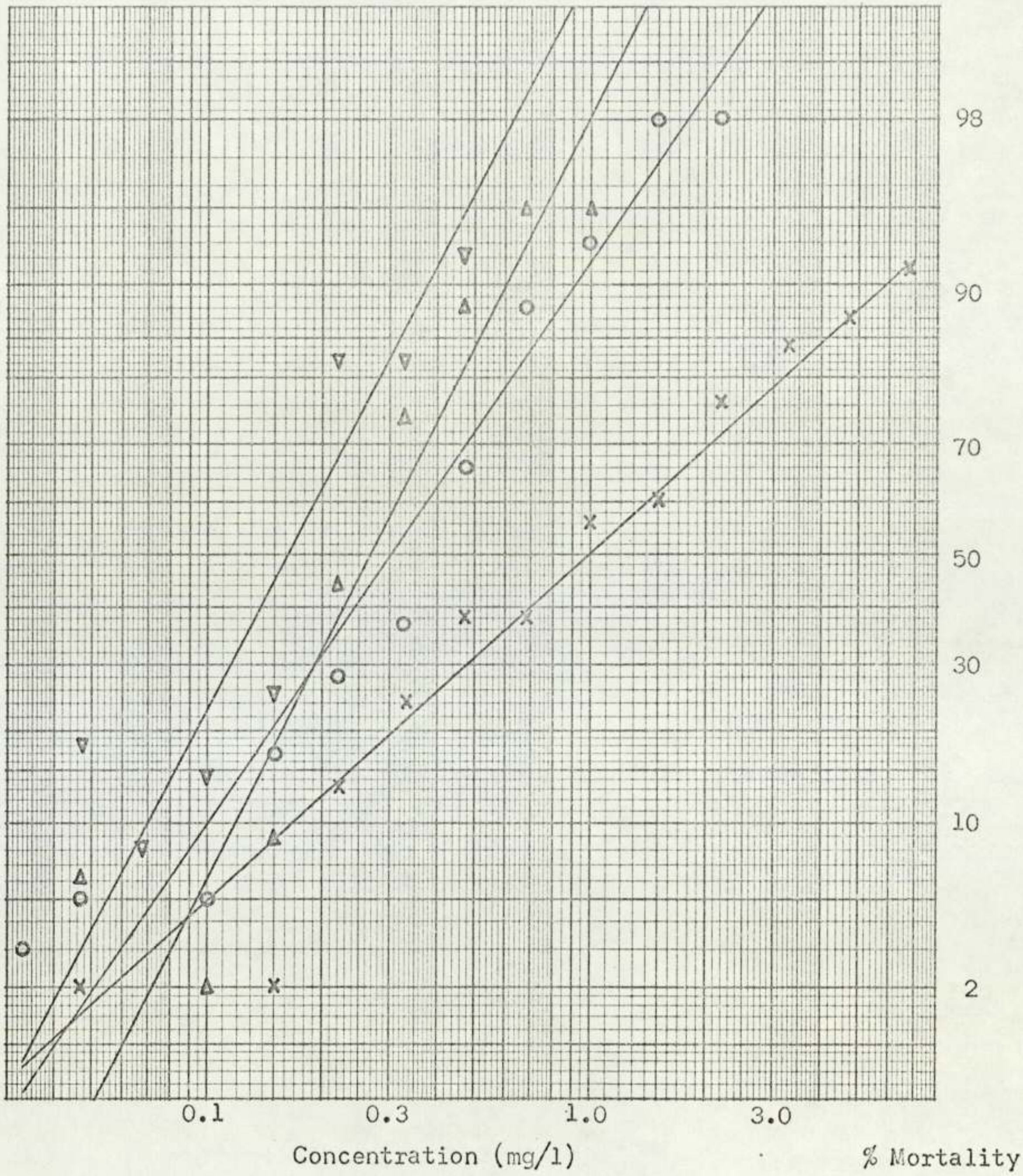


Fig. 43c. Toxicity of copper to Gammarus at 100 hardness



x 35 hours

o 127 hours

Δ 272 hours

∇ 600 hours

Fig. 43d. Toxicity of copper to Gammarus at 100 hardness

Table 70. Zinc: 15 Gammarus/800ml solution/dish. 100 hardness

Mortality in each dish and total for each concentration at given times

Time(hrs)	8		13		24		35		48		72	
Conc(mg/l)	No	Tot	No	Tot	No	Tot	No	Tot	No	Tot	No	Tot
Control	0	0	0	0	0	0	0	0	0	1	0	2
	0		0		0		0		0		0	
	0		0		0		0		1		2	
0.15	0	0	0	0	0	0	0	0	0	1	0	1
	0		0		0		0		1		1	
	0		0		0		0		0		0	
0.22	0	0	0	0	0	0	0	2	0	3	0	3
	0		0		0		2		2		2	
	0		0		0		0		1		1	
0.33	0	0	0	0	0	0	0	0	0	1	0	3
	0		0		0		0		0		2	
	0		0		0		0		1		1	
0.47	0	0	0	0	0	0	0	0	0	0	0	1
	0		0		0		0		0		1	
	0		0		0		0		0		0	
0.68	0	0	0	0	0	0	0	0	0	1	0	3
	0		0		0		0		1		2	
	0		0		0		0		0		1	
1.0	0	0	0	0	1	2	2	4	4	8	8	19
	0		0		1		2		3		8	
	0		0		0		0		1		3	
1.5	0	0	0	0	0	2	1	7	4	17	11	38
	0		0		1		3		5		15	
	0		0		1		3		8		12	
2.2	0	0	0	0	0	2	0	3	2	8	7	27
	0		0		1		2		4		11	
	0		0		1		1		2		9	
3.3	0	0	1	1	2	4	4	14	8	23	14	42
	0		0		2		8		9		14	
	0		0		0		2		6		14	
4.7	0	0	0	1	4	12	4	18	10	27	13	42
	0		0		3		6		8		15	
	0		1		5		8		9		14	
6.8	0	0	1	3	8	24	12	36	15	43	15	45
	0		1		8		10		13		15	
	0		1		8		14		15		15	
10	0	3	7	21	13	40	15	44	15	45	15	45
	0		4		12		14		15		15	
	3		10		15		15		15		15	
15	2	8	9	32	14	44	15	45	15	45	15	45
	2		12		15		15		15		15	
	4		11		15		15		15		15	
22	8	17	10	33	14	43	15	45	15	45	15	45
	4		10		14		15		15		15	
	5		13		15		15		15		15	
33	6	24	13	41	15	45	15	45	15	45	15	45
	8		14		15		15		15		15	
	10		14		15		15		15		15	

Zinc: continued

Time(hrs)	96		128		168		200		240		270	
Conc(mg/l	No	Tot	No	Tot	No	Tot	No	Tot	No	Tot	No	Tot
Control	0	2	0	3	1	5	1	6	2	8	3	10
	0		1		1		1		2		2	
	2		2		3		4		4		5	
0.15	0	1	0	2	1	5	1	5	2	7	2	8
	1		2		3		3		4		4	
	0		0		1		1		1		2	
0.22	1	4	4	7	5	11	6	13	6	16	6	16
	2		2		3		4		5		5	
	1		1		3		3		5		5	
0.33	0	4	1	6	3	14	3	14	4	17	5	19
	2		3		6		6		6		7	
	2		2		5		5		7		7	
0.47	0	2	3	7	6	16	7	17	7	22	8	28
	1		2		3		3		6		8	
	1		2		7		7		9		12	
0.68	3	6	6	17	8	24	11	28	12	32	14	34
	2		6		9		9		10		10	
	1		5		7		8		10		10	
1.0	11	24	13	29	14	37	14	39	14	41	14	42
	9		10		10		11		12		13	
	4		6		13		14		15		15	
1.5	13	42	13	42	14	44	14	44	15	45	15	45
	15		15		15		15		15		15	
	14		14		15		15		15		15	
2.2	9	35	13	42	15	45	15	45	15	45	15	45
	13		14		15		15		15		15	
	13		15		15		15		15		15	
3.3	15	45	100% Mortality									
	15											
	15											
4.7	15	45	100% Mortality									
	15											
	15											
6.8	15	45	100% Mortality									
	15											
	15											
10	15	45	100% Mortality									
	15											
	15											
15	15	45	100% Mortality									
	15											
	15											
22	15	45	100% Mortality									
	15											
	15											
33	15	45	100% Mortality									
	15											
	15											

Zinc: continued

Time: 8 hours

v	n	r	p^1	p	e	Y	w	x	y
Cont	45	0	0	-	-	-	-	-	-
6.8	45	0	0	0	2	2.9	0.110	0.832	2.49
10	45	3	7	7	7	3.5	0.208	1.000	3.52
15	45	8	18	18	18	4.1	0.471	1.176	4.08
22	45	17	38	38	35	4.6	0.600	1.342	4.70
33	45	24	53	53	58	5.2	0.627	1.518	5.07

Time: 13 hours

v	n	r	p^1	p	e	Y	w	x	y
Cont	45	0	0	-	-	-	-	-	-
2.2	45	0	0	0	-	-	-	-	-
3.3	45	1	2	2	1	2.7	0.076	0.518	3.03
4.7	45	1	2	2	4	3.2	0.180	0.672	3.00
6.8	45	3	7	7	13	3.9	0.405	0.832	3.60
10	45	21	47	47	33	4.6	0.600	1.000	4.94
15	45	32	71	71	60	5.3	0.616	1.176	5.54
22	45	33	73	73	84	6.0	0.439	1.342	5.54
33	45	41	91	91	94	6.6	0.238	1.518	6.28

Time: 24 hours

v	n	r	p^1	p	e	Y	w	x	y
Cont	45	0	0	-	-	-	-	-	-
1.0	45	2	4	4	-	-	-	-	-
1.5	45	2	4	4	2	2.9	0.110	0.176	3.40
2.2	45	2	4	4	8	3.6	0.302	0.342	3.33
3.3	45	4	9	9	22	4.2	0.503	0.518	3.78
4.7	45	12	27	27	41	4.8	0.627	0.672	4.41
6.8	45	24	53	53	64	5.4	0.600	0.832	5.06
10	45	40	89	89	86	6.1	0.405	1.000	6.22
15	45	44	98	98	94	6.6	0.238	1.176	6.91
22	45	43	96	96	98	7.1	0.110	1.342	6.60
33	45	45	100	100	-	-	-	-	-

Zinc: continued

Time: 35 hours

v	n	r	p^1	p	e	Y	w	x	y
Cont	45	0	0	-	-	-	-	-	-
0.68	45	0	0	0	-	-	-	-	-
1.0	45	4	9	9	2	2.9	0.110	0.000	4.54
1.5	45	7	16	16	9	3.7	0.336	0.176	4.07
2.2	45	3	7	7	22	4.2	0.503	0.342	3.71
3.3	45	14	31	31	44	4.8	0.627	0.518	4.52
4.7	45	18	40	40	67	5.4	0.600	0.672	4.71
6.8	45	36	80	80	85	6.0	0.439	0.832	5.83
10	45	44	98	98	95	6.6	0.238	1.000	6.91
15	45	45	100	100	99	7.3	0.076	1.176	7.68

Time: 48 hours

v	n	r	p^1	p	e	Y	w	x	y
Cont	45	1	2	-	-	-	-	-	-
0.68	45	1	2	0	2	2.9	0.051	-0.167	2.49
1.0	45	8	18	16	7	3.5	0.206	0.000	4.22
1.5	45	17	38	37	18	4.1	0.424	0.176	4.80
2.2	45	8	18	16	36	4.6	0.567	0.342	4.10
3.3	45	23	51	50	58	5.2	0.606	0.518	5.00
4.7	45	27	60	59	76	5.7	0.518	0.672	5.16
6.8	45	43	96	96	88	6.2	0.362	0.832	6.59
10	45	45	100	100	96	6.8	0.176	1.000	7.25

Time: 72 hours

v	n	r	p^1	p	e	Y	w	x	y
Cont	45	2	4	-	-	-	-	-	-
0.33	45	3	7	3	1	2.7	0.015	-0.481	3.38
0.47	45	1	2	(-2)	4	3.2	0.083	-0.328	2.51
0.68	45	3	7	3	11	3.8	0.272	-0.167	3.36
1.0	45	19	42	40	27	4.4	0.484	0.000	4.78
1.5	45	38	84	83	51	5.0	0.588	0.176	5.83
2.2	45	27	60	58	73	5.6	0.528	0.342	5.16
3.3	45	42	93	93	90	6.3	0.321	0.518	6.46
4.7	45	42	93	93	96	6.8	0.172	0.672	6.37
6.8	45	45	100	100	99	7.3	0.073	0.832	7.68

Zinc: continued

Time: 96 hours

v	n	r	p^1	p	e	Y	w	x	y
Cont	45	2	4	-	-	-	-	-	-
0.15	45	1	2	(-2)	-	-	-	-	-
0.22	45	4	9	5	1	2.7	0.015	-0.658	4.09
0.33	45	4	9	5	5	3.4	0.135	-0.481	3.36
0.47	45	2	4	0	13	3.9	0.310	-0.328	3.28
0.68	45	6	13	9	29	4.4	0.484	-0.167	3.85
1.0	45	24	53	51	51	5.0	0.588	0.000	5.02
1.5	45	42	93	93	75	5.7	0.504	0.176	6.25
2.2	45	35	78	77	90	6.3	0.321	0.342	5.52
3.3	45	45	100	100	97	6.9	0.148	0.518	7.34

Time: 128 hours

v	n	r	p^1	p	e	Y	w	x	y
Cont	45	3	7	-	-	-	-	-	-
0.15	45	2	4	(-3)	-	-	-	-	-
0.22	45	7	16	10	2	2.9	0.021	-0.658	4.77
0.33	45	6	13	6	9	3.7	0.189	-0.481	3.48
0.47	45	7	16	10	22	4.2	0.371	-0.328	3.81
0.68	45	17	38	33	42	4.8	0.532	-0.167	4.57
1.0	45	29	64	61	66	5.4	0.539	0.000	5.28
1.5	45	42	93	92	86	6.1	0.372	0.176	6.35
2.2	45	42	93	92	95	6.6	0.222	0.342	6.37
3.3	45	45	100	100	99	7.3	0.071	0.518	7.68

Time: 168 hours

v	n	r	p^1	p	e	Y	w	x	y
Cont	45	5	11	-	-	-	-	-	-
0.15	45	5	11	0	2	2.9	0.014	-0.824	2.49
0.22	45	11	24	15	7	3.5	0.094	-0.658	4.14
0.33	45	14	31	22	21	4.2	0.317	-0.481	4.23
0.47	45	16	36	28	41	4.8	0.485	-0.328	4.44
0.68	45	24	53	47	65	5.4	0.505	-0.167	4.90
1.0	45	37	82	80	85	6.0	0.382	0.000	5.83
1.5	45	44	98	98	96	6.8	0.159	0.176	7.00
2.2	45	45	100	100	99	7.3	0.067	0.342	7.68

Zinc: continued

Time: 200 hours

v	n	r	p^1	p	e	Y	w	x	y
Cont	45	6	13	-	-	-	-	-	-
0.15	45	5	11	(-2)	2	2.9	0.012	-0.824	2.04
0.22	45	13	29	18	7	3.5	0.083	-0.658	4.37
0.33	45	14	31	21	22	4.2	0.295	-0.481	4.19
0.47	45	17	38	29	45	4.9	0.479	-0.328	4.47
0.68	45	28	62	56	69	5.5	0.478	-0.167	5.13
1.0	45	39	87	85	88	6.2	0.317	0.000	6.02
1.5	45	44	98	98	97	6.9	0.134	0.176	7.03
2.2	45	45	100	100	99	7.3	0.066	0.342	7.68

Time: 240 hours

v	n	r	p^1	p	e	Y	w	x	y
Cont	45	8	18	-	-	-	-	-	-
0.15	45	7	16	(-2)	2	2.9	0.008	-0.824	2.04
0.22	45	16	36	22	9	3.7	0.103	-0.658	4.42
0.33	45	17	38	24	25	4.3	0.279	-0.481	4.29
0.47	45	22	49	38	47	4.9	0.429	-0.328	4.70
0.68	45	32	71	65	70	5.5	0.441	-0.167	5.38
1.0	45	41	91	89	88	6.2	0.297	0.000	6.23
1.5	45	45	100	100	96	6.8	0.147	0.176	7.25

Time: 270 hours

v	n	r	p^1	p	e	Y	w	x	y
Cont	45	10	22	-	-	-	-	-	-
0.15	45	8	18	(-5)	4	3.2	0.020	-0.824	2.11
0.22	45	16	36	18	13	3.9	0.131	-0.658	4.10
0.33	45	19	42	26	30	4.5	0.303	-0.481	4.36
0.47	45	28	62	51	54	5.1	0.417	-0.328	5.02
0.68	45	34	76	69	76	5.7	0.387	-0.167	5.48
1.0	45	42	93	91	91	6.3	0.256	0.000	6.34
1.5	45	45	100	100	98	7.1	0.086	0.176	7.51

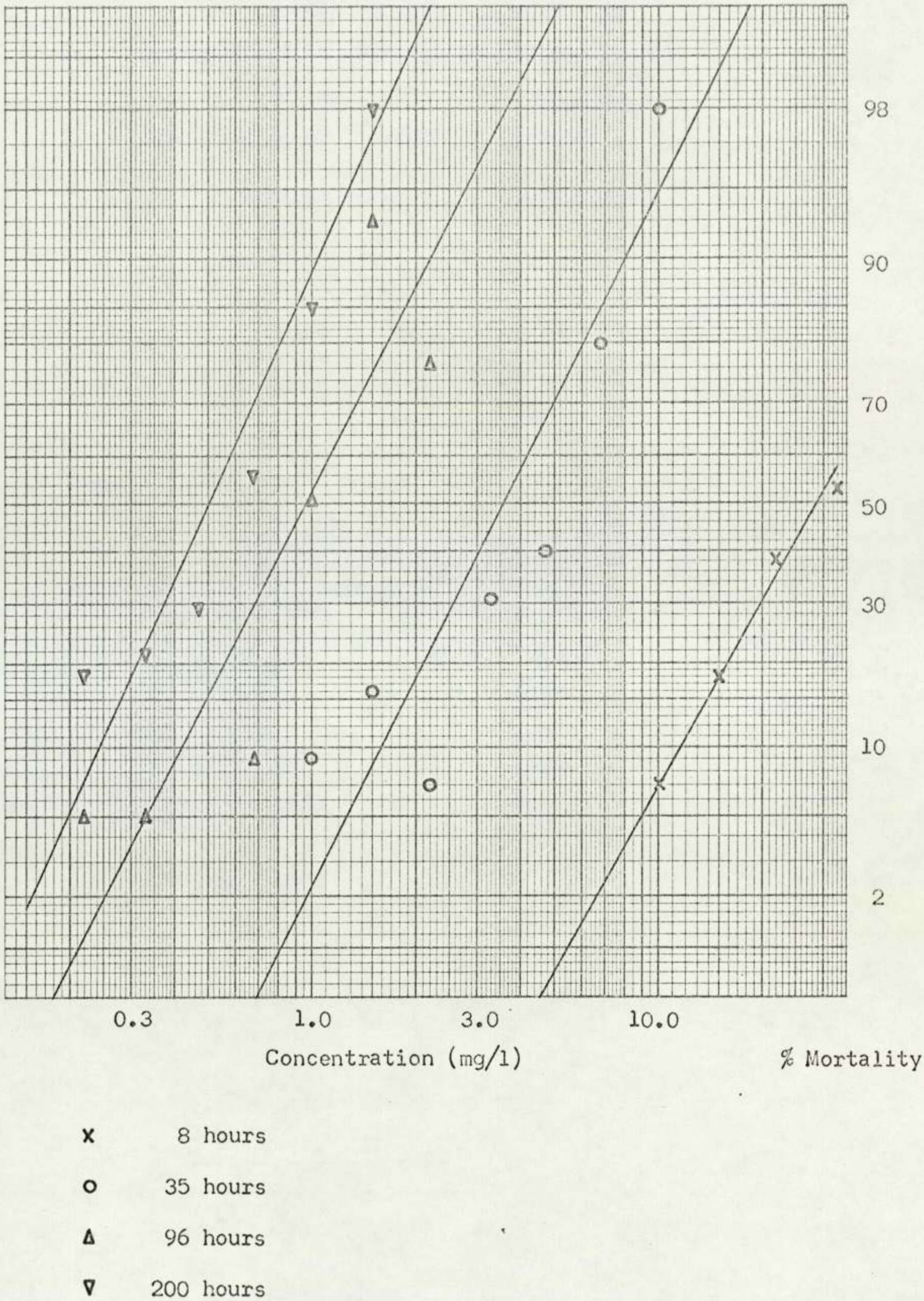


Fig. 44a. Toxicity of zinc to Gammarus at 100 hardness

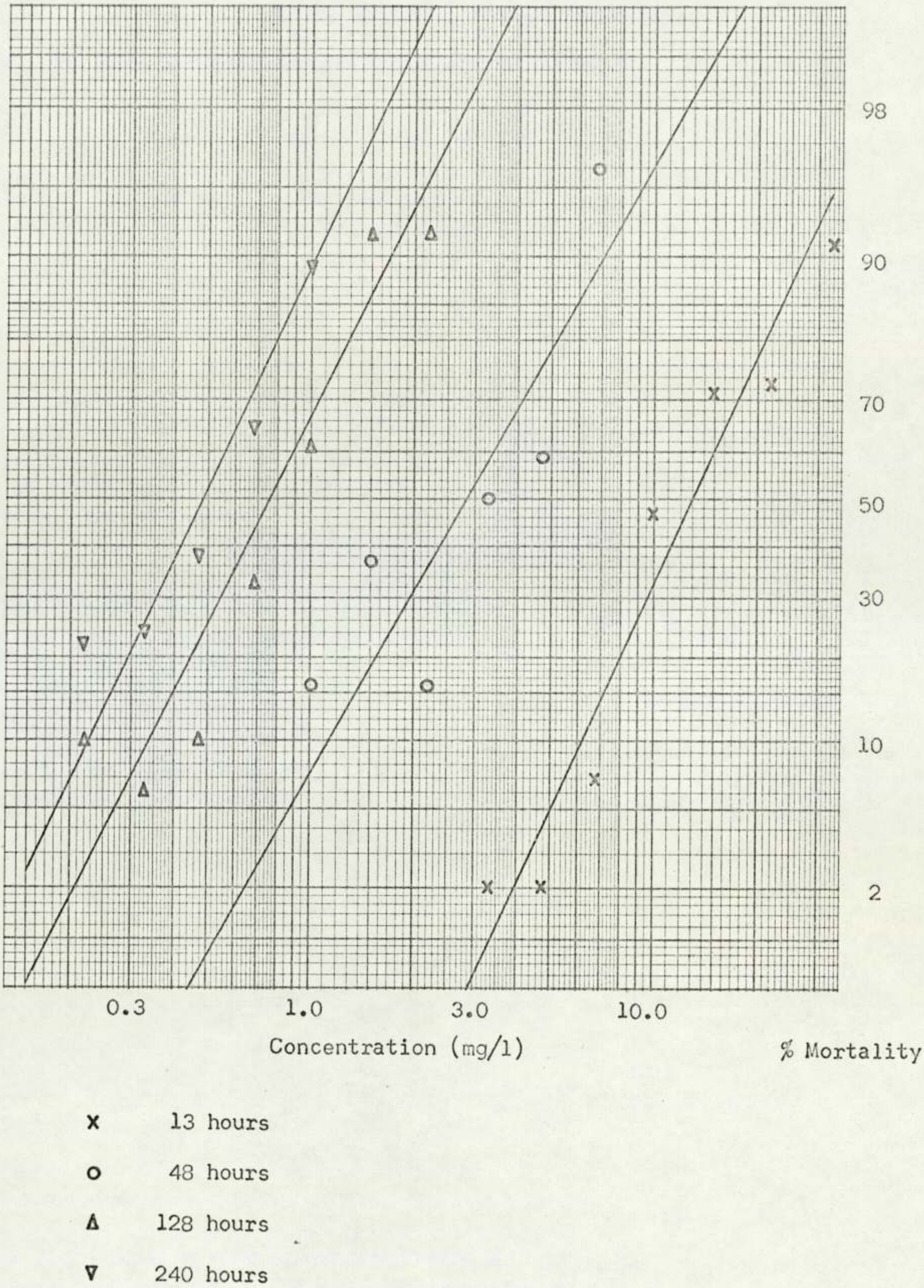
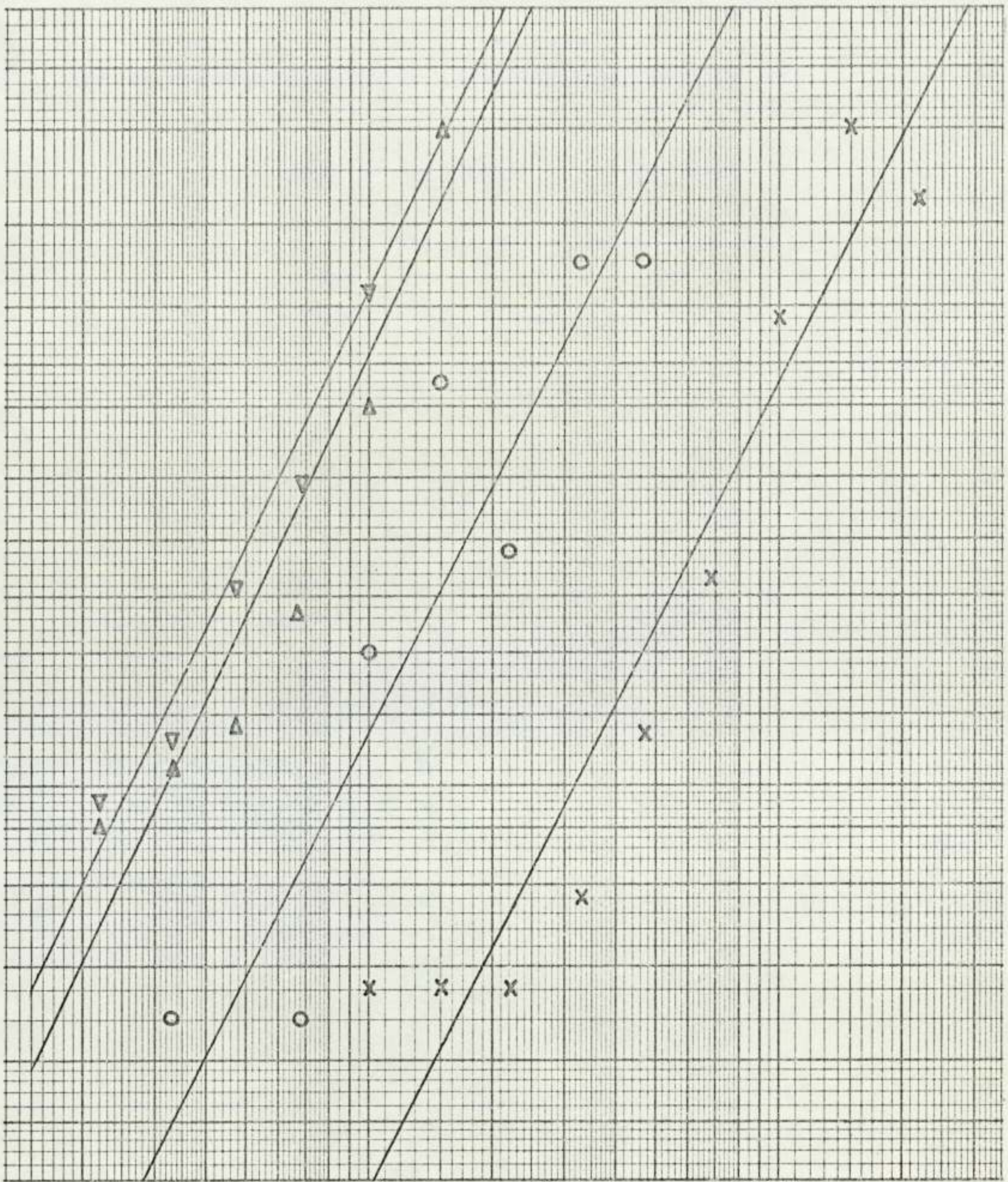


Fig. 44b. Toxicity of zinc to Gammarus at 100 hardness



x 24 hours

o 72 hours

Δ 168 hours

∇ 270 hours

Fig. 44c. Toxicity of zinc to Gammarus at 100 hardness

Table 71. Chromium: 15 Gammarus/800ml solution/dish. 100 hardness
Mortality in each dish and total for each concentration at given times

Time(hrs) Conc(mg/l	21 No	21 Tot	34 No	34 Tot	48 No	48 Tot	72 No	72 Tot	96 No	96 Tot
Control	0	0	0	0	1	1	1	1	1	2
	0		0		0		0		0	
	0		0		0		0		1	
0.15	0	0	0	0	0	1	1	3	3	6
	0		0		1		1		1	
	0		0		0		1		2	
0.22	0	1	0	1	0	1	0	1	1	5
	1		1		1		1		2	
	0		0		0		0		2	
0.33	0	0	0	0	2	3	2	3	6	13
	0		0		1		1		5	
	0		0		0		0		2	
0.47	0	0	0	2	1	6	5	20	11	39
	0		1		2		8		15	
	0		1		3		7		13	
0.68	0	0	1	3	1	4	12	30	15	43
	0		1		1		9		14	
	0		1		2		9		14	
1.0	0	1	3	5	7	17	15	41	15	45
	0		1		8		15		15	
	1		1		2		11		15	
1.5	2	3	3	8	5	23	15	44	15	45
	0		4		9		15		15	
	1		1		9		14		15	
2.2	4	4	7	8	13	24	15	45	15	45
	0		0		7		15		15	
	0		1		4		15		15	
3.3	1	2	4	11	11	34	15	45	15	45
	1		6		13		15		15	
	0		1		10		15		15	

Chromium: continued

Time: 21 hours

v	n	r	p^1	p	e	Y	w	x	y
Cont	45	0	0	0	-	-	-	-	-
0.15	45	0	0	0	-	-	-	-	-
0.22	45	1	2	2	1	2.7	0.076	-0.658	3.03
0.33	45	0	0	0	1	2.7	0.076	-0.481	2.32
0.47	45	0	0	0	2	2.9	0.110	-0.328	2.49
0.68	45	0	0	0	2	2.9	0.110	-0.167	2.49
1.0	45	1	2	2	3	3.1	0.154	0.000	2.97
1.5	45	3	7	7	4	3.2	0.180	0.176	3.63
2.2	45	4	9	9	6	3.4	0.237	0.342	3.72
3.3	45	2	4	4	8	3.6	0.302	0.518	3.33

Time: 34 hours

v	n	r	p^1	p	e	Y	w	x	y
Cont	45	0	0	-	-	-	-	-	-
0.15	45	0	0	0	1	2.7	0.076	-0.824	2.32
0.22	45	1	2	2	2	2.9	0.110	-0.658	2.95
0.33	45	0	0	0	3	3.1	0.154	-0.481	2.66
0.47	45	2	4	4	5	3.4	0.237	-0.328	3.27
0.68	45	3	7	7	7	3.5	0.269	-0.167	3.52
1.0	45	5	11	11	10	3.7	0.336	0.000	3.78
1.5	45	8	18	18	15	4.0	0.439	0.176	4.09
2.2	45	8	18	18	21	4.2	0.503	0.342	4.09
3.3	45	11	24	24	28	4.4	0.558	0.518	4.30

Time: 48 hours

v	n	r	p^1	p	e	Y	w	x	y
Cont	45	1	2	-	-	-	-	-	-
0.15	45	1	2	0	-	-	-	-	-
0.22	45	1	2	0	1	2.7	0.026	-0.658	2.32
0.33	45	3	7	5	4	3.2	0.115	-0.481	3.38
0.47	45	6	13	11	8	3.6	0.241	-0.328	3.79
0.68	45	4	9	7	15	4.0	0.389	-0.167	3.63
1.0	45	17	38	37	26	4.4	0.519	0.000	4.69
1.5	45	23	51	50	42	4.8	0.598	0.176	5.00
2.2	45	24	53	52	58	5.2	0.606	0.342	5.05
3.3	45	34	76	76	74	5.6	0.543	0.518	5.70

Chromium: continued

Time: 72 hours

v	n	r	p^1	p	e	Y	w	x	y
Cont	45	1	2	-	-	-	-	-	-
0.15	45	3	7	5	-	-	-	-	-
0.22	45	1	2	0	2	2.9	0.051	-0.658	2.49
0.33	45	3	7	5	13	3.9	0.352	-0.481	3.51
0.47	45	20	44	43	37	4.7	0.585	-0.328	4.83
0.68	45	30	67	66	68	5.5	0.564	-0.167	5.41
1.0	45	41	91	91	90	6.3	0.328	0.000	6.34
1.5	45	44	98	98	98	7.1	0.108	0.176	7.05
2.2	45	45	100	100	-	-	-	-	-
3.3	45	45	100	100	-	-	-	-	-

Time: 96 hours

v	n	r	p^1	p	e	Y	w	x	y
Cont	45	2	4	-	-	-	-	-	-
0.15	45	6	13	9	2	2.9	0.033	-0.824	4.54
0.22	45	5	11	7	14	3.9	0.310	-0.658	3.60
0.33	45	13	29	26	48	4.9	0.582	-0.481	4.40
0.47	45	39	87	87	80	5.8	0.477	-0.328	6.08
0.68	45	43	96	96	96	6.8	0.172	-0.167	6.75
1.0	45	45	100	100	99	7.3	0.073	0.000	7.68
1.5	45	45	100	100	-	-	-	-	-
2.2	45	45	100	100	-	-	-	-	-
3.3	45	45	100	100	-	-	-	-	-

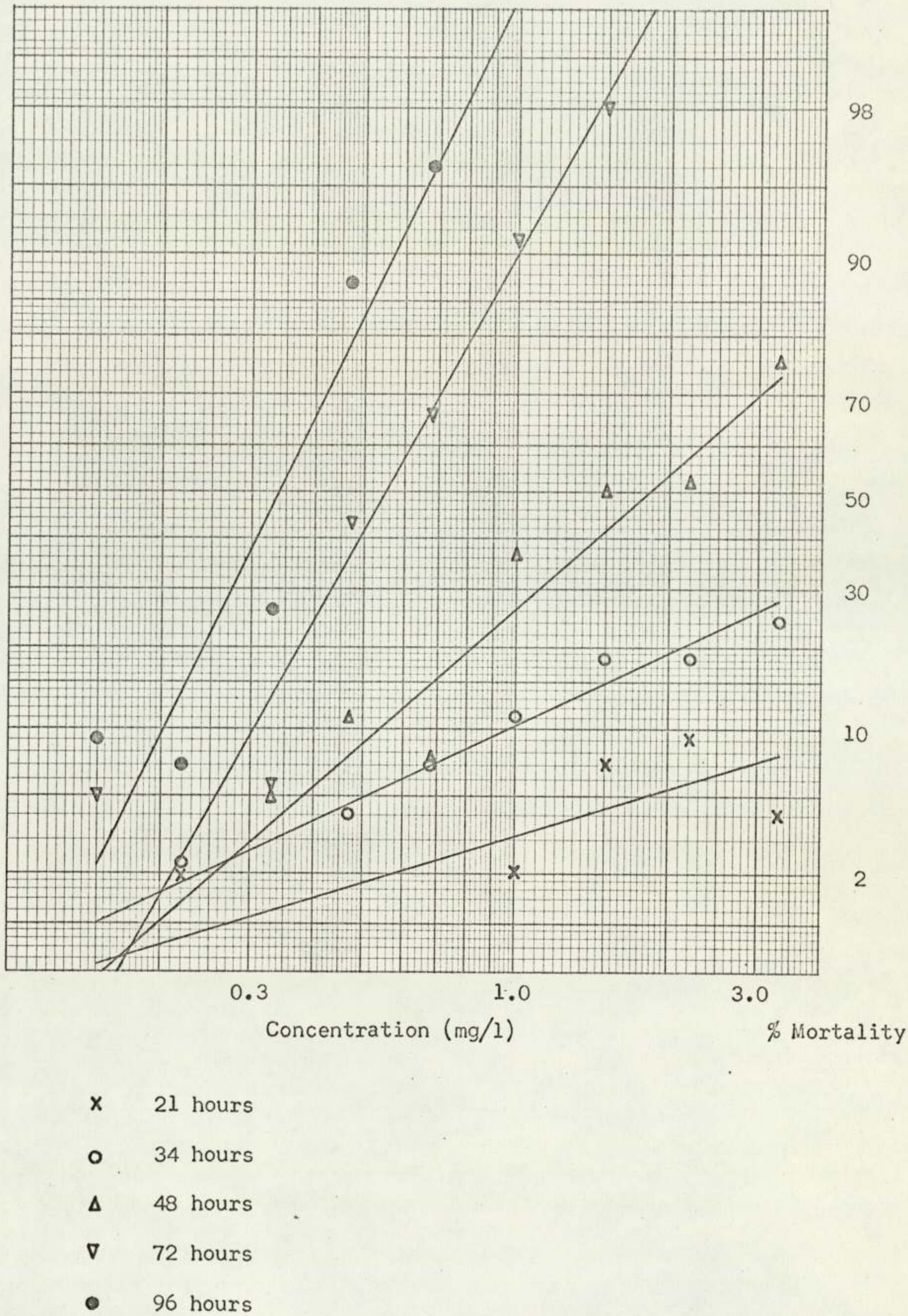


Fig. 45. Toxicity of chromium to Gammarus at 100 hardness

Table 72. Copper: 15 Gammarus/800ml solution/dish. 300 hardness

Mortality in each dish and total for each concentration at given times

Time(hrs)	11		22		34		46		70		142		336	
Conc(mg/l)	No	Tot	No	Tot	No	Tot	No	Tot	No	Tot	No	Tot	No	Tot
Control	0	0	0	0	0	0	0	0	0	0	0	2	3	8
	0		0		0		0		0		2		2	
	0		0		0		0		0		0		3	
0.15	0	0	0	0	0	0	0	0	0	0	0	1	1	6
	0		0		0		0		0		1		4	
	0		0		0		0		0		0		1	
0.22	0	0	0	0	0	0	0	0	0	0	0	1	3	10
	0		0		0		0		0		0		3	
	0		0		0		0		0		1		4	
0.33	0	0	0	0	0	1	0	1	0	2	4	9	6	19
	0		0		0		0		0		1		5	
	0		0		1		1		2		4		8	
0.47	0	0	0	0	0	2	0	2	1	5	2	8	5	15
	0		0		2		2		2		2		5	
	0		0		0		0		2		4		5	
0.68	0	0	0	0	2	3	2	4	4	7	5	17	8	29
	0		0		1		1		1		6		11	
	0		0		0		1		2		6		10	
1.0	0	0	0	2	1	3	2	7	5	12	9	33	13	41
	0		1		1		3		5		14		15	
	0		1		1		2		2		10		13	
1.5	0	0	1	1	3	5	3	5	6	15	13	40	15	45
	0		0		1		1		3		14		15	
	0		0		1		1		6		13		15	
2.2	0	0	2	3	6	11	7	15	10	27	14	42	15	45
	0		0		3		4		9		13		15	
	0		1		2		4		8		15		15	
3.3	0	0	1	4	2	9	6	13	11	28	15	45	15	45
	0		3		4		4		8		15		15	
	0		0		3		3		9		15		15	
4.7	0	0	0	7	2	14	6	25	9	34	15	44	15	45
	0		5		9		11		14		14		15	
	0		2		3		8		11		15		15	
6.8	0	0	2	7	5	15	7	23	13	36	15	45	15	45
	0		3		8		9		13		15		15	
	0		2		2		7		10		15		15	
10.0	0	0	8	14	9	19	14	35	15	40	15	45	15	45
	0		4		6		9		13		15		15	
	0		2		4		12		12		15		15	

Copper: continued

Time: 22 hours

v	n	r	p^1	p	e	Y	w	x	y
Cont	45	0	0	-	-	-	-	-	-
0.47	45	0	0	0	-	-	-	-	-
0.68	45	0	0	0	1	2.7	0.076	-0.167	2.32
1.0	45	2	4	4	2	2.9	0.110	0.000	3.40
1.5	45	1	2	2	4	3.2	0.180	0.176	3.00
2.2	45	3	7	7	6	3.4	0.237	0.342	3.54
3.3	45	4	9	9	9	3.7	0.336	0.518	3.66
4.7	45	7	16	16	13	3.9	0.405	0.672	4.01
6.8	45	7	16	16	19	4.1	0.471	0.832	4.01
10.0	45	14	31	31	26	4.4	0.558	1.000	4.51

Time: 34 hours

v	n	r	p^1	p	e	Y	w	x	y
Cont	45	0	0	-	-	-	-	-	-
0.15	45	0	0	0	-	-	-	-	-
0.22	45	0	0	0	2	2.9	0.110	-0.658	2.49
0.33	45	1	2	2	3	3.1	0.154	-0.481	2.97
0.47	45	2	4	4	4	3.2	0.180	-0.328	3.25
0.68	45	3	7	7	6	3.4	0.237	-0.167	3.54
1.0	45	3	7	7	9	3.7	0.336	0.000	3.54
1.5	45	5	11	11	13	3.9	0.405	0.176	3.78
2.2	45	11	24	24	18	4.1	0.471	0.342	4.31
3.3	45	9	20	20	24	4.3	0.532	0.518	4.17
4.7	45	14	31	31	30	4.5	0.581	0.672	4.50
6.8	45	15	33	33	36	4.6	0.600	0.832	4.56
10.0	45	19	42	42	44	4.8	0.627	1.000	4.80

Copper: continued

Time: 46 hours

v	n	r	p^1	p	e	Y	w	x	y
Cont	45	0	0	-	-	-	-	-	-
0.15	45	0	0	0	-	-	-	-	-
0.22	45	0	0	0	1	2.7	0.076	-0.658	2.32
0.33	45	1	2	2	2	2.9	0.110	-0.481	2.95
0.47	45	2	4	4	4	3.2	0.180	-0.328	3.25
0.68	45	4	9	9	7	3.5	0.269	-0.167	3.68
1.0	45	7	16	16	12	3.8	0.370	0.000	4.03
1.5	45	5	11	11	18	4.1	0.471	0.176	3.82
2.2	45	15	33	33	27	4.4	0.558	0.342	4.57
3.3	45	13	29	29	38	4.7	0.616	0.518	4.46
4.7	45	25	56	56	48	5.0	0.637	0.672	5.15
6.8	45	23	51	51	59	5.2	0.627	0.832	5.02
10.0	45	35	78	78	69	5.5	0.581	1.000	5.75

Time: 70 hours

v	n	r	p^1	p	e	Y	w	x	y
Cont	45	0	0	-	-	-	-	-	-
0.15	45	0	0	0	-	-	-	-	-
0.22	45	0	0	0	2	2.9	0.110	-0.658	2.49
0.33	45	2	4	4	5	3.4	0.237	-0.481	3.27
0.47	45	5	11	11	9	3.7	0.336	-0.328	3.78
0.68	45	7	16	16	16	4.0	0.439	-0.167	4.01
1.0	45	12	27	27	25	4.3	0.531	0.000	4.39
1.5	45	15	33	33	37	4.7	0.616	0.176	4.56
2.2	45	27	60	60	50	5.0	0.637	0.342	5.25
3.3	45	28	62	62	64	5.4	0.600	0.518	5.30
4.7	45	34	76	76	74	5.6	0.558	0.672	5.70
6.8	45	36	80	80	84	6.0	0.439	0.832	5.83
10.0	45	40	89	89	90	6.3	0.337	1.000	6.22

Copper: continued

Time: 142 hours

v	n	r	p^1	p	e	Y	w	x	y
Cont	45	2	4	-	-	-	-	-	-
0.15	45	1	2	0	-	-	-	-	-
0.22	45	1	2	0	3	3.1	0.063	-0.658	2.66
0.33	45	9	20	17	10	3.7	0.235	-0.481	4.13
0.47	45	8	18	15	23	4.3	0.453	-0.328	4.00
0.68	45	17	38	35	43	4.8	0.571	-0.167	4.62
1.0	45	33	72	71	67	5.4	0.565	0.000	5.55
1.5	45	40	89	89	86	6.1	0.386	0.176	6.22
2.2	45	42	93	93	95	6.6	0.227	0.342	6.46
3.3	45	45	100	100	99	7.3	0.073	0.518	7.68
4.7	45	44	98	98	100	-	-	-	-

Time: 336 hours

v	n	r	p^1	p	e	Y	w	x	y
Cont	45	8	18	-	-	-	-	-	-
0.15	45	6	13	0	1	2.7	0.004	-0.824	2.32
0.22	45	10	22	5	4	3.2	0.025	-0.658	3.42
0.33	45	19	42	29	15	4.0	0.184	-0.481	4.54
0.47	45	15	33	18	35	4.6	0.367	-0.328	4.15
0.68	45	29	64	56	62	5.3	0.454	-0.167	5.15
1.0	45	41	91	89	85	6.0	0.348	0.000	6.20
1.5	45	45	100	100	96	6.7	0.169	0.176	7.17
2.2	45	45	100	100	-	-	-	-	-

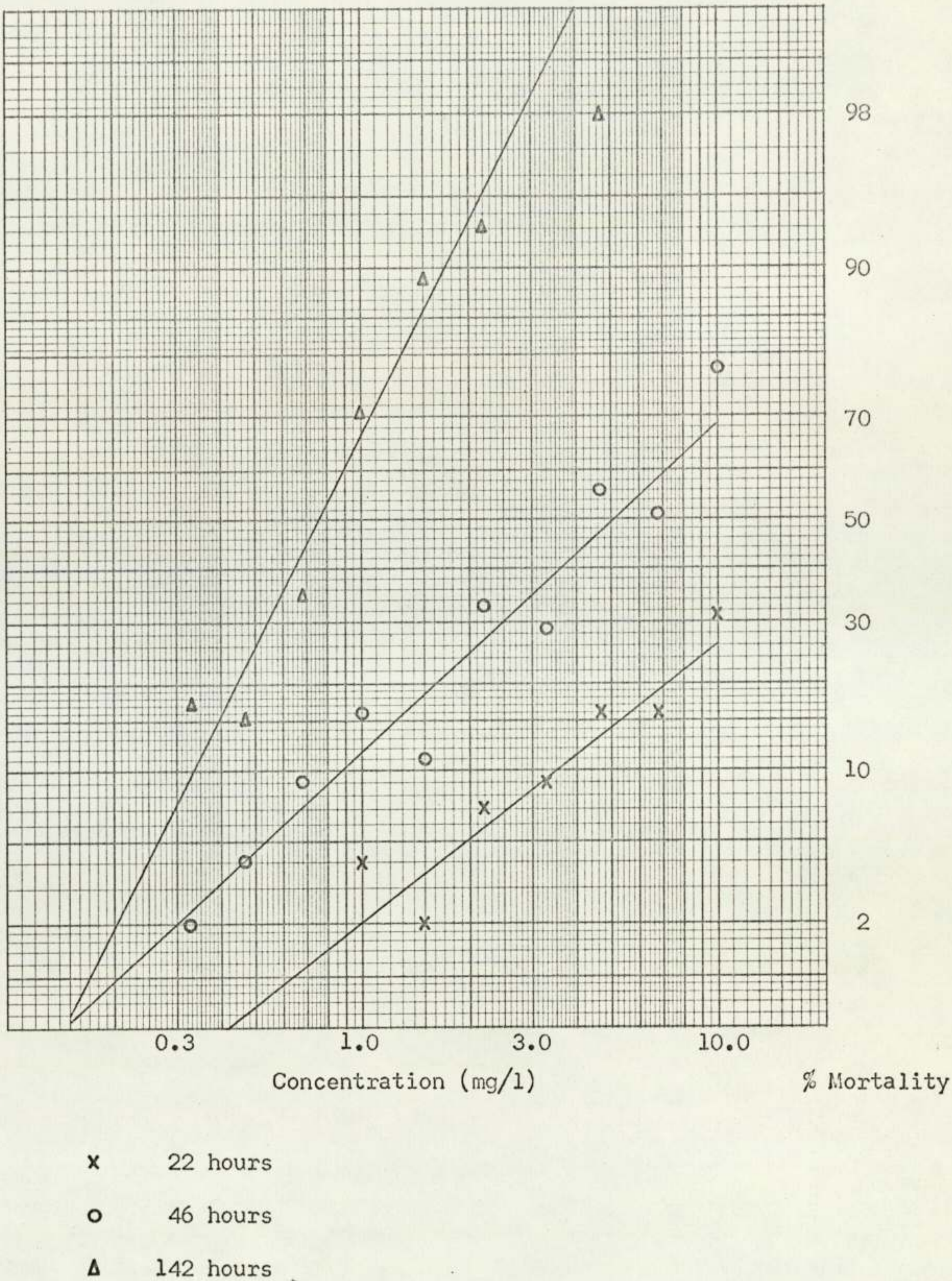


Fig. 46a. Toxicity of copper to Gammarus at 300 hardness

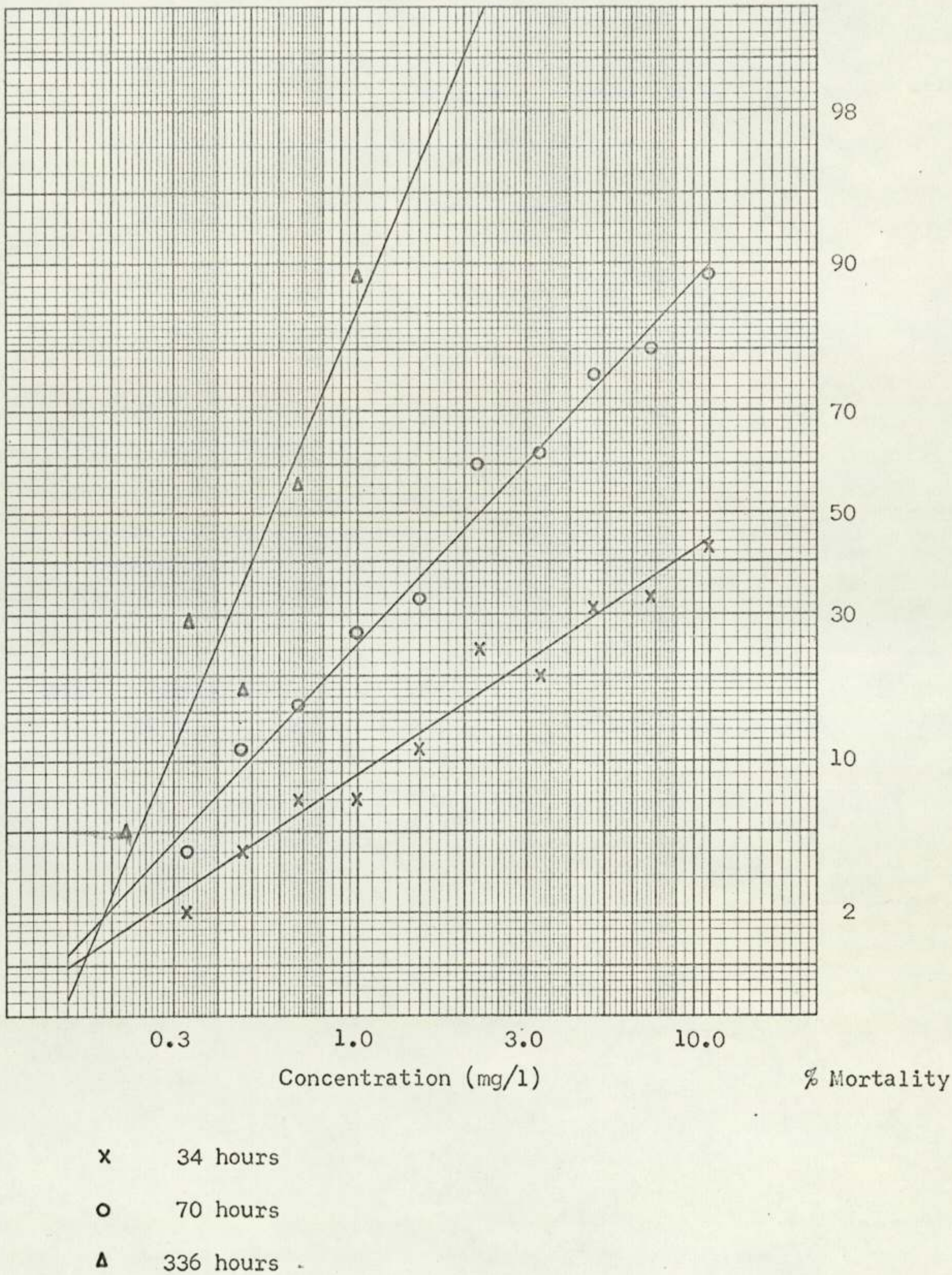


Fig. 46 b. Toxicity of copper to Gammarus at 300 hardness

Table 73. Zinc: 15 Gammarus/800ml solution/dish. 300 hardness.

Mortality in each dish and total for each concentration at given times

Time(hrs)	25		34		50		70		100		145		216	
Conc(mg/l)	No	Tot	No	Tot	No	Tot	No	Tot	No	Tot	No	Tot	No	Tot
Control	0	0	0	1	0	1	1	2	1	3	2	6	6	14
	0		0		0		0		0		2		5	
	0		1		1		1		2		2		3	
0.33	0	0	0	1	1	3	1	3	1	4	2	9	5	16
	0		1		1		1		2		4		5	
	0		0		1		1		1		3		6	
0.47	0	0	1	1	1	3	2	5	3	6	5	13	8	20
	0		0		1		1		1		3		4	
	0		0		1		2		2		5		8	
0.68	2	4	3	6	3	7	3	10	5	14	7	19	13	31
	1		2		2		5		6		7		11	
	1		1		2		2		3		5		7	
1.0	0	0	0	0	1	4	4	9	7	15	10	25	12	36
	0		0		2		2		3		5		11	
	0		0		1		3		5		10		13	
1.5	1	1	1	2	2	6	4	15	8	25	10	35	12	41
	0		1		2		7		8		13		15	
	0		0		2		4		9		12		14	
2.2	0	0	0	5	3	17	7	22	9	34	14	44	15	45
	0		3		6		6		11		15		15	
	0		2		8		9		14		15		15	
3.3	1	4	1	7	6	15	10	30	12	39	15	43	15	45
	1		3		4		10		13		14		15	
	2		3		5		10		14		14		15	
4.7	0	5	3	12	10	30	11	34	13	40	13	42	15	45
	2		5		12		12		14		15		15	
	3		4		8		11		13		14		15	
6.8	1	4	2	10	7	24	9	34	13	42	15	45	15	45
	2		5		8		11		14		15		15	
	1		3		9		14		15		15		15	

Zinc: continued

Time: 34 hours

v	n	r	p^1	p	e	Y	w	x	y
Cont	45	1	2	-	-	-	-	-	-
0.33	45	1	2	0	-	-	-	-	-
0.47	45	1	2	0	5	3.4	0.173	-0.328	2.91
0.68	45	6	13	11	6	3.4	0.173	-0.167	3.90
1.0	45	0	0	0	8	3.6	0.241	0.000	3.06
1.5	45	2	4	2	10	3.7	0.277	0.176	3.25
2.2	45	5	11	9	12	3.8	0.314	0.342	3.67
3.3	45	7	16	14	15	4.0	0.389	0.518	3.92
4.7	45	12	27	25	19	4.1	0.424	0.672	4.35
6.8	45	10	22	20	23	4.3	0.490	0.832	4.17

Time: 50 hours

v	n	r	p^1	p	e	Y	w	x	y
Cont	45	1	2	-	-	-	-	-	-
0.33	45	3	7	5	3	3.1	0.090	-0.481	3.42
0.47	45	3	7	5	5	3.4	0.173	-0.328	3.36
0.68	45	7	16	14	9	3.7	0.277	-0.167	3.95
1.0	45	4	9	7	14	3.9	0.352	0.000	3.60
1.5	45	6	13	11	22	4.2	0.458	0.176	3.85
2.2	45	17	38	37	32	4.5	0.545	0.342	4.67
3.3	45	15	33	32	43	4.8	0.598	0.518	4.54
4.7	45	30	67	66	54	5.1	0.611	0.672	5.40
6.8	45	24	53	52	65	5.4	0.582	0.832	5.03

Time: 70 hours

v	n	r	p^1	p	e	Y	w	x	y
Cont	45	2	4	-	-	-	-	-	-
0.33	45	3	7	3	4	3.2	0.083	-0.481	3.13
0.47	45	5	11	7	7	3.5	0.166	-0.328	3.52
0.68	45	10	22	19	12	3.8	0.272	-0.167	4.19
1.0	45	9	20	17	20	4.2	0.420	0.000	4.06
1.5	45	15	33	30	32	4.5	0.512	0.176	4.49
2.2	45	22	49	47	44	4.8	0.571	0.342	4.93
3.3	45	30	67	66	58	5.2	0.585	0.518	5.41
4.7	45	34	76	75	70	5.5	0.548	0.672	5.67
6.8	45	34	76	75	80	5.8	0.477	0.832	5.67

Zinc: continued

Time: 100 hours

v	n	r	p^1	p	e	Y	w	x	y
Cont	45	3	7	-	-	-	-	-	-
0.33	45	4	9	2	3	3.1	0.043	-0.481	2.97
0.47	45	6	13	6	7	3.5	0.126	-0.328	3.45
0.68	45	14	31	26	16	4.0	0.297	-0.167	4.42
1.0	45	15	33	28	30	4.5	0.467	0.000	4.42
1.5	45	25	56	53	49	5.0	0.553	0.176	5.07
2.2	45	34	76	74	67	5.4	0.539	0.342	5.63
3.3	45	39	87	86	82	5.9	0.432	0.518	6.05
4.7	45	40	89	88	91	6.3	0.310	0.672	6.16
6.8	45	42	93	92	96	6.8	0.167	0.832	6.24

Time: 145 hours

v	n	r	p^1	p	e	Y	w	x	y
Cont	45	6	13	-	-	-	-	-	-
0.33	45	9	20	8	8	3.6	0.106	-0.481	3.59
0.47	45	13	29	18	18	4.1	0.260	-0.328	4.08
0.68	45	19	42	33	33	4.6	0.419	-0.167	4.56
1.0	45	25	56	49	53	5.1	0.497	0.000	4.97
1.5	45	35	78	75	73	5.6	0.463	0.176	5.67
2.2	45	44	98	98	87	6.1	0.345	0.342	6.63
3.3	45	43	96	95	95	6.6	0.205	0.518	6.64
4.7	45	42	93	92	98	7.1	0.096	0.672	7.05
6.8	45	45	100	100	99	7.3	0.066	0.832	7.68

Time: 216 hours

v	n	r	p^1	p	e	Y	w	x	y
Cont	45	14	31	-	-	-	-	-	-
0.33	45	16	36	7	7	3.5	0.035	-0.481	3.52
0.47	45	20	44	19	20	4.2	0.161	-0.328	4.12
0.68	45	31	69	55	43	4.8	0.303	-0.167	5.13
1.0	45	36	80	71	71	5.6	0.345	0.000	5.55
1.5	45	41	91	87	90	6.3	0.224	0.176	6.11
2.2	45	45	100	100	98	7.1	0.076	0.342	7.51
3.3	45	45	100	100	-	-	-	-	-
4.7	45	45	100	100	-	-	-	-	-
6.8	45	45	100	100	-	-	-	-	-

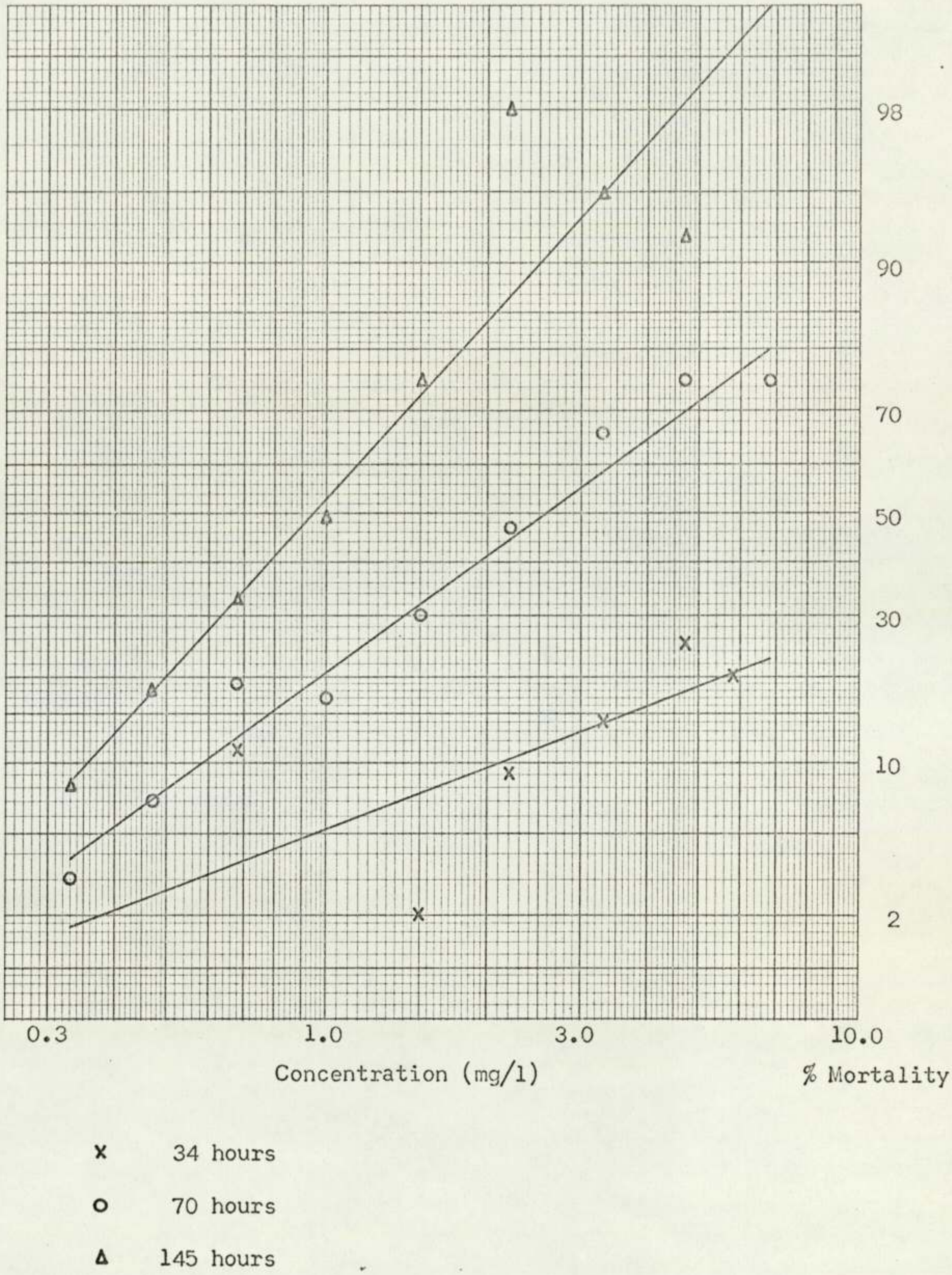


Fig. 47a. Toxicity of zinc to Gammarus at 300 hardness

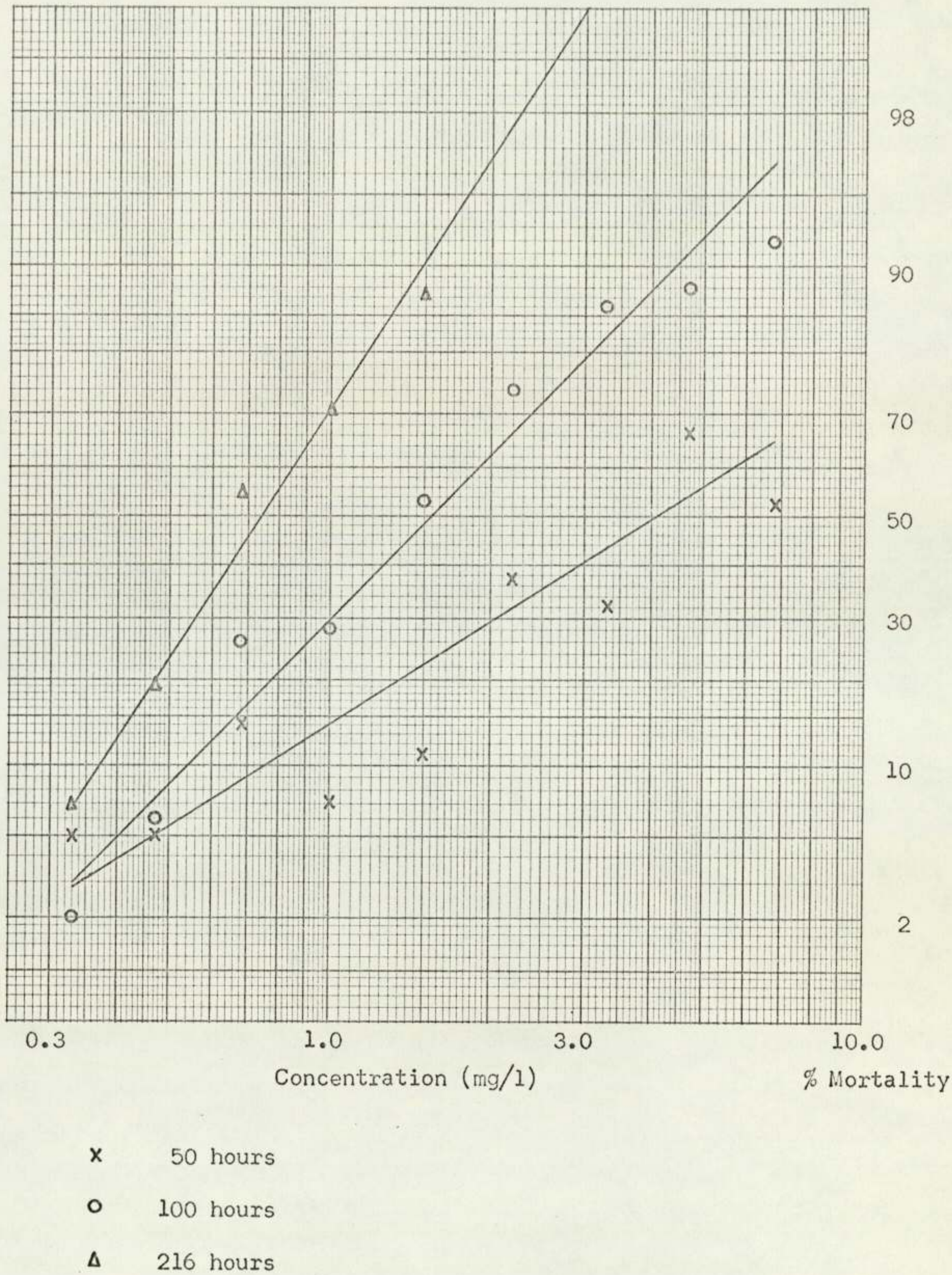


Fig. 47b. Toxicity of zinc to Gammarus at 300 hardness

Table 74. Chromium: 15 Gammarus/800ml solution/dish. 300 hardness
Mortality in each dish and total for each concentration at given times

Time(hrs)	18		30		48		72		96		142		213		330	
Conc(mg/l)	No	Tot	No	Tot	No	Tot	No	Tot	No	Tot	No	Tot	No	Tot	No	Tot
Control	0	0	0	0	0	1	0	1	1	2	1	2	3	7	3	11
	0		0		1		1		1		1		2		3	
	0		0		0		0		0		0		2		5	
0.22	0	1	0	1	1	3	1	3	2	6	2	9	3	11	5	18
	1		1		2		2		4		5		6		9	
	0		0		0		0		0		2		2		4	
0.33	0	0	0	1	1	2	1	3	1	5	3	10	4	19	7	25
	0		1		1		2		2		4		7		10	
	0		0		0		0		2		3		8		8	
0.47	0	0	0	0	1	2	3	8	4	13	6	18	7	28	10	35
	0		0		0		1		4		5		11		13	
	0		0		1		4		5		7		10		12	
0.68	0	0	0	2	1	6	5	15	9	21	12	28	15	34	15	38
	0		1		3		5		5		7		8		10	
	0		1		2		5		7		9		11		13	
1.0	0	1	1	3	1	5	9	18	12	24	14	30	14	33	15	39
	1		1		3		6		8		11		13		15	
	0		1		1		3		4		5		6		9	
1.5	1	1	2	5	3	7	11	23	14	31	15	37	15	40	15	43
	0		2		3		4		6		7		10		13	
	0		1		1		8		11		15		15		15	
2.2	0	0	0	2	1	16	8	32	10	37	15	44	15	45	15	45
	0		1		11		14		14		14		15		15	
	0		1		4		10		13		15		15		15	
3.3	0	0	1	6	5	17	12	33	13	41	15	45	15	45	15	45
	0		2		8		13		14		15		15		15	
	0		3		4		8		14		15		15		15	
4.7	0	0	3	5	5	18	14	42	14	44	15	45	15	45	15	45
	0		0		6		14		15		15		15		15	
	0		2		7		14		15		15		15		15	
6.8	1	2	7	14	9	31	15	45	100% Mortality							
	1		4		11		15									
	0		3		11		15									
10.0	1	1	5	10	13	33	15	45	100% Mortality							
	0		1		9		15									
	0		4		11		15									

Chromium: continued

Time: 30 hours

v	n	r	p^1	p	e	Y	w	x	y
Cont	45	0	0	-	-	-	-	-	-
0.22	45	1	2	2	1	2.7	0.076	-0.658	3.03
0.33	45	1	2	2	2	2.9	0.110	-0.481	2.95
0.47	45	0	0	0	3	3.1	0.154	-0.328	2.66
0.68	45	2	4	4	4	3.2	0.180	-0.167	3.25
1.0	45	3	7	7	6	3.4	0.238	0.000	3.54
1.5	45	5	11	11	8	3.6	0.302	0.176	3.79
2.2	45	2	4	4	11	3.8	0.370	0.342	3.41
3.3	45	6	13	13	14	3.9	0.405	0.518	3.87
4.7	45	5	11	11	18	4.1	0.471	0.672	3.82
6.8	45	14	31	31	23	4.3	0.532	0.832	4.52
10.0	45	10	22	22	28	4.4	0.558	1.000	4.24

Time: 48 hours

v	n	r	p^1	p	e	Y	w	x	y
Cont	45	1	2	-	-	-	-	-	-
0.22	45	3	7	5	1	2.7	0.026	-0.658	4.09
0.33	45	2	4	2	2	2.9	0.051	-0.481	2.95
0.47	45	2	4	2	3	3.1	0.090	-0.328	2.97
0.68	45	6	13	11	6	3.4	0.173	-0.167	3.90
1.0	45	5	11	9	10	3.7	0.277	0.000	3.66
1.5	45	7	16	14	17	4.0	0.389	0.176	3.92
2.2	45	16	36	35	26	4.4	0.519	0.342	4.63
3.3	45	17	38	37	38	4.7	0.585	0.518	4.67
4.7	45	18	40	39	49	5.0	0.612	0.672	4.72
6.8	45	31	69	68	60	5.3	0.596	0.832	5.46
10.0	45	33	73	72	72	5.6	0.543	1.000	5.58

Time: 72 hours

v	n	r	p^1	p	e	y	w	x	y
Cont	45	1	2	-	-	-	-	-	-
0.22	45	3	7	5	3	3.1	0.090	-0.658	3.42
0.33	45	3	7	5	8	3.6	0.241	-0.481	3.39
0.47	45	8	18	16	14	3.9	0.352	-0.328	4.01
0.68	45	15	33	32	25	4.3	0.490	-0.167	4.55
1.0	45	18	40	39	39	4.7	0.585	0.000	4.72
1.5	45	23	51	50	55	5.1	0.611	0.176	5.00
2.2	45	32	71	70	70	5.5	0.564	0.342	5.52
3.3	45	33	73	72	83	6.0	0.428	0.518	5.50
4.7	45	42	93	93	90	6.3	0.328	0.672	6.46
6.8	45	45	100	100	95	6.6	0.233	0.832	7.09
10.0	45	45	100	100	-	-	-	-	-

Chromium: continued

Time: 96 hours

v	n	r	p^1	p	e	Y	w	x	y
Cont	45	2	4	-	-	-	-	-	-
0.22	45	6	13	9	5	3.4	0.135	-0.658	3.72
0.33	45	5	11	7	12	3.8	0.272	-0.481	3.57
0.47	45	13	29	26	21	4.2	0.420	-0.328	4.37
0.68	45	21	47	45	35	4.6	0.536	-0.167	4.89
1.0	45	24	53	51	51	5.0	0.588	0.000	5.02
1.5	45	31	69	68	68	5.5	0.548	0.176	5.47
2.2	45	37	82	81	81	5.9	0.449	0.342	5.91
3.3	45	41	91	91	91	6.3	0.321	0.518	6.34
4.7	45	44	98	98	96	6.8	0.172	0.672	7.00
6.8	45	45	100	100	98	7.1	0.106	0.832	7.51
10.0	45	45	100	100	-	-	-	-	-

Time: 142 hours

v	n	r	p^1	p	e	Y	w	x	y
Cont	45	2	4	-	-	-	-	-	-
0.22	45	9	20	17	11	3.8	0.272	-0.658	4.08
0.33	45	10	22	19	24	4.3	0.453	-0.481	4.13
0.47	45	18	40	37	38	4.7	0.555	-0.328	4.67
0.68	45	28	62	61	56	5.2	0.585	-0.167	5.28
1.0	45	30	67	66	74	5.6	0.528	0.000	5.40
1.5	45	37	82	81	87	6.1	0.386	0.176	5.85
2.2	45	44	98	98	94	6.6	0.228	0.342	6.91
3.3	45	45	100	100	98	7.1	0.106	0.518	7.51
4.7	45	45	100	100	-	-	-	-	-

Time: 213 hours

v	n	r	p^1	p	e	Y	w	x	y
Cont	45	7	16	-	-	-	-	-	-
0.22	45	11	24	10	16	4.0	0.199	-0.658	3.76
0.33	45	19	42	31	31	4.5	0.359	-0.481	4.50
0.47	45	28	62	55	48	4.9	0.449	-0.328	5.13
0.68	45	34	76	71	65	5.4	0.465	-0.167	5.55
1.0	45	33	73	68	80	5.8	0.405	0.000	5.43
1.5	45	40	89	87	90	6.3	0.277	0.176	6.11
2.2	45	45	100	100	96	6.8	0.150	0.342	7.25
3.3	45	45	100	100	-	-	-	-	-

Chromium: continued

Time: 330 hours

v	n	r	p^1	p	e	Y	w	x	y
Cont	45	11	24	-	-	-	-	-	-
0.22	45	18	40	21	23	4.3	0.231	-0.658	4.20
0.33	45	25	56	42	42	4.8	0.358	-0.481	4.80
0.47	45	35	78	71	60	5.3	0.408	-0.328	5.54
0.68	45	38	84	79	77	5.7	0.375	-0.167	5.80
1.0	45	39	87	83	89	6.2	0.273	0.000	5.92
1.5	45	43	96	95	96	6.8	0.136	0.176	6.62
2.2	45	45	100	100	99	7.3	0.057	0.342	7.68
3.3	45	45	100	100	-	-	-	-	-

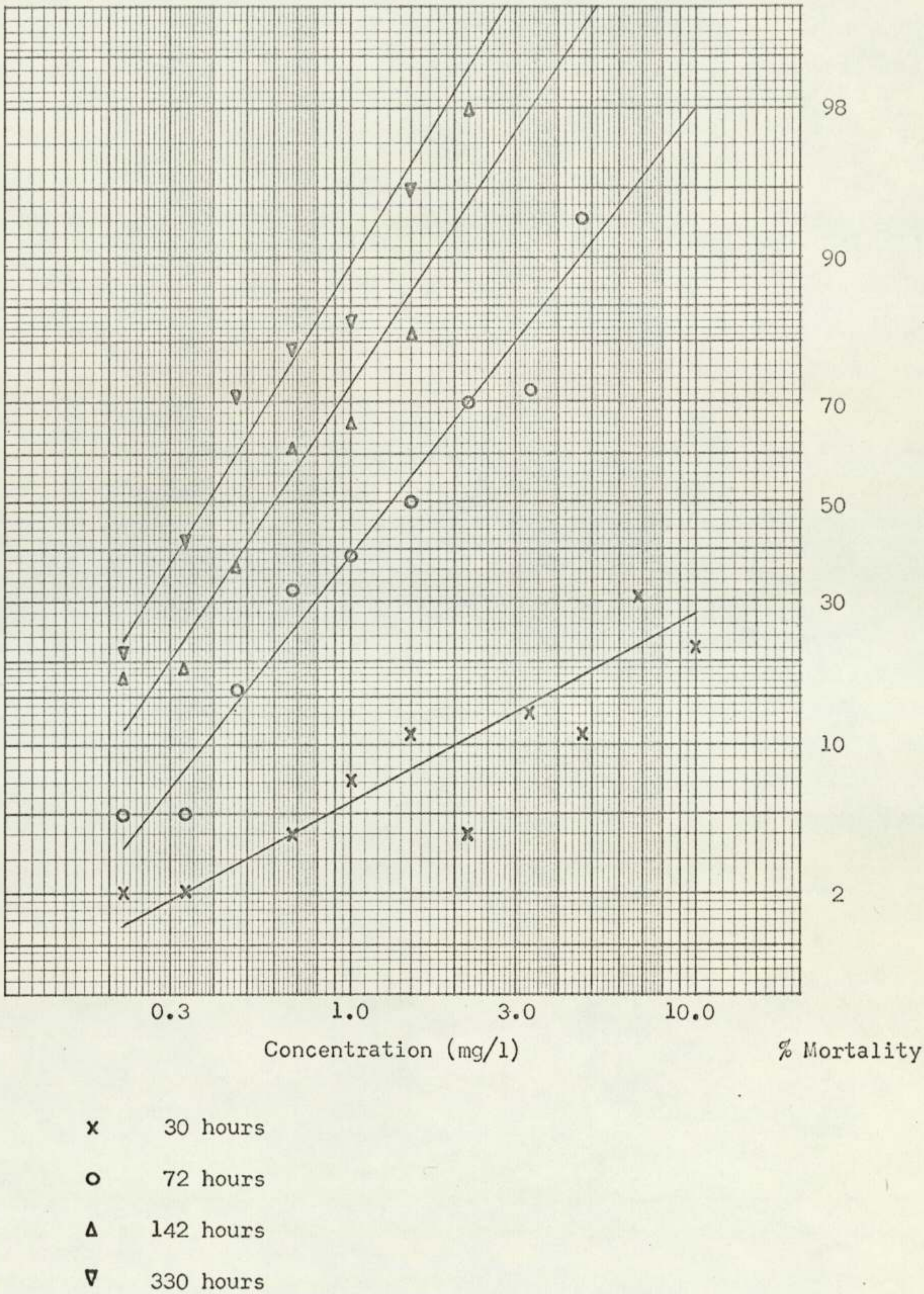
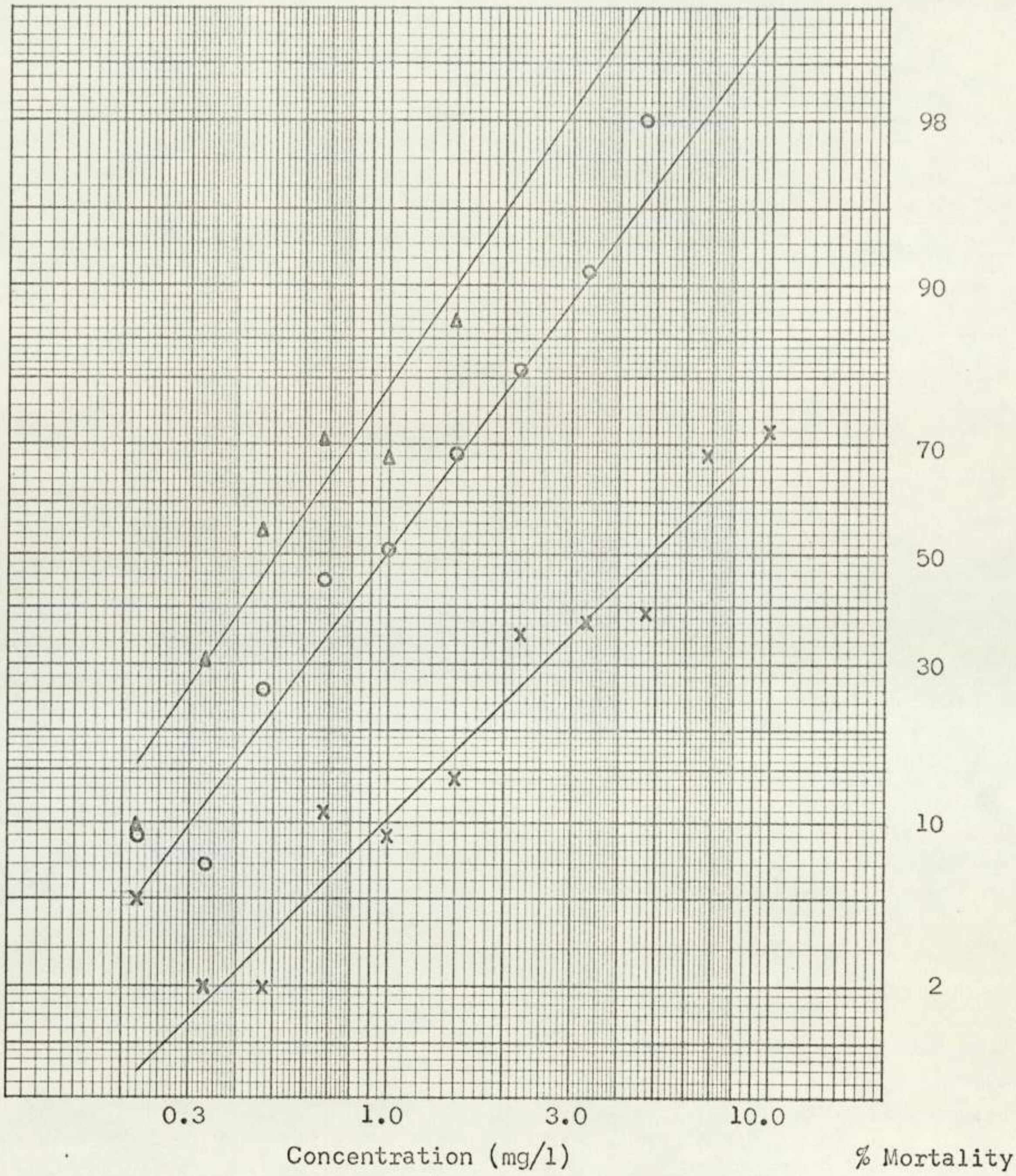


Fig. 48a. Toxicity of chromium to Gammarus at 300 hardness



x 48 hours

o 96 hours

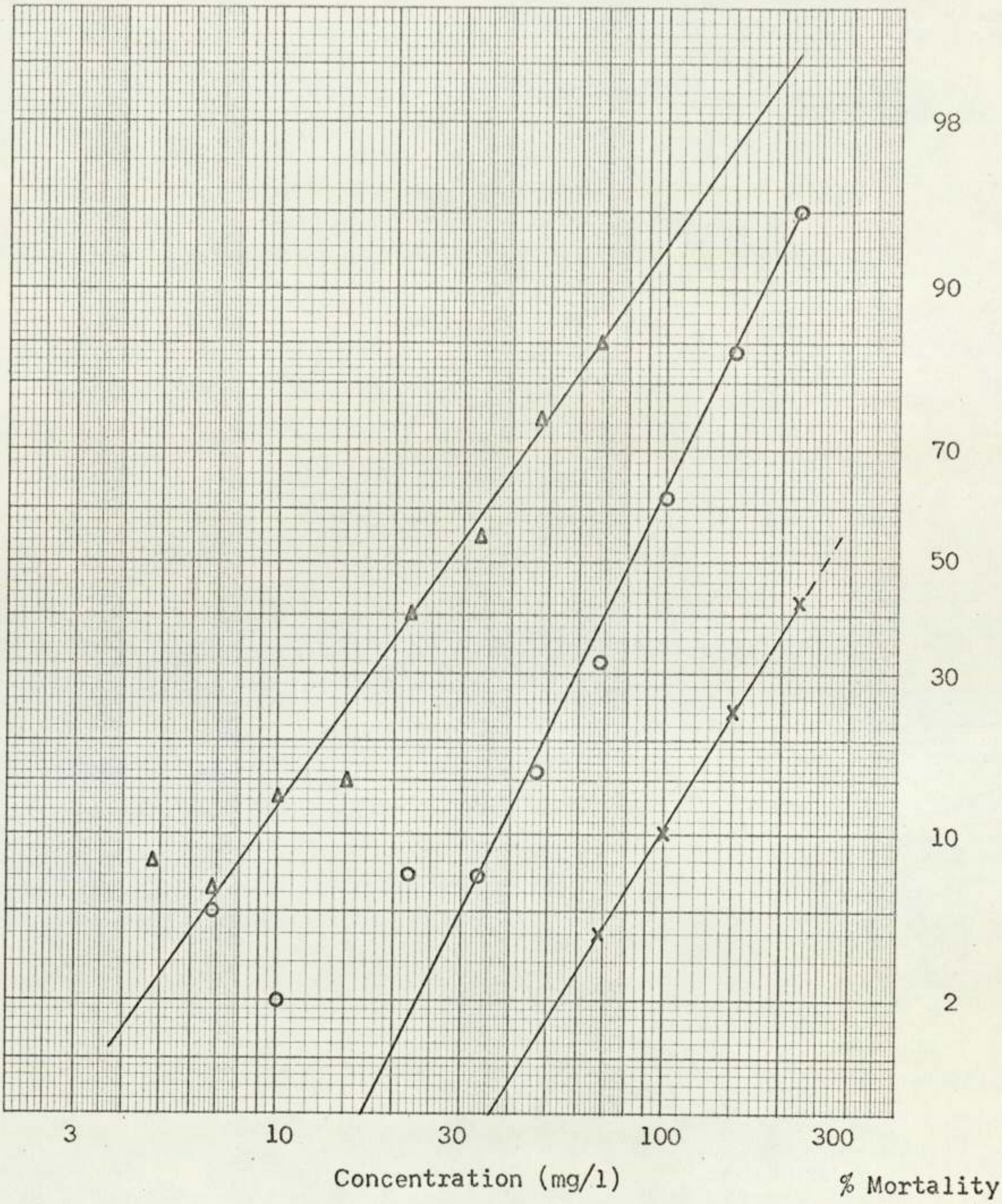
Δ 213 hours

Fig. 48b. Toxicity of chromium to Gammarus at 300 hardness

Table 75. Nickel: 15 Gammarus/800ml solution/dish. 300 hardness

Mortality in each dish, total for each concentration, observed percentage mortality p^1, and corrected percentage mortality p, for given times

Time (hrs)	47				95				165				237			
Conc(mg/l)	No	Tot	p^1	p	No	Tot	p^1	p	No	Tot	p^1	p	No	Tot	p^1	p
Control	0	1	2	-	0	4	9	-	1	8	18	-	2	12	27	-
	0				1				4				5			
	1				3				3				5			
4.7	0	0	0	0	0	3	7	(-2)	2	8	18	0	5	15	33	8
	0				2				3				4			
	0				1				3				6			
6.8	1	1	2	0	1	2	4	(-5)	4	10	22	5	7	14	31	6
	0				0				4				5			
	0				1				2				2			
10	1	3	7	5	1	4	9	0	2	9	20	2	5	16	36	13
	1				1				3				5			
	1				2				4				6			
15	0	1	2	0	0	2	4	(-5)	3	8	18	0	7	17	38	15
	0				1				3				7			
	1				1				2				3			
22	0	0	0	(-2)	0	3	7	(-2)	4	11	24	7	10	25	56	40
	0				2				3				8			
	0				1				4				7			
33	0	1	2	0	2	4	9	0	5	11	24	7	12	30	67	55
	1				1				3				8			
	0				1				3				10			
47	0	0	0	(-2)	1	2	4	(-5)	7	14	31	16	13	37	82	75
	0				0				3				12			
	0				1				4				12			
68	0	1	2	0	4	6	13	4	8	20	44	32	14	40	89	85
	1				1				8				13			
	0				1				4				13			
100	2	7	16	14	3	8	18	10	11	31	69	62	15	45	100	100
	2				2				8				15			
	3				3				12				15			
150	0	1	2	0	5	14	31	24	12	39	87	84	15	45	100	100
	0				5				13				15			
	1				4				14				15			
220	3	6	13	11	8	21	47	42	14	43	96	95	15	45	100	100
	1				6				15				15			
	6				7				14				15			



x 96 hours
o 165 hours
Δ 237 hours

Fig. 49. Toxicity of nickel to Gammarus at 300 hardness

Experiment at water hardness of 200 mg/l

Table 76. Nickel: 50 Gammarus/ 8 l. solution. Food provided, water circulated

Control

Time (days)	Number Dead	Observed % Dead	Expected % Dead
0	0	0	0
4	0	0	1
7	1	2	2
10	3	6	3
18	3	6	7
28	7	14	12
35	8	16	17
42	9	18	21
49	14	28	26
56	15	30	30
65	15	30	35
73	18	36	40
82	21	42	44
94	26	52	50
105	28	56	56
128	32	64	64

Nickel: continued

Conc (mg/l)	Time (days)	Number Dead	Observed % Dead	Control % Dead	Corrected % Dead
100	4	13	26	1	25
100	7	39	78	2	78
100	10	47	94	3	94
100	18	50	100	7	100
10	4	3	6	1	5
10	7	6	12	2	10
10	10	10	20	3	18
10	18	27	54	7	51
10	28	46	92	12	91
4.7	6	3	6	2	4
4.7	13	20	40	5	37
4.7	20	28	56	8	52
4.7	27	39	78	12	75
4.7	34	48	96	16	95
2.2	9	3	6	3	3
2.2	18	11	22	7	16
2.2	26	25	50	11	44
2.2	38	44	88	19	85
2.2	49	50	100	26	100
1.0	9	7	14	3	11
1.0	18	14	28	7	23
1.0	26	25	50	11	44
1.0	38	43	86	19	83
1.0	49	50	100	26	100

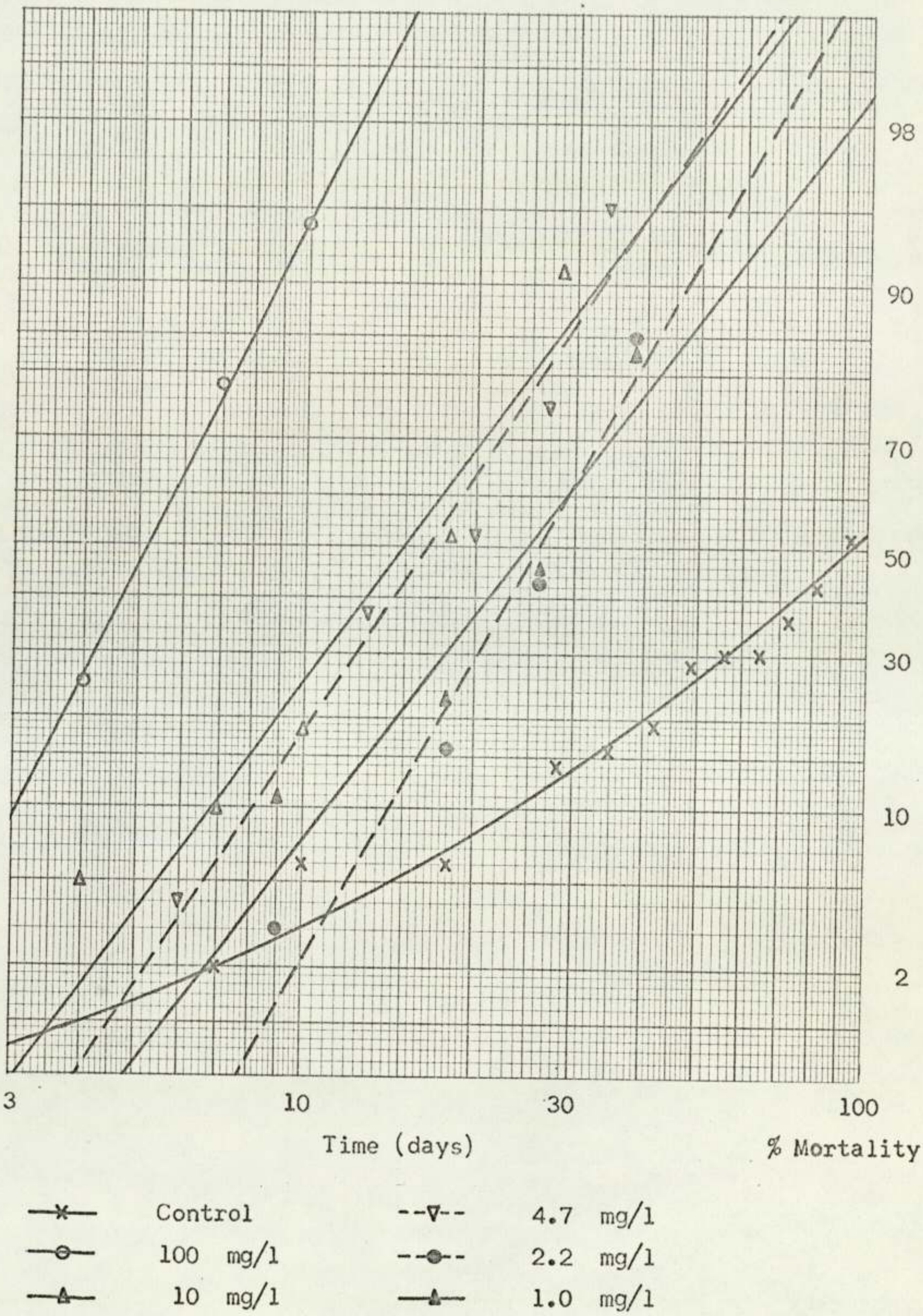


Fig. 50. Toxicity of nickel to Gammarus at 200 hardness

Experiments with mixtures of copper and zinc for 48 hours at 100 hardness

Table 77. 12 Gammarus/800ml solution/dish. 100 hardness

Mortality after 48 hours

Conc (mg/l) Copper	0.080		0.106		0.141		0.188		0.250	
Zinc	No	Tot	No	Tot	No	Tot	No	Tot	No	Tot
1.70	9	13	6	15	10	20	11	22	10	21
	4		9		10		11		11	
1.85	9	13	8	15	9	17	12	23	12	23
	4		7		8		11		11	
2.02	7	15	11	17	11	23	12	23	11	23
	8		6		12		11		12	
2.20	8	15	5	8	10	20	8	19	10	21
	7		3		10		11		11	
2.40	8	15	7	14	11	22	12	24	11	22
	7		7		11		12		11	

Table 78. 15 Gammarus/800ml solution/dish. 100 hardness

Mortality after 48 hours

Conc (mg/l) Copper	0.037		0.050		0.067		0.090		0.120		0.161	
Zinc	No	Tot	No	Tot	No	Tot	No	Tot	No	Tot	No	Tot
1.26	1	22	6	20	1	29	3	36	8	52	8	57
	3		1		5		6		5		9	
	0		0		3		3		10		6	
	6		5		8		8		10		9	
	2		6		5		6		10		12	
	10		2		7		10		9		13	
1.40	2	28	2	21	3	33	7	45	8	52	6	47
	1		3		4		7		10		9	
	4		5		4		5		8		7	
	7		2		12		8		8		13	
	10		5		6		9		10		10	
	4		4		4		9		8		2	
1.55	0	18	1	18	1	32	5	26	4	32	5	47
	2		0		6		2		6		7	
	2		4		1		3		3		4	
	5		3		10		4		6		11	
	4		6		5		8		7		10	
	5		4		9		4		6		10	
1.72	4	34	5	25	5	37	4	39	6	49	6	64
	2		1		6		7		5		10	
	4		3		1		3		10		8	
	9		3		11		9		8		14	
	6		6		6		7		11		13	
	9		7		8		9		9		13	
1.90	7	35	7	34	3	45	7	45	9	55	10	71
	3		5		5		4		7		12	
	2		4		9		7		8		9	
	6		6		11		9		14		14	
	4		4		7		9		9		12	
	13		8		10		9		8		14	

Mixtures of copper, zinc and chromium for over 48 hours

Table 79. 15 Gammarus/800ml solution/dish. 300 hardness

Mortality in each dish at given times

Mixture Percentage		Sum of Proportions	Time (hours) 22			35			48			69			96		
Control		0	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0
		0.50	0	0	0	0	0	1	0	1	2	2	3	3	3	6	3
Copper	25	0.75	0	0	0	0	1	3	1	3	5	3	6	7	8	12	12
Zinc	37.5	1.00	0	2	0	1	3	2	4	4	6	7	8	7	8	9	11
Chromium	37.5	1.25	0	0	0	2	4	4	7	9	7	13	13	11	14	14	12
		1.50	1	1	2	4	2	6	7	6	9	14	11	10	15	13	13
		0.50	0	0	0	1	0	0	1	0	1	2	1	3	3	2	7
Copper	50	0.75	0	0	0	1	1	0	1	1	0	2	5	1	2	8	4
Zinc	25	1.00	1	0	0	1	0	5	1	5	6	5	6	10	10	11	12
Chromium	25	1.25	0	0	1	2	5	3	8	7	6	13	11	7	15	13	8
		1.50	0	2	1	7	7	4	13	9	8	14	13	12	15	14	14
		0.50	0	1	1	2	1	1	2	4	2	5	7	3	10	9	6
Copper	75	0.75	0	1	1	2	1	2	3	2	3	5	7	6	10	13	12
Zinc	12.5	1.00	0	0	1	0	2	2	1	6	4	3	10	8	10	14	9
Chromium	12.5	1.25	0	1	1	5	4	4	6	6	6	11	9	10	13	9	12
		1.50	1	1	3	4	6	9	9	11	10	13	15	11	15	15	13
		0.50	1	0	0	2	1	0	2	2	2	4	5	3	5	6	4
Copper	37.5	0.75	1	0	0	2	4	1	3	5	2	4	8	3	5	11	6
Zinc	25	1.00	0	1	0	2	3	1	3	8	5	8	10	6	13	13	10
Chromium	37.5	1.25	0	0	1	0	3	2	5	9	5	9	11	10	11	13	12
		1.50	0	2	1	5	10	3	8	11	4	12	15	8	14	15	12
		0.50	0	1	0	0	1	0	1	2	1	2	3	1	4	4	9
Copper	25	0.75	0	0	0	0	1	1	1	3	1	2	3	6	8	11	10
Zinc	50	1.00	0	1	0	3	2	3	5	3	6	7	7	10	14	11	12
Chromium	25	1.25	1	2	0	3	5	4	5	10	5	9	15	10	13	15	12
		1.50	0	2	3	8	5	5	10	9	10	13	13	11	14	14	14
		0.50	0	0	1	0	0	3	1	0	3	3	2	4	5	6	9
Copper	12.5	0.75	1	0	3	3	3	4	5	4	8	10	7	9	12	10	12
Zinc	75	1.00	1	0	2	4	3	4	6	4	9	11	10	10	12	13	14
Chromium	12.5	1.25	0	2	1	3	6	2	6	9	4	12	10	8	14	12	11
		1.50	1	2	1	7	8	2	8	12	6	12	14	9	15	14	10
		0.50	1	2	0	1	4	0	1	4	1	2	5	3	2	8	10
Copper	37.5	0.75	1	0	1	1	2	2	1	3	5	3	4	9	6	8	11
Zinc	37.5	1.00	0	0	0	1	2	1	2	6	3	4	10	7	7	11	12
Chromium	25	1.25	2	0	1	3	1	4	5	4	5	12	10	10	14	15	13
		1.50	1	0	0	5	3	5	9	10	7	14	12	10	15	14	13
		0.50	0	0	0	1	1	1	3	1	3	3	1	7	6	4	11
Copper	25	0.75	0	1	1	2	4	2	2	7	3	2	8	5	4	12	9
Zinc	25	1.00	2	0	0	3	3	0	4	4	7	8	13	11	9	14	12
Chromium	50	1.25	2	0	0	2	3	4	5	5	7	8	8	10	11	13	14
		1.50	1	0	1	4	5	3	5	12	7	9	13	9	15	14	11
		0.50	1	0	1	2	0	2	5	2	2	6	3	4	8	6	6
Copper	12.5	0.75	0	0	0	1	0	2	3	1	2	5	2	5	9	6	7
Zinc	12.5	1.00	0	1	1	3	5	5	8	8	6	11	10	8	14	14	10
Chromium	75	1.25	1	1	1	5	4	3	8	9	5	9	11	9	12	13	13
		1.50	1	2	1	9	5	4	11	7	7	13	12	10	15	14	14

Table 80. Total and percentage mortality in each mixture

45 Gammarus/mixture. 300 hardness

Mixture Percentage		Sum of Proportions	22 No	22 %	35 No	35 %	48 No	48 %	69 No	69 %	96 No	96 %
Control		0	1	2	1	2	1	2	1	2	1	2
		0.50	0	0	1	2	3	7	8	18	12	27
Copper	25	0.75	0	0	4	9	9	20	16	36	32	71
Zinc	37.5	1.00	2	4	6	13	14	31	22	49	28	62
Chromium	37.5	1.25	0	0	10	22	23	51	37	82	40	89
		1.50	4	9	12	27	22	49	35	78	41	91
		0.50	0	0	1	2	2	4	6	13	12	27
Copper	50	0.75	0	0	2	4	2	4	8	18	14	31
Zinc	25	1.00	1	2	6	13	12	27	21	47	33	73
Chromium	25	1.25	1	2	10	22	21	47	31	69	36	80
		1.50	3	7	18	40	30	67	39	87	43	96
		0.50	2	4	4	9	8	18	15	33	25	56
Copper	75	0.75	2	4	5	11	8	18	18	40	35	78
Zinc	12.5	1.00	1	2	4	9	11	24	21	47	33	73
Chromium	12.5	1.25	2	4	13	29	18	40	30	67	34	76
		1.50	5	11	19	42	30	67	39	87	43	96
		0.50	1	2	3	7	6	13	12	27	15	33
Copper	37.5	0.75	1	2	7	16	10	22	15	33	22	49
Zinc	25	1.00	1	2	6	13	16	36	24	53	36	80
Chromium	37.5	1.25	1	2	5	11	19	42	30	67	36	80
		1.50	3	7	18	40	23	51	35	78	41	91
		0.50	1	2	1	2	4	9	6	13	17	38
Copper	25	0.75	0	0	2	4	5	11	11	24	29	64
Zinc	50	1.00	1	2	8	18	14	31	24	53	37	82
Chromium	25	1.25	3	7	12	27	20	44	34	76	40	89
		1.50	5	11	18	40	29	64	37	82	42	93
		0.50	1	2	3	7	4	9	9	20	20	44
Copper	12.5	0.75	4	9	10	22	17	38	26	58	34	76
Zinc	75	1.00	3	7	11	24	19	42	31	69	39	87
Chromium	12.5	1.25	3	7	11	24	19	42	30	67	37	82
		1.50	4	9	17	38	26	58	35	78	39	87
		0.50	3	7	5	11	6	13	10	22	20	44
Copper	37.5	0.75	2	4	5	11	9	20	16	36	25	56
Zinc	37.5	1.00	0	0	4	9	11	24	21	47	30	67
Chromium	25	1.25	3	7	8	18	14	31	32	71	42	93
		1.50	1	2	13	29	26	58	36	80	42	93
		0.50	0	0	3	7	7	16	11	24	21	47
Copper	25	0.75	2	4	8	18	12	27	15	33	25	56
Zinc	25	1.00	2	4	6	13	15	33	32	71	35	78
Chromium	50	1.25	2	4	9	20	17	38	26	58	38	84
		1.50	2	4	12	27	24	53	31	69	40	89
		0.50	2	4	4	9	9	20	13	29	20	44
Copper	12.5	0.75	0	0	3	7	6	13	12	27	22	49
Zinc	12.5	1.00	2	4	13	29	22	49	29	64	38	84
Chromium	75	1.25	3	7	12	27	22	49	29	64	38	84
		1.50	4	9	18	40	25	56	35	78	43	96

Table 81. Equi-proportional mixtures of copper, zinc and chromium
15 Gammarus/800ml solution/dish. 300 hardness

Mortality in each dish and total for each proportion at given times

Time(hrs)	48		70		96		125		167		220		265		336	
S of P	No	Tot	No	Tot	No	Tot	No	Tot	No	Tot	No	Tot	No	Tot	No	Tot
Control	1	1	1	3	1	4	2	5	5	10	6	12	7	15	10	19
	0		0		1		1		2		3		4		5	
	0		2		2		2		3		3		4		4	
0.10	0	1	1	2	1	3	3	7	7	15	8	22	10	29	12	32
	1		1		1		3		5		10		14		14	
	0		0		1		1		3		4		5		6	
0.12	1	1	1	4	2	7	3	9	6	17	9	22	12	27	12	28
	0		1		2		2		3		4		5		6	
	0		2		3		4		8		9		10		10	
0.15	1	2	1	3	1	4	2	7	4	13	8	20	8	22	9	24
	1		2		3		3		4		5		7		7	
	0		0		0		2		5		7		7		8	
0.18	0	1	1	5	3	9	5	13	6	19	9	29	11	32	13	36
	1		2		2		3		6		9		9		11	
	0		2		4		5		7		11		12		12	
0.22	1	2	2	4	3	10	6	16	9	28	10	33	11	36	13	41
	0		0		1		4		11		14		15		15	
	1		2		6		6		8		9		10		13	
0.27	1	3	2	6	3	13	5	17	8	25	10	31	12	35	13	39
	1		2		4		6		8		10		11		12	
	1		2		6		6		9		11		12		14	
0.33	1	4	1	9	3	19	8	32	12	39	14	42	15	44	15	45
	1		4		9		11		14		15		15		15	
	2		4		7		13		13		13		14		15	
0.39	1	6	1	12	6	27	12	35	14	41	15	44	15	44	15	45
	2		5		10		11		13		14		14		15	
	3		6		11		12		14		15		15		15	
0.47	2	7	4	15	6	22	9	31	15	44	15	45	15	45	15	45
	3		5		9		13		15		15		15		15	
	2		6		7		9		14		15		15		15	
0.56	2	14	4	20	9	32	13	39	15	44	15	45	15	45	15	45
	4		7		12		13		15		15		15		15	
	8		9		11		13		14		15		15		15	
0.68	5	24	10	35	12	39	12	40	15	45	100% Mortality					
	9		12		14		14		15							
	10		13		13		14		15							
0.82	7	22	10	30	12	37	13	40	15	45	100% Mortality					
	8		12		13		13		15							
	7		8		12		14		15							

Equi-proportional mixtures: continued

Time: 48 hours

S of P	n	r	p^1	p	e	Y	w	x	y
Cont	45	1	2	-	-	-	-	-	-
0.10	45	1	2	0	-	-	-	-	-
0.12	45	1	2	0	-	-	-	-	-
0.15	45	2	4	2	-	-	-	-	-
0.18	45	1	2	0	1	2.7	0.026	-0.745	2.32
0.22	45	2	4	2	2	2.9	0.051	-0.658	2.95
0.27	45	3	7	5	4	3.2	0.115	-0.569	3.38
0.33	45	4	9	7	8	3.6	0.241	-0.481	3.53
0.39	45	6	13	11	13	3.9	0.352	-0.409	3.78
0.47	45	7	16	14	21	4.2	0.458	-0.328	3.95
0.56	45	14	31	30	30	4.5	0.545	-0.252	4.48
0.68	45	24	53	52	42	4.8	0.598	-0.167	5.05
0.82	45	22	50	49	55	5.1	0.611	-0.086	5.00

Time: 70 hours

S of P	n	r	p^1	p	e	Y	w	x	y
Cont	45	3	7	-	-	-	-	-	-
0.10	45	2	4	(-3)	-	-	-	-	-
0.12	45	4	9	2	-	-	-	-	-
0.15	45	3	7	0	-	-	-	-	-
0.18	45	5	11	4	1	2.7	0.009	-0.745	3.73
0.22	45	4	9	2	3	3.1	0.043	-0.658	2.97
0.27	45	6	13	6	7	3.5	0.126	-0.569	3.45
0.33	45	9	20	14	13	3.9	0.260	-0.481	3.92
0.39	45	12	27	21	21	4.2	0.371	-0.409	4.19
0.47	45	15	33	28	33	4.6	0.493	-0.328	4.42
0.56	45	20	44	40	45	4.9	0.545	-0.252	4.75
0.68	45	35	78	76	59	5.2	0.555	-0.167	5.66
0.82	45	30	67	65	72	5.6	0.505	-0.086	5.37

Time: 96 hours

S of P	n	r	p^1	p	e	Y	w	x	y
Cont	45	4	9	-	-	-	-	-	-
0.10	45	3	7	(-2)	1	2.7	0.007	-1.000	1.62
0.12	45	7	16	8	2	2.9	0.017	-0.921	4.31
0.15	45	4	9	0	5	3.4	0.085	-0.824	2.91
0.18	45	9	20	12	8	3.6	0.166	-0.745	3.86
0.22	45	10	22	14	14	3.9	0.234	-0.658	3.92
0.27	45	13	29	22	23	4.3	0.377	-0.569	4.23
0.33	45	19	42	36	34	4.6	0.467	-0.481	4.64
0.39	45	27	60	56	45	4.9	0.522	-0.409	5.15
0.47	45	22	49	44	57	5.2	0.536	-0.328	4.84
0.56	45	32	71	68	68	5.5	0.508	-0.252	5.47
0.68	45	39	87	86	78	5.8	0.447	-0.167	6.05
0.82	45	37	82	80	86	6.1	0.363	-0.086	5.80

Equi-proportional mixtures: continued

Time: 125 hours

S of P	n	r	p^1	p	e	Y	w	x	y
Cont	45	5	11	-	-	-	-	-	-
0.10	45	7	16	6	2	2.9	0.014	-1.000	3.86
0.12	45	9	20	10	5	3.4	0.073	-0.921	3.81
0.15	45	7	16	6	10	3.7	0.147	-0.824	3.48
0.18	45	13	29	20	16	4.0	0.246	-0.745	4.17
0.22	45	16	36	28	26	4.4	0.385	-0.658	4.42
0.27	45	17	38	30	39	4.7	0.466	-0.569	4.48
0.33	45	32	71	67	53	5.1	0.516	-0.481	5.43
0.39	45	35	78	75	64	5.4	0.505	-0.409	5.66
0.47	45	31	69	65	75	5.7	0.457	-0.328	5.35
0.56	45	39	87	85	84	6.0	0.382	-0.252	6.04
0.68	45	40	89	88	91	6.3	0.295	-0.167	6.16
0.82	45	40	89	88	95	6.6	0.210	-0.086	6.01

Time: 167 hours

S of P	n	r	p^1	p	e	Y	w	x	y
Cont	45	10	22	-	-	-	-	-	-
0.10	45	15	33	14	4	3.2	0.020	-1.000	4.52
0.12	45	17	38	20	8	3.6	0.067	-0.921	4.40
0.15	45	13	29	9	19	4.1	0.186	-0.824	3.75
0.18	45	19	42	26	32	4.5	0.303	-0.745	4.36
0.22	45	28	62	51	50	5.0	0.407	-0.658	5.02
0.27	45	25	56	44	68	5.5	0.413	-0.569	4.79
0.33	45	39	87	83	85	6.0	0.328	-0.481	5.95
0.39	45	41	91	89	90	6.3	0.256	-0.409	6.22
0.47	45	44	98	98	96	6.8	0.139	-0.328	7.00
0.56	45	44	98	98	98	7.1	0.086	-0.252	7.05
0.68	45	45	100	100	-	-	-	-	-
0.82	45	45	100	100	-	-	-	-	-

Time: 220 hours

S of P	n	r	p^1	p	e	Y	w	x	y
Cont	45	12	27	-	-	-	-	-	-
0.10	45	22	49	30	7	3.5	0.041	-1.000	5.30
0.12	45	22	49	30	14	3.9	0.109	-0.921	4.65
0.15	45	20	44	23	30	4.5	0.264	-0.824	4.28
0.18	45	29	64	51	46	4.9	0.352	-0.745	5.02
0.22	45	33	73	63	65	5.4	0.384	-0.658	5.33
0.27	45	31	69	58	81	5.9	0.324	-0.569	5.01
0.33	45	42	93	90	91	6.3	0.238	-0.481	6.28
0.39	45	44	98	97	96	6.8	0.130	-0.409	6.87
0.47	45	45	100	100	99	7.3	0.055	-0.328	7.68
0.56	45	45	100	100	-	-	-	-	-
0.68	45	45	100	100	-	-	-	-	-
0.82	45	45	100	100	-	-	-	-	-

Equi-proportional mixtures: continued

Time: 265 hours

S of P	n	r	p^1	p	e	Y	w	x	y
Cont	45	15	33	-	-	-	-	-	-
0.10	45	29	64	46	8	3.6	0.043	-1.000	6.13
0.12	45	27	60	40	18	4.1	0.128	-0.921	4.91
0.15	45	22	49	24	36	4.6	0.247	-0.824	4.32
0.18	45	32	71	57	55	5.1	0.332	-0.745	5.18
0.22	45	36	80	70	73	5.6	0.332	-0.658	5.52
0.27	45	35	78	67	87	6.1	0.258	-0.569	5.21
0.33	45	44	98	97	95	6.6	0.156	-0.481	5.82
0.39	45	44	98	97	98	7.1	0.073	-0.409	6.82
0.47	45	45	100	100	-	-	-	-	-
0.56	45	45	100	100	-	-	-	-	-
0.68	45	45	100	100	-	-	-	-	-
0.82	45	45	100	100	-	-	-	-	-

Time: 336 hours

S of P	n	r	p^1	p	e	Y	w	x	y
Cont	45	19	42	-	-	-	-	-	-
0.10	45	32	71	50	18	4.1	0.096	-1.000	5.29
0.12	45	28	62	34	31	4.5	0.174	-0.921	4.59
0.15	45	24	53	19	52	5.1	0.271	-0.824	4.22
0.18	45	36	80	65	68	5.5	0.284	-0.745	5.38
0.22	45	41	91	84	83	6.0	0.236	-0.658	5.99
0.27	45	39	87	78	92	6.4	0.169	-0.569	5.47
0.33	45	45	100	100	97	6.9	0.088	-0.481	7.34
0.39	45	45	100	100	-	-	-	-	-
0.47	45	45	100	100	-	-	-	-	-
0.56	45	45	100	100	-	-	-	-	-
0.68	45	45	100	100	-	-	-	-	-
0.82	45	45	100	100	-	-	-	-	-

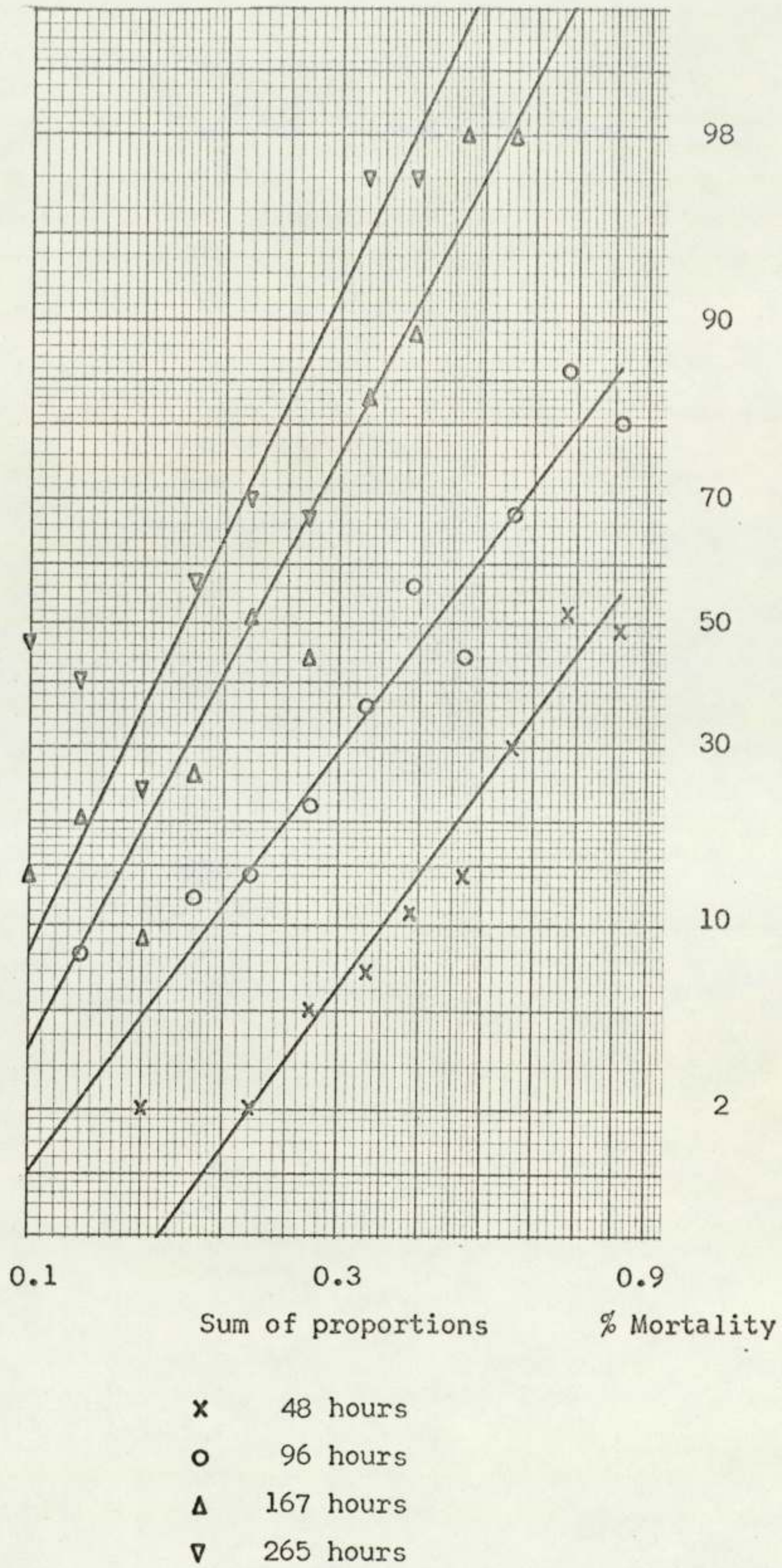


Fig. 51a. Toxicity of mixtures of copper, zinc and chromium to Gammarus at 300 hardness

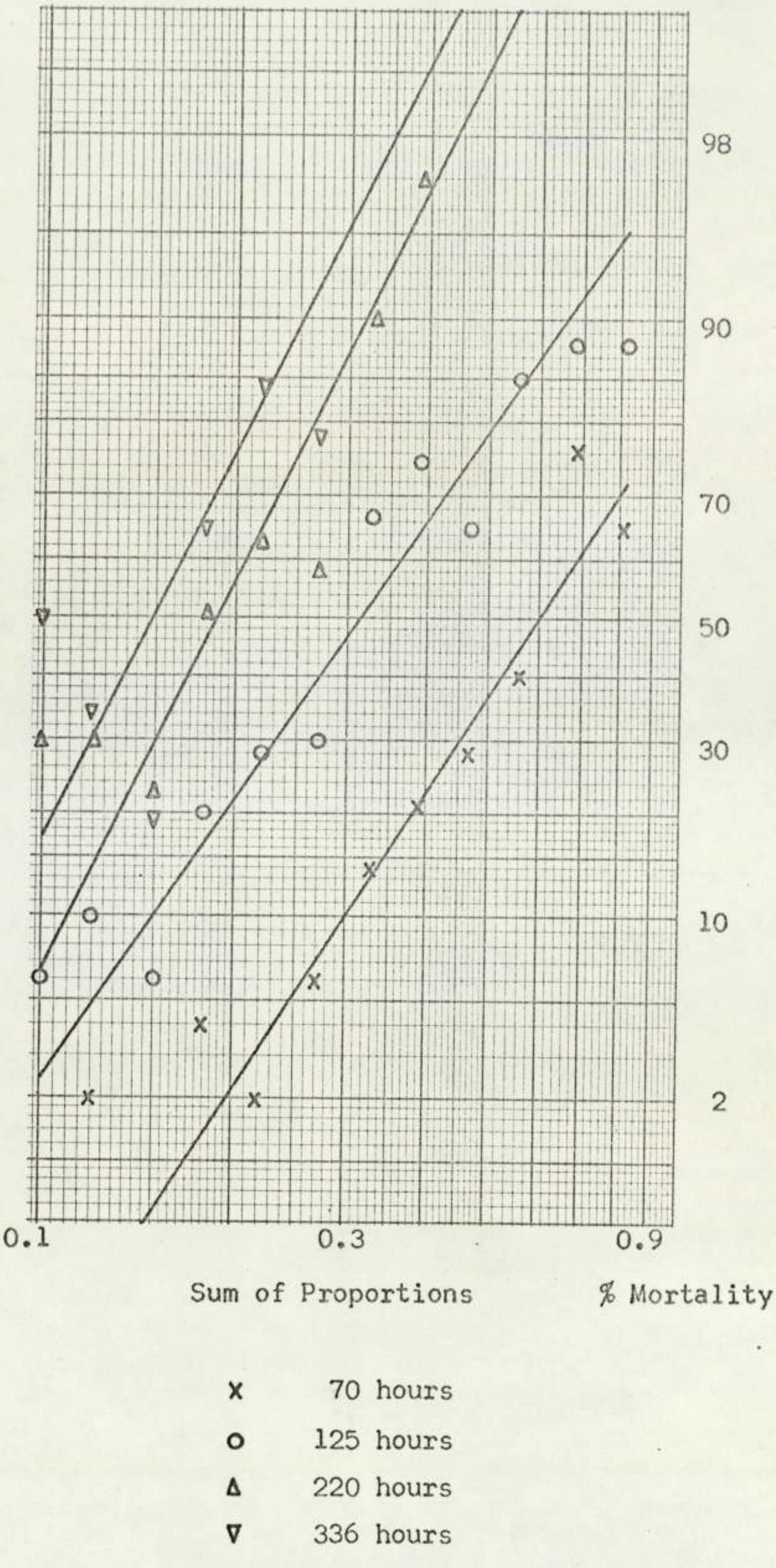


Fig. 51b. Toxicity of mixtures of copper, zinc and chromium to Gammarus at 300 hardness

Experiments at Reduced Dissolved Oxygen Concentrations

Table 82. Copper: Mortality in each dish, total and percentage mortality for each concentration and 48hr Dissolved Oxygen Concentrations

15 Gammarus/800ml solution/dish. 300 hardness

Time(hrs)	17			29			41			48				
Conc(mg/l)	No	Tot	%	No	Tot	%	No	Tot	%	No	Tot	%	D.O.	Mean
Cont	0	0	0	0	0	0	0	0	0	0	0	0	11.2	11.1
	0			0			0			0			11.5	
1.0	1	2	7	2	3	10	2	4	13	2	4	13	11.2	
	1			1			2			2			11.3	
2.2	1	1	3	2	2	7	3	6	20	4	8	27	11.1	
	0			0			3			4			11.1	
4.7	7	12	40	10	19	63	10	20	67	11	21	70	11.0	
	5			9			10			10			11.0	
10.0	15	27	90	15	29	97	15	29	97	15	29	97	11.0	
	12			14			14			14			11.1	
Cont	1	1	3	1	1	3	1	1	3	1	1	3	4.8	4.8
	0			0			0			0			4.6	
1.0	0	0	0	2	5	17	2	6	20	2	6	20	4.8	
	0			3			4			4			4.6	
2.2	3	5	17	4	9	30	9	16	53	11	20	67	4.3	
	2			5			7			9			4.8	
4.7	4	9	30	11	18	60	11	22	73	12	23	77	5.0	
	5			7			11			11			5.0	
10.0	12	25	83	13	26	87	13	26	87	13	26	87	4.8	
	13			13			13			13			5.6	
Cont	1	6	20	1	6	20	1	6	20	2	7	23	2.4	2.3
	5			5			5			5			1.8	
1.0	8	10	33	10	15	50	10	19	63	13	25	83	1.4	
	2			5			9			12			2.8	
2.2	0	0	0	2	4	13	9	14	47	13	22	73	2.0	
	0			2			5			9			2.5	
4.7	3	5	17	6	12	40	10	20	67	11	24	80	2.3	
	2			6			10			13			1.4	
10.0	7	18	60	10	23	77	14	28	93	15	30	100	2.6	
	11			13			14			15			3.5	
Cont	0	1	3	0	1	3	0	2	7	2	4	13	1.4	1.7
	1			1			2			2			2.3	
1.0	6	11	37	8	13	43	15	22	73	15	25	83	1.4	
	5			5			7			10			1.7	
2.2	4	7	23	8	18	60	14	29	97	15	30	100	1.5	
	3			10			15			15			1.3	
4.7	5	8	27	9	22	73	14	29	97	15	30	100	0.9	
	3			13			15			15			1.6	
10.0	4	11	37	10	25	83	12	27	90	12	27	90	2.8	
	7			15			15			15			2.2	

Table 83. Zinc: Mortality in each dish, percentage mortality for each concentration and 48hr Dissolved Oxygen Concentration

15 Gammarus/800ml solution/dish. 300 hardness

Time(hrs)	17		30		41		48			
Conc(mg/l)	No	%	No	%	No	%	No	%	D.O.	Mean
Cont	0	0	0	0	0	0	0	0	10.5	10.7
0.47	0	0	1	7	1	7	1	7	10.6	
0.68	0	0	0	0	0	0	0	0	10.8	
1.0	0	0	0	0	0	0	0	0	10.6	
1.5	0	0	1	7	1	7	1	7	10.6	
2.2	0	0	1	7	2	13	2	13	10.8	
3.3	0	0	0	0	2	13	4	27	10.6	
4.7	0	0	0	0	4	27	8	53	10.7	
6.8	0	0	1	7	5	33	8	53	10.8	
10.0	0	0	1	7	3	20	7	47	10.7	
Cont	0	0	0	0	0	0	0	0	4.4	4.5
0.47	0	0	0	0	2	13	3	20	4.6	
0.68	0	0	1	7	1	7	1	7	4.7	
1.0	0	0	1	7	2	13	3	20	4.2	
1.5	0	0	2	13	2	13	3	20	4.2	
2.2	0	0	1	7	3	20	7	47	4.0	
3.3	1	7	2	13	6	40	9	60	4.1	
4.7	1	7	4	27	9	60	11	73	4.6	
6.8	2	13	5	33	7	47	9	60	5.1	
10.0	3	20	7	47	10	67	13	87	4.9	
Cont	0	0	0	0	0	0	1	7	2.5	2.8
0.47	1	7	6	40	8	53	10	67	2.1	
0.68	0	0	3	20	5	33	10	67	2.8	
1.0	3	20	6	40	12	80	13	87	2.6	
1.5	0	0	8	53	9	60	10	67	2.4	
2.2	3	20	5	33	8	53	9	60	3.2	
3.3	1	7	5	33	12	80	13	87	3.9	
4.7	2	13	4	27	11	73	14	93	2.5	
6.8	2	13	5	33	11	73	13	87	3.5	
10.0	6	40	9	60	14	93	15	100	2.6	
Cont	1	7	3	20	4	27	7	47	1.5	1.4
0.47	1	7	11	73	12	80	12	80	1.7	
0.68	5	33	8	53	13	87	13	87	1.9	
1.0	7	47	12	80	15	100	15	100	1.3	
1.5	4	27	12	80	15	100	15	100	1.2	
2.2	1	7	12	80	13	87	13	87	1.1	
3.3	7	47	13	87	14	93	15	100	1.1	
4.7	3	20	8	53	11	73	15	100	1.4	
6.8	4	27	10	67	14	93	14	93	1.7	
10.0	7	47	13	87	14	93	14	93	1.5	

Experiments at Reduced Dissolved Oxygen Concentration

Table 84. Copper and Zinc. Percentage mortality in controls, corrected percentage mortality in experimental solutions, mean dissolved oxygen concentrations and percentage saturation

15 Gammarus/800ml solution/dish. 300 hardness

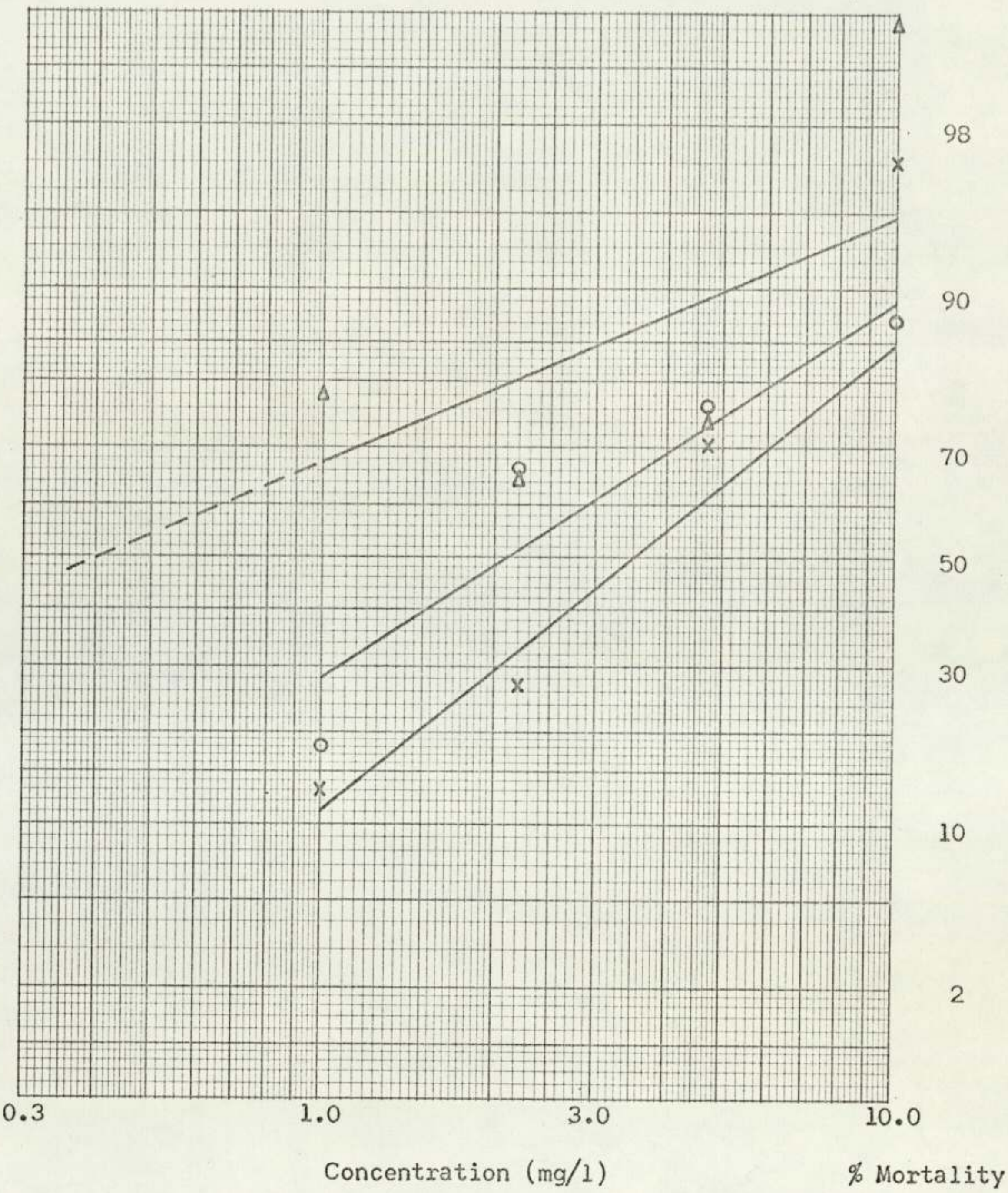
Temperature: 9.8°C. 100% saturation = 11.3 mg/l

Copper

Conc(mg/l)	Time(hrs) 17	29	41	48	Mean D.O.
Cont	(0)	(0)	(0)	(0)	11.1
1.0	7	10	13	13	
2.2	3	7	20	27	98%
4.7	40	63	67	70	
10.0	90	97	97	97	
Cont	(3)	(3)	(3)	(3)	4.8
1.0	(0)	14	18	18	
2.2	14	28	52	66	42%
4.7	28	59	72	76	
10.0	83	87	87	87	
Cont	(20)	(20)	(20)	(23)	2.3
1.0	16	37	54	78	
2.2	(0)	(0)	34	65	20%
4.7	(0)	25	59	74	
10.0	50	71	91	100	
Cont	(3)	(3)	(7)	(13)	1.7
1.0	35	41	72	80	
2.2	21	59	97	100	15%
4.7	25	72	97	100	
10.0	35	82	89	89	

Zinc

Conc(mg/l)	Time(hrs) 17	30	41	48	Mean D.O.
Cont	(0)	(0)	(0)	(0)	10.7
0.47	0	7	7	7	
0.68	0	0	0	0	95%
1.0	0	0	0	0	
1.5	0	7	7	7	
2.2	0	7	13	13	
3.3	0	0	13	27	
4.7	0	0	27	53	
6.8	0	7	33	53	
10.0	0	7	20	47	
Cont	(0)	(0)	(0)	(0)	4.5
0.47	0	0	13	20	
0.68	0	7	7	7	40%
1.0	0	7	13	20	
1.5	0	13	13	20	
2.2	0	7	20	47	
3.3	7	13	40	60	
4.7	7	27	60	73	
6.8	13	33	47	60	
10.0	20	47	67	87	
Cont	(0)	(0)	(0)	(7)	2.8
0.47	7	40	53	65	
0.68	0	20	33	65	25%
1.0	20	40	80	86	
1.5	0	53	60	65	
2.2	20	33	53	57	
3.3	7	33	80	86	
4.7	13	27	73	93	
6.8	13	33	73	86	
10.0	40	60	93	100	
Cont	(7)	(20)	(27)	(47)	1.4
0.47	0	66	73	62	
0.68	28	41	82	75	12%
1.0	43	75	100	100	
1.5	21	75	100	100	
2.2	0	75	82	75	
3.3	43	84	90	100	
4.7	14	41	63	100	
6.8	21	59	90	87	
10.0	43	84	90	87	



x 11.1 mg/l Dissolved Oxygen

o 4.8 mg/l Dissolved Oxygen

Δ 2.3 mg/l Dissolved Oxygen

Fig. 52. Effect of Dissolved Oxygen concentration on the toxicity of copper to Gammarus after 48 hours at 300 hardness

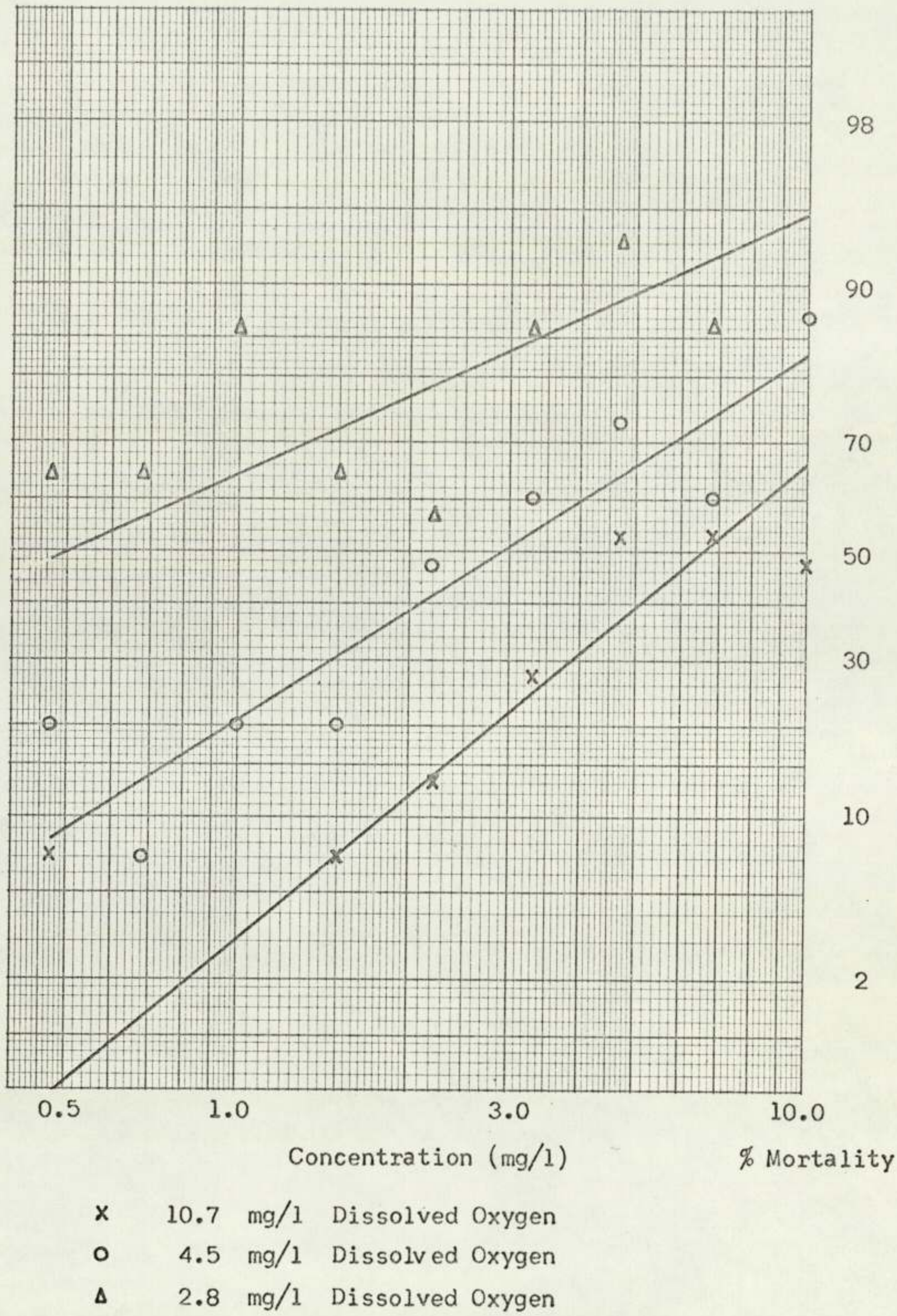


Fig. 53. Effect of Dissolved Oxygen Concentration on the toxicity of zinc to Gammarus after 48 hours at 300 hardness

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