

# **The Waste Assimilation Capacity of a reach of the Jukskei River just downstream of Alexandra Township.**

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## **Introduction**

### **Description of the study area**

The Jukskei river is the largest of the three rivers draining the northern and north-eastern suburbs of the Witwatersrand. Its source is in the Bezuidenhout valley, east of Johannesburg. The Jukskei River then flows downstream past Lombardy East, Alexandra Township, past northern residential areas like Kelvin and Buccleuch and then through more rural areas like Waterval, Leeukop and Midrand. It is joined by the Modderfontein, Braamfontein and Sand Spruits before its confluence with the Crocodile river, which flows into the Hartbeespoort dam. The catchment covers an area of 800 km<sup>2</sup> and includes many of the highly industrialised and urbanised parts of Johannesburg.

The Jukskei River is an example of an urban catchment in which problems have arisen, as a result of rapid urbanisation, due to the development of a squatter camp on the west bank of the river in Alexandra Township. Development in the Alexandra area began in 1905. Between the years 1945 and 1948 there was a large influx of people to this area. This put a great strain on the environment as no formal sanitation services were yet available. Over the years a number of resettling policies have been implemented to try and limit the number of people flocking to and staying in this area (De Jager, 1990). However, due to the high demand and low availability of affordable housing in the PWV area, people continued to move into the Alexandra area, and an informal settlement has now sprung up which has no formal sanitation services. The Alexandra Town Council have set up rudimentary services such as public stand-pipes and portable toilets (Sithole, 1991) which are serviced on a daily basis but many people living in areas like the Genisville squatter area (situated right on the banks of the Jukskei river), discard their sewage and litter directly into the river. Urban runoff from overflowing portable toilets, backyard businesses, washing of clothes and daily chores is a major source of pollution.

### **Monitoring of the Jukskei River**

A reach of the Jukskei River, 6 km downstream of Alexandra township, was chosen for this study (Figure 1). Four monitoring points were selected each about 2km apart from one another. Measurements of pH, conductivity, total dissolved solids, temperature and dissolved oxygen were carried out on a 'grab' sample at each monitoring point using the Mettler-Toledo Checkmate field system. It consists of a hand-held meter module to which different sensors can be attached. Autoclaved glass bottles were used to collect water for the faecal coliform and E. coli analyses, while the water for the chemical analyses was collected in clean PVC bottles.

The major pollutants sampled for were suspended solids, Total Dissolved Solids (TDS), nitrogen, phosphorus, pathogens, metals and oxygen demanding pollutants. Nutrient and oxygen changes were concentrated on however, as most pollution in high-density developments like the townships are organic in nature. Wimberley's (1992) report on the pollution in Alexandra Township, clearly showed that the greatest impact on the Jukskei River was in the increased concentration of nutrients and oxygen depletion arising from the discharge of organic material with a high oxygen demand. The results also showed that the urban runoff from Alexandra was responsible for an increase of 56 to 89% of the mean pollutant loads in the river. A number of water quality variables were chosen for investigation in this study, with the emphasis being on those which were considered to have the most severe impact on the river water quality.

## **Results**

### **Dissolved Oxygen (DO)**

For both the low flow (winter) and the high flow (summer) period a recovery in the dissolved oxygen is seen (See Figures 2 & 3). The median DO concentration at Alexandra (JUK1) is around  $2.5 \text{ mg.l}^{-1}$  for the low flow period when the concentration of oxidisable pollutants is greater. During the high flow summer months, dilution takes place and the median increased to  $3.1 \text{ mg.l}^{-1}$ .

Outcrops of medium to coarse textured grey to pink granite rock occurs in the river bed and on decomposing forms a residual soil layer of loamy sand which varies in depth between 0.5 and 6.0 metres. The bedrock lies relatively close to the surface which gives rise to a perched water table. The resulting rocky bed of the Jukskei river just downstream of Alexandra thus allows for the rapid reaeration of the river with a corresponding reduction in the Biological Oxygen Demand (BOD) load (Partridge, De Villiers and associates, 1980). During the winter months when the flow is less the water tumbles over these rocks and reaeration by means of turbulence takes place. There are a greater number of rapids just below the Alexandra site (JUK1) and this is seen in Figure 1 where there is a sharper increase in the DO concentration between JUK1 and JUK2. During the summer months when the water is deeper, these rocks do not cause as much turbulence (Figure 2).

The time period between stations also plays a part. In summer when there is a greater flow between stations, the time for diffusion of air into the water column is decreased and the increase in the DO concentration between the stations is seen to be less than in the low flow winter period.

The effect of water temperature on the saturation concentration of DO can also be seen. The DO concentration of the water recovers to a greater extent during the colder winter months when a greater saturation concentration can be expected. From  $2 \text{ mg.l}^{-1}$  it increases sharply to  $6 \text{ mg.l}^{-1}$  and then reaches an equilibrium of around  $8 \text{ mg.l}^{-1}$ . During summer the DO concentration only increases to an equilibrium DO concentration of  $6 \text{ mg.l}^{-1}$ . The most greatest effect that dissolved oxygen has is on the maintenance of aquatic life. The physiological efficiency of aquatic species like fish is reduced when the dissolved oxygen

levels decrease in the water column and may cause fish kills. A target guideline value of >5 mg/l for warm-water species and a value of >8 mg/l for cold water species e.g. Salmonids have been set by the Department of Water Affairs and Forestry.

### **Biological Oxygen Demand (BOD)**

The BOD test gives a measure of the oxygen utilised by bacteria during oxidation of organic material in the water sample. The test is based on the premise that all biodegradable organic material contained in the wastewater sample will be oxidised to CO<sub>2</sub> and H<sub>2</sub>O. Hence it is a direct measurement of the oxygen requirements and an indirect measure of biodegradable organic matter pollution.

The oxidation of carbonaceous pollutants in streams is usually described as being a first order rate reaction (Metcalf & Eddy, 1979). In a first order reaction the rate of oxidation is proportional to the concentration of oxidizable organic matter remaining and once a suitable colony of microorganisms has developed, the rate of the reaction is only controlled by the amount of readily available carbon available.

The equation used to describe the reaction is:

$$L_t = L_o \exp^{-kt}$$

Where:

L = concentration of BOD remaining

L<sub>o</sub> = the ultimate concentration of BOD

k = rate constant for a particular group of microorganisms.

t = time

Using the above equation and regression analysis, the carbonaceous rate constant for the Jukskei river was determined by plotting the log(BOD at t) against time t in days which gives us a slope of -k Log(e). The average carbonaceous rate constant during the summer high flow period was found to be 0.27 day<sup>-1</sup>. An average k of 0.17 day<sup>-1</sup> is usually used for natural waters if the k value is unknown but it may vary considerably depending on the type of waste being oxidised (Metcalf & Eddy, 1979). k values have been found to range from 0.05 to greater than 0.3 day<sup>-1</sup>. The BOD seemed to follow an exponential curve but due to the expense of the test and thus the lack of sufficient data the statistical tests were inconclusive (Figures 3 & 4).

### **Chemical Oxygen Demand (COD)**

COD is a measure of all the material in the wastewater sample that can undergo oxidation. If a great enough concentration of dissolved oxygen is available a number of oxidation reactions can take place.

The COD can be seen to be higher during the low flow period where greater concentration of the material takes place (Figures 4 & 5). During the high flow periods more dilution takes

place and the concentrations are less. The effect of instream velocity can also be seen. The material undergoing the oxidation reactions spend more time in the water column between stations during the low flow periods so more of the oxidation reaction can take place and this is reflected in the Figures 4 & 5. A large decrease in the COD concentration is seen between JUK1 and JUK2 during the low flow period. The corresponding decrease in the COD concentration during the high flow period is much less noticeable as the water is flowing so fast that only a small concentration of the material has been oxidised by the time it passes JUK2.

## Nutrients

From Wimberley's (1992) report it was found that the major source of high nutrient loads reaching the Jukskei river was human and animal faeces. Sewage from blocked drains is flowing into the Jukskei river, or is washed off the catchment during rainfall events. The majority of the organic pollutants are thus in the form of proteins, carbohydrates and fats, or in the form of excretory products such as ammonia, urea and uric acid. The organic products are broken down by bacteria in the water into nitrates and nitrites, making them available to the various plants in an inorganic form. The above reactions only occur under aerobic conditions. If the dissolved oxygen concentration drops to below 1 mg/l, then the anaerobic denitrifying bacteria take over and nitrites, nitrates and ammonia are converted to nitrogen gas ( $N_2$ ) which is then lost to the atmosphere. Changes in the ammonia or Total Kjeldahl Nitrogen (TKN) concentration with distance downstream can be a useful indicator of the rate of conversion to nitrate-N. Nitrogen compounds are related by means of a series of reactions known as the nitrogen cycle, which regulates the flow of nitrogen from inorganic forms in soil, air and water into living organisms and then back into inorganic forms (See Fig. 6). The six most important processes taking place are (P.J.Ashton, pers. comm.):

- i) Nitrogen assimilation (nitrates and ammonia) by plants;
- ii) Heterotrophic conversions of organic nitrogen from one organism to the next;
- iii) Ammonification, the breakdown of organic nitrogen into ammonia;
- iv) Nitrification, the aerobic oxidation of ammonia to nitrite then to nitrates by the nitrifying bacteria;
- v) Denitrification, The anaerobic conversion of nitrate to nitrite and ammonia by bacteria and fungi;
- vi) Nitrogen fixation, the biological fixation of molecular nitrogen to produce ammonia, which is then converted to nitrogen compounds in organisms.

Another reaction is the volatilisation of ammonia which is then lost to the atmosphere. This process occurs at high temperature and pH values. During this process, the ammonium ions are converted to the toxic un-ionised ammonia form ( $NH_4^+ \rightarrow NH_3$ ) which is then lost as a gas into the atmosphere. The two reactions by which inorganic nitrogen is lost from the aquatic environment is the conversion of nitrites to gaseous nitrogen by denitrifying bacteria and the

volatilisation of ammonia.

The two most important reactions under aerobic and anaerobic conditions however, are the biological conversion between the inorganic forms of ammonia, nitrites and nitrates. During the high flow period, the drop in TKN and ammonia followed exponential curves with a 0.98 and a 0.99 correlation respectively (Figures 7 & 9). This corresponds to bacterial conversion of TKN and ammonia to nitrites and nitrates. During the high flow period the concentration of oxidisable pollutants is less due to dilution, so the dissolved oxygen is always kept above the limiting DO value of 1 to 1.5mg.l<sup>-1</sup> ensuring that the main reaction taking place is nitrification by the *Nitrobacter* and *Nitrosomonas* bacteria.



During the colder winter months a greater decrease in TKN and ammonia is seen between JUK1 and JUK2. A number of processes could be at work here. There are longer reaction times between stations which allows for greater conversion of TKN and ammonia and the flow is less so more sedimentation of particulate nitrogen and adsorbed nitrogen takes place. The longer flow time between stations also allows for the formation of a larger colony of nitrifying bacteria.

The concentration of nitrites in natural waters is never very high as the conversion of nitrites to nitrates is very fast and not much is accumulated. An increase in nitrite concentration is an indication that nitrification and denitrification is taking place. From the results an increase in nitrite concentration is observed (Figures 11 & 12). As the dissolved oxygen is always above the 1.0 mg.l<sup>-1</sup> limit for denitrification, the main reaction taking place must be nitrification. As more ammonia is converted to nitrates, an equilibrium will result where the concentration of nitrite will remain at a certain equilibrium concentration. From Figures 11 and 12, the median for both the high flow and low flow periods are at their highest at JUK1, and drops to a constant value.

The concentration of nitrates is low at the JUK1 site and increases up to JUK2 and JUK3 where it seems to reach a plateau before it decreases slightly at JUK4 (Figures 13 & 14). At high concentrations of ammonia, the nitrification reaction is taking place at optimum rate. An increase in nitrates is thus observed. Once the concentration of ammonia starts to decline however, as it does at JUK2, the uptake of nitrates by plants is greater than the production of nitrates by the nitrification process and a decrease in nitrates is observed.

The percentages that each inorganic nitrogen species makes up of the total inorganic nitrogen at JUK1 and JUK2 were calculated. At JUK1 the mean total Kjeldahl nitrogen was found to make up 92% of total inorganic nitrogen; ammonia making up 65%; nitrite 3% and nitrate 10%. The percentage nitrogen for TKN then dropped to 62% at the JUK2 site, ammonia to 33%, while nitrites remained at 3% and nitrates increased to 10% (Figure 15). In unimpacted waters which are well oxygenated, >80% of the inorganic nitrogen will be in the nitrate form and ammonia will make up less than 20% of the inorganic nitrogen. With run-off into the waters the ammonia concentration may rise to greater than 40% of the inorganic nitrogen (Ashton, pers. comm.). In the Jukskei River at the JUK1 site, ammonia made up

65% of the inorganic nitrogen with the nitrate concentration only making up 10%. This indicates recent pollution of the river.

## Microbiological

There has been a lot of speculation in the media on the dangerously high concentrations of faecal coliforms in the Jukskei river (Star, 01/02/1995 & Engineering News, 13/04/1995). A low of 140 000 and a high of 31 million faecal coliforms per 100 ml was recorded in July 1994 and September 1994 respectively. The concentration with respect to the distance downstream followed an exponential curve as expected of biological decay reactions. Both the high and the low flow data correlated by 0.98 and 0.99 respectively to an exponential fit (Figures 16 & 17). Natural die-off of the faecal coliforms is due to UV radiation from sunlight, dilution, being in a hostile environment (in water instead of in a mammalian gut), predation and substrate reduction. The effect of UV from sunlight and dilution can be seen in the results for the high flow period. During this period there is more UV light and there are greater flows with the resulting reduction in the concentration of faecal coliforms. A greater decrease in the concentration of faecal coliforms between monitoring points is thus observed.

## Conclusions

From the study, the types of reactions taking place during the assimilation of waste were determined and equations were fitted to the data to see what trends were taking place. These trends can be used to predict what impact waste will have on a river.

Most of the waste from Alexandra is organic in nature and thus most of the waste assimilation reactions were seen to follow the exponential decay of bacterial assimilation. Nitrification of nitrogen compounds by the *Nitrosomonas* and the *Nitrobacter* bacteria was seen to be the main reaction taking place in the assimilation of nitrogen compounds. Oxidation of carbonaceous organic compounds was also the main reaction taking place with the data again following exponential curves with a 0.98 to 0.99 fit. The DO concentration is very important as it gives us an idea of the state of health of a particular stretch of a river. At the Alexandra site, recent pollution could be seen in both the greater percentage of ammonia to nitrates concentration as well as the low concentration of DO. The DO then increased rapidly due to the greater entrainment of air by turbulence, diffusion and the lower concentration of oxidisable pollutants. The microbiological aspects is very important as many possibly fatal diseases are water-borne. It was found that the concentration of faecal coliforms at the Alexandra site was dangerously high reaching a high of 31 million counts per 100ml during September 1994. This then decreased by exponential decay to 1.4 million counts per 100ml with a decay rate of  $1.42 \text{ day}^{-1}$  at the Modderfontein Spruit monitoring point. This is worrying as it is at the Alexandra site that the water is used for drinking and cooking purposes. The Department of Water Affairs and Forestry gives a domestic drinking guideline value of 0 counts per 100ml for the complete protection against water-borne diseases with the risk of contracting a disease increasing greatly above 20 counts per 100 ml. The only solution is to prevent the runoff of sewage into the river which involves unblocking the sewage pipes and providing enough facilities for the collection and treatment of sewage.

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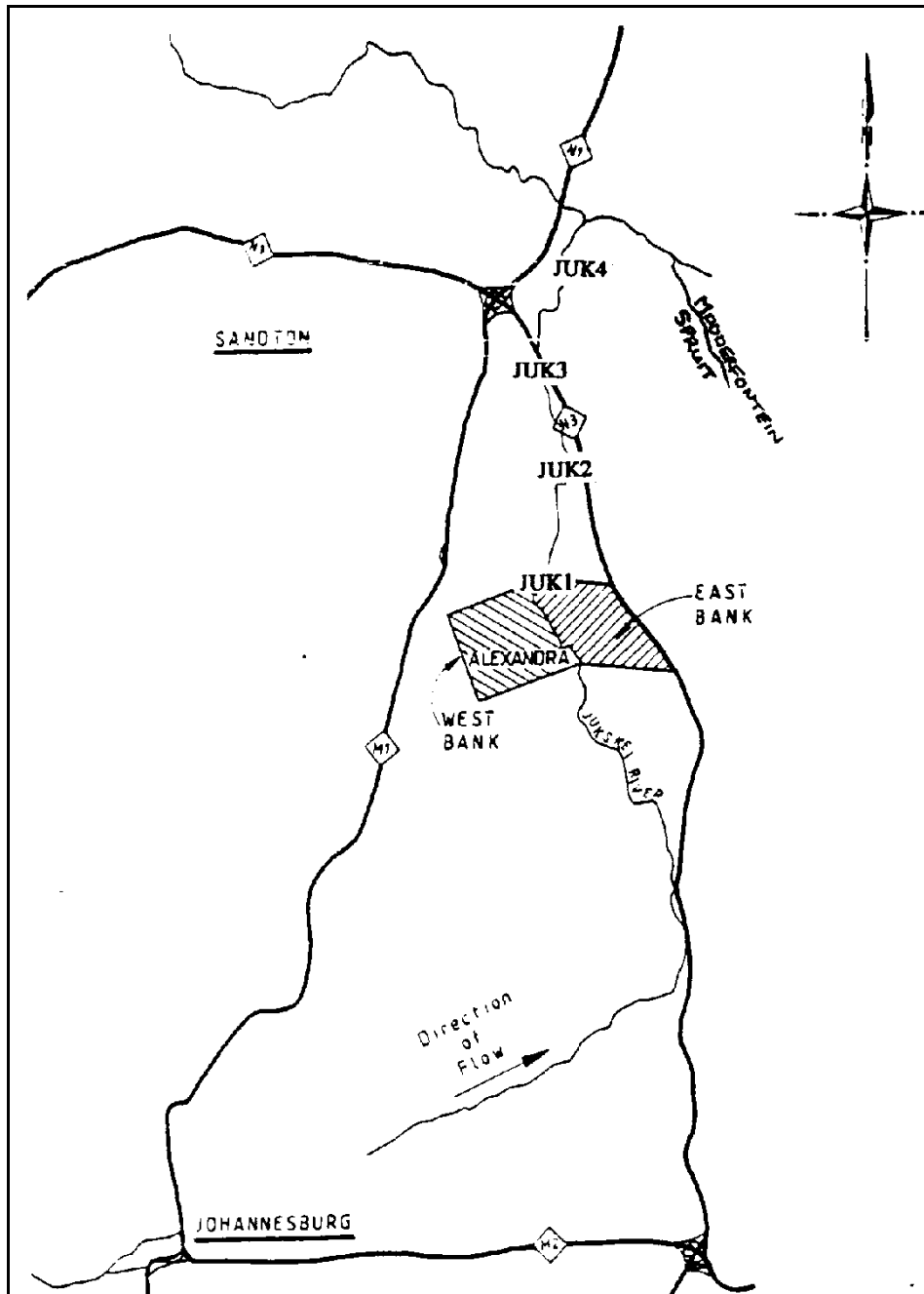


Figure 1:Monitoring and flow points on the Jukskei River.



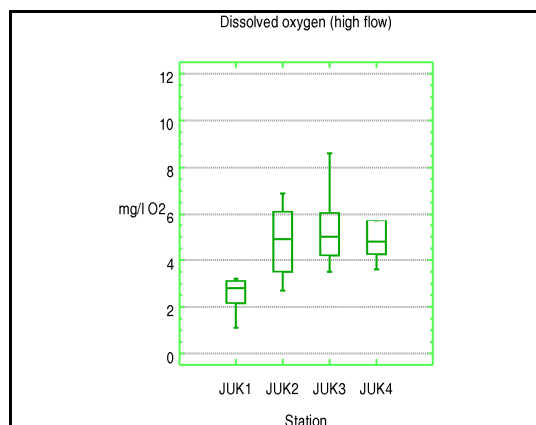


Figure 2:Box and whisker plot of the DO concentration wrt distance downstream during the high flow (summer) period.

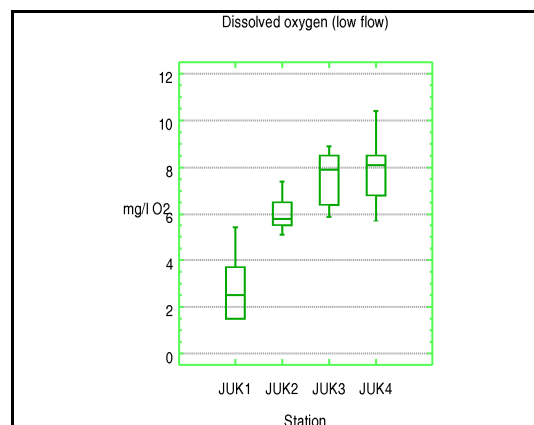


Figure 3:Box and whisker plot of the DO concentration wrt distance downstream during the low flow (winter) period.

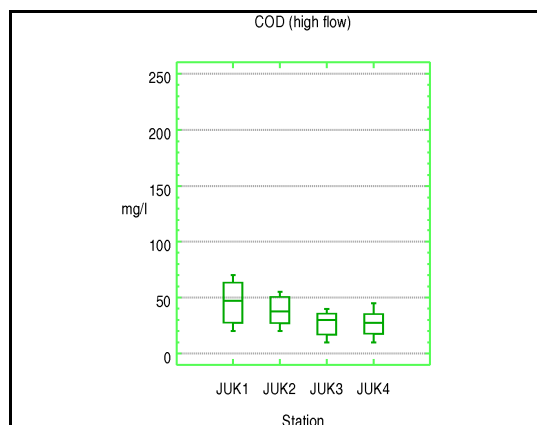


Figure 4:Box and whisker plot of the COD concentration wrt distance downstream during the high flow (summer) period.

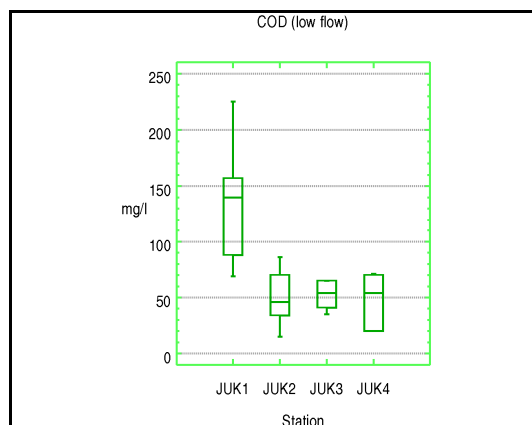


Figure 5:Box and whisker plot of the COD concentration wrt distance downstream during the low flow (winter) period.

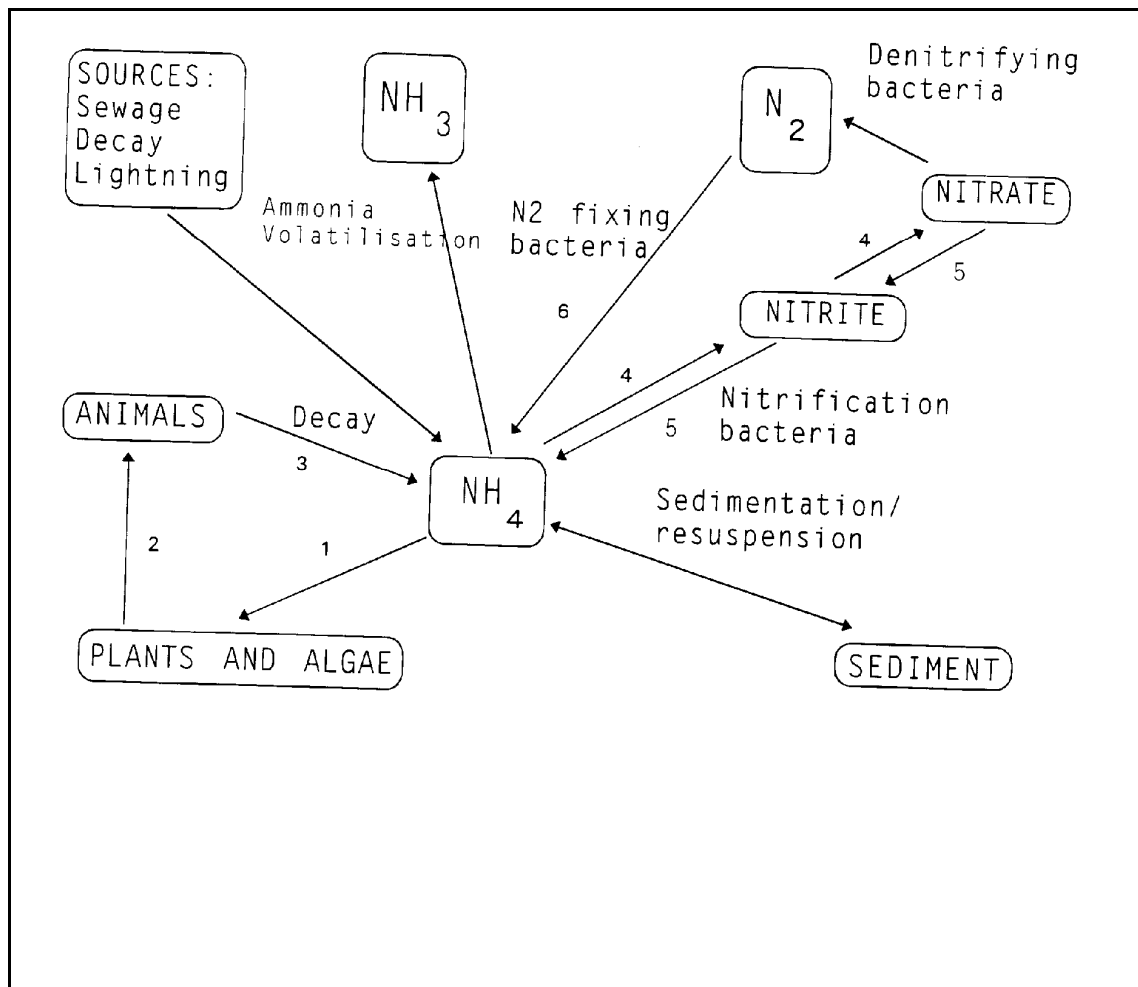


Figure 6: The instream nitrogen cycle.

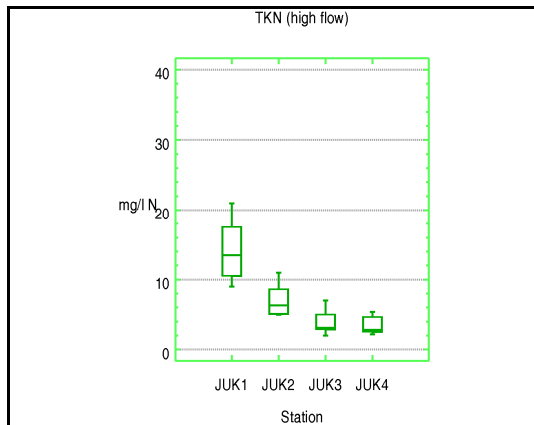


Figure 7:Box and whisker plot of the TKN concentration wrt distance downstream during high flow (summer) period.

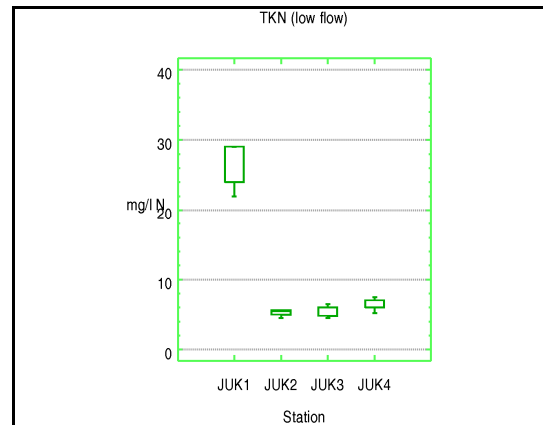


Figure 8:Box and whisker plot of the TKN concentration wrt distance downstream during the low flow (winter) period.

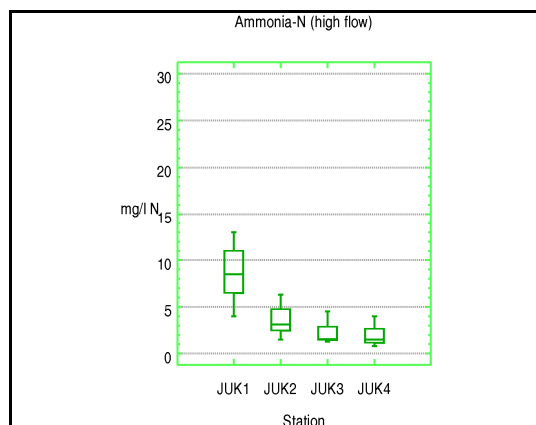


Figure 9:Box and whisker plot of ammonia concentration wrt distance downstream during the high flow (summer) period.

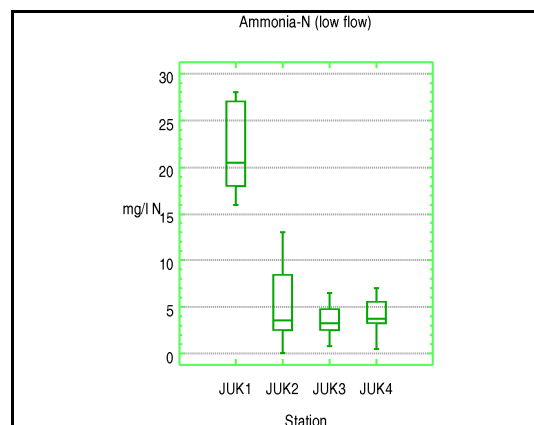


Figure 10:Box and whisker plot of ammonia concentration wrt distance downstream during the low flow (winter) period.

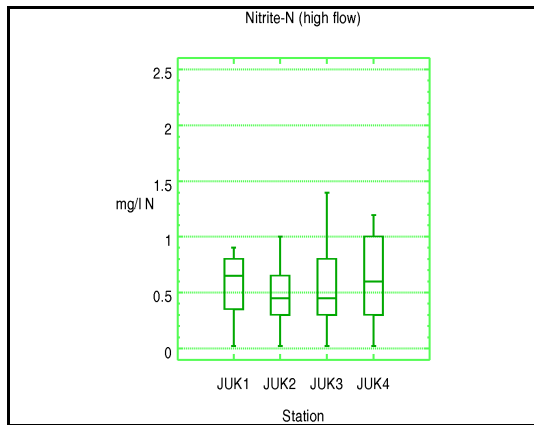


Figure 11:Box and whisker plot of the nitrite concentration wrt distance downstream during the high flow (summer) period.

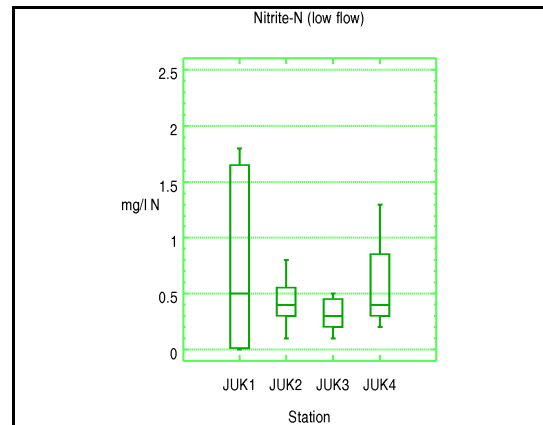


Figure 12:Box and whisker plot of the nitrite concentration wrt distance downstream during the low flow (winter) period.

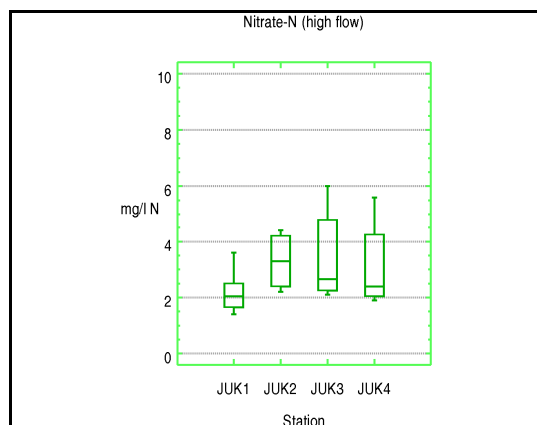


Figure 13:Box and whisker plot of the nitrate concentration wrt distance downstream during the high flow (summer) period.

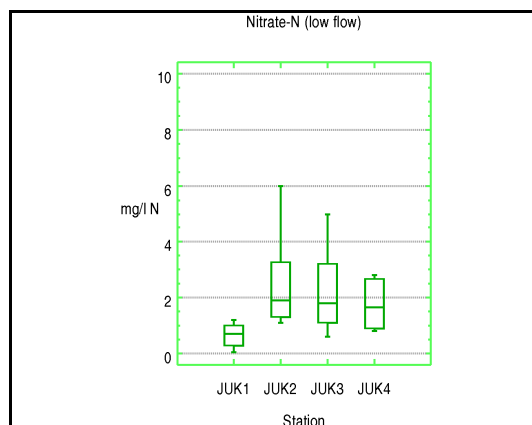


Figure 14:Box and whisker plot of the nitrate concentration wrt distance downstream during the low flow (winter) period.

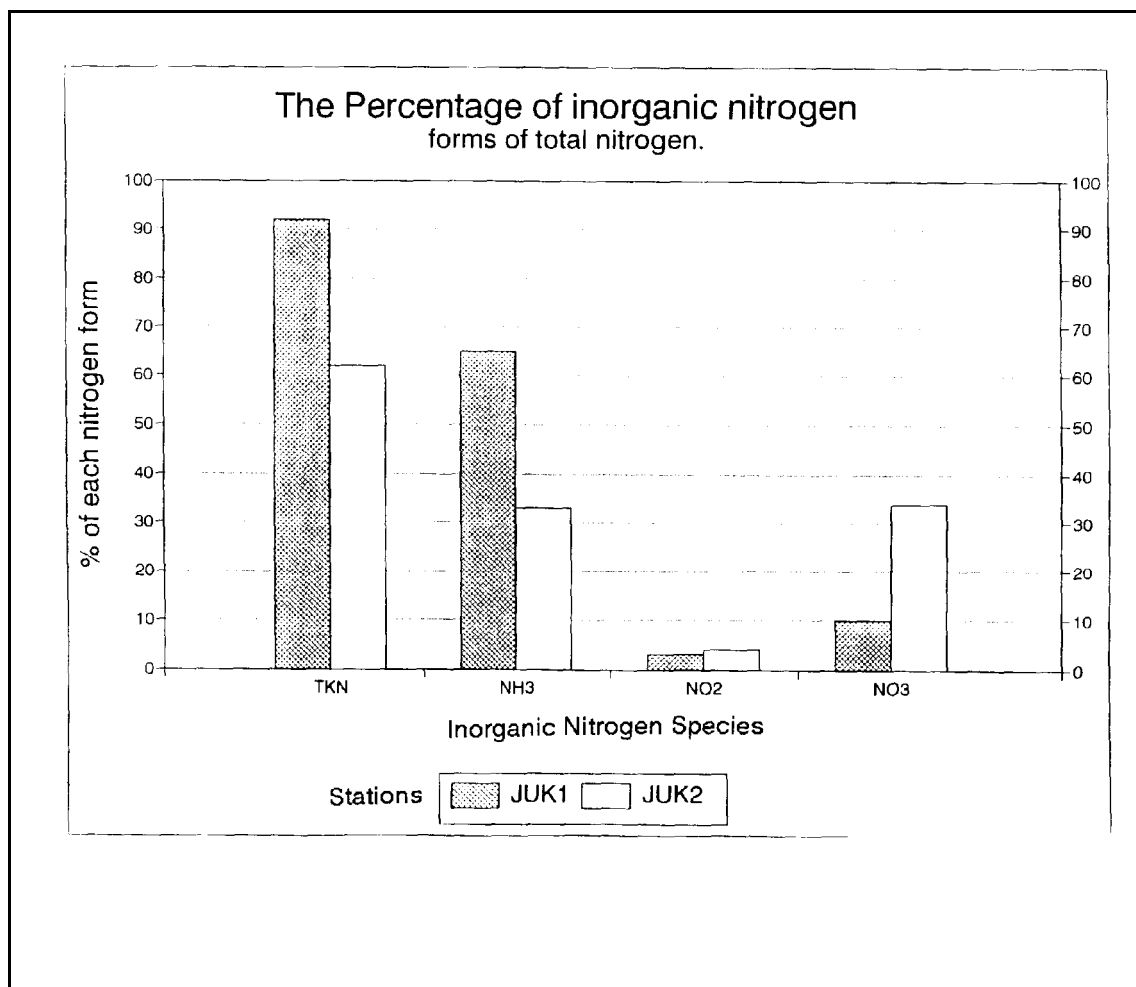


Figure 15:Box plot of the percentages of each nitrogen species makes of the total inorganic nitrogen concentration.



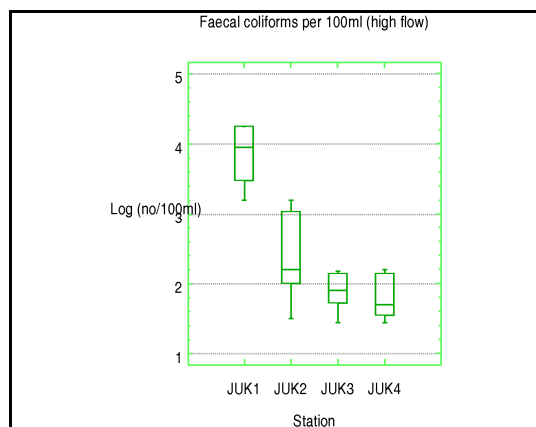


Figure 16:Box and whisker plot of the faecal coliform concentration wrt distance downstream during the high flow (summer) period.

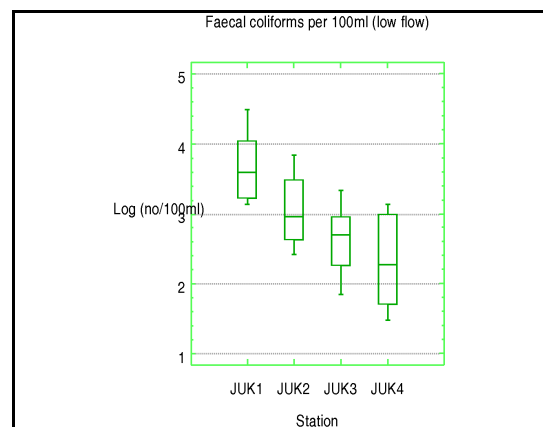


Figure 17:Box and whisker plot of the faecal coliform concentration wrt distance downstream during the low flow (winter) period.