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DEPARTMENT OF WATER AFFAIRS

SOUTH WEST AFRICA/NAMIBIA

LITERATURE SURVEY: WATER QUALITY CHANGES DURING THE LONG DISTANCE TRANSFER OF WATER IN PIPELINES AND CANALS WITH SPECIAL REFERENCE TO THE EASTERN NATIONAL WATER CARRIER.

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REPORT NO: 85/8

APRIL 1985

"THERE ARE NO GENERALLY ACCEPTED, TRIED AND TESTED SCIENTIFIC HYDROBIOLOGICAL METHODS FOR THE PREDICTION OF THE ECOLOGICAL CONSEQUENCES OF LARGE SCALE HYDRAULIC ENGINEERING WORKS"

(Romanenko et al 1980)

1. INTRODUCTION

A 700 km long Eastern National Water Carrier (ENWC) is presently being constructed by the Department of Water Affairs to supply water from the Okavango River, the Karstveld boreholes and other surface sources via a series of pipelines, open canals, inverted syphons and storage impoundments to meet some of the future water demands in the interior of South West Africa/Namibia.

During such long distance water transfers both the quality of the water being transported and the materials used in the construction of the carrier can be adversely affected and influence the operation and maintenance of the scheme.

A literature survey was carried out to obtain information on the effects of long distance water transfer. Although much of the published work on the subject is not strictly pertinent to South West Africa/Namibia, general inferences can be drawn to serve as a basis for recommendations.

This report is a discussion of the information obtained which is relevent to local circumstances and considers some control strategies applicable to problems likely to occur on the ENWC.

2. BRIEF DESCRIPTION OF THE ENWC

The Eastern National Water Carrier has been planned to eventually transport water from the Okavango River on the northern border of South West Africa to the interior of the country.

The project is being built in phases as follows:

Phase I: Von Bach and Swakoppoort dams, water treatment plant at Von Bach and pumping scheme to Windhoek from Von Bach.

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Phase II: Omatako dam, 95 km north of Von Bach dam and raw water pumping scheme to Von Bach dam.

Both of these phases have been completed and commissioned.

Phase III: Grootfontein to Omatako canal scheme and related groundwater abstraction scheme in the Grootfontein Karst area. The canal will be an open, concrete lined, parabolic section. Parts of the canal link, which is close to 300 km long, will consist of large diameter inverted pipe sections.

This phase will come into operation in about 1987 and will be completed in steps (i.e. increases in borehole abstraction capacity) during the next decade.

Phase IV: The final phase of the ENWC will be a 250 km pipeline and pumping scheme from the Okavango River to Grootfontein.

The ENWC's purpose is to augment and consolidate water supply to the interior of the country, mainly the central area, although links to the east and west are envisaged.

The ENWC will probably not be operated on a full capacity continuous basis, but will be used to meet shortfalls not supplied out of the more southern sources. This can be interpreted to mean that the three southern dams, viz. the Omatako, Von Bach and Swakoppoort dams will be operated on a high yield basis, with periodic shortfalls (depending on rainfall, runoff and water demand) being met from sources further north. Initially the bulk of the water demand will be met from present sources with the balance shifting to the northern sources in later years.

Water from the Okavango River will be pumped in an untreated form to the head of the canal at Grootfontein and then gravitate to the pump station at the Omatako dam. In the normal course of events water from the Okavango River or the Grootfontein Karst groundwater sources will not enter the Omatako dam, but will be pumped directly into Von Bach dam.

It is anticipated that the canal will, under normal operating conditions, be kept filled with water (the water level being controlled by longweirs) and a minimum base flow to supply minor off-takes en route.

3. BIOLOGICAL ASPECTS OF WATER QUALITY DECLINE

3.1 PROBLEMS IDENTIFIED BY THE LITERATURE SURVEY

Biological problems are those caused by living organisms or organic materials. The main problems identified by the literature survey were water quality deterioration, excessive algal growth and disease transmission. The nature and intensity of these problems are determined by the biology of the source water and by the design features and operational procedure of the water carrier.

Living organisms and organic material have caused significant operational and water quality problems in large water supply schemes elsewhere. Several general articles (1-3) and books (4) have been published on long distance water transfer. The more pertinent literature deals with the problems encountered during long-term studies on: the Israel National Water System (5-11); the inter-basin canals and pipelines in the Ukraine and Siberia, USSR (12-25); irrigation canals linked to the Nile in Egypt (26-28) and Sudan (29-32); South African irrigation canals (33-36) and inter-basin tunnels (37-39,59-62); bilharzia transmission in Southern Africa (37-45) and elsewhere (46-50,55-58-69); navigation canals in Germany (52,53); and fish entrainment into water carriers (59-67).

Few of the articles obtained deal with biological problems in pipelines, therefore this report deals largely with problems encountered in open canals. The most intensive studies on the biological aspects of water quality decline in canals have been done in the Ukraine. Although climatic conditions in South West Africa/Namibia are very different to in the USSR, some of the principles established during these studies are applicable here.

The biological problems associated with long distance water transfer can be divided into those caused by decomposing organic material (biological pollution), living plants and living animals.

3.1.1 BIOLOGICAL POLLUTION

The main cause of water quality deterioration in an artificial water carrier is biological pollution.

In pipelines, biological material from the source water which cannot survive the adverse conditions inside the pipe, subsequently decomposes and causes a decline in water quality. As very little self-purification can occur inside a pipeline, the problem is often more pronounced in pipes than in canals. However in large water supply canals biological pollution can increase the cost of water purification.

In canals, water quality deterioration occurs as follows: Biological material may be introduced with the source water, with surface runoff or as wind-blown debris, and either decomposes or becomes established in the artificially created aquatic habitat. If, for example algae becomes established it will follow a seasonal growth pattern dependent on temperature, nutrient availability and water clarity, - plants require light for photosynthesis. The algal mass can physically obstruct flow in the canal, but the main problem occurs when the algae die and decay.

Decomposition is the main biological cause of water quality deterioration in a water carrier. The decomposing biological material releases substances which can impart undesirable tastes and odours to the water, and increases the concentration of dissolved organic matter i.e. enriches the water to unacceptable levels. Further decomposition is usually associated with an increase in the abundance of heterotrophic and coliform bacteria and a decrease in dissolved oxygen concentrations.

Biological pollution in canals can also be of terrestrial origin. In the 473 km long Irtysh-Karaganda Canal in Siberia, most biological pollution is from the allochtonous input of saltworts, terrestrial plants which are blown into the canal in autumm (23). In the 100 km long Northern Donetz - Donbass Canal in the Ukraine, the decomposition of filamentous benthic algae growing in the lined canal causes water quality deterioration equivalent to the pollution caused by the sewage effluent from a city with 200 000 to 300 000 inhabitants (20).

3.1.2 BOTANICAL PROBLEMS

Botanical problems are caused by algae and higher plants, termed macrophytes. Excessive aquatic plant growth can influence the efficient operation of water transfer and storage systems, and, as already mentioned, can be the cause of biological pollution.

Most of the documentation on the deterioration of water quality over long distances deals with unlined and lined open canals (12-20, 23-29, 31-35, 43,44, 47,48).

Unlined or gravel canals provide a suitable substrate for aquatic macrophytes to take root (16, 17, 23, 25, 31, 43). A local example is found in certain sections of the Ombalantu canal in Owambo (31) where rooted aquatic plant species such as Potamogeton and Lagarosiphon (oxygen weed) occur. Other examples include the North Crimean Canal (23,25), and irrigation canals in Sudan (31). Aquatic macrophytes should not cause any problems in the cement-lined canals of the ENWC.

In lined canals blue-green algae, diatoms and filamentous green algae are potential problems.

3.1.2.1 BLUE-GREEN ALGAE (CYANOPHYTES)

In enriched standing water blue-green algal blooms can impart unpleasant tastes and odours to the water. An algal bloom can be defined as a massive seasonal occurance of algae usually associated with the availability of nutrients from the sediments when all the water in an impoundment is at the same temperature allowing the density stratification to break down and the waters to mix.

One strain of the cyanophyte species Microcystis aeruginosa contains a toxin which causes gastro-enteritis in humans, liver damage in primates and rodents and if consumed in large quantities can kill livestock. This toxin cannot be removed by conventional purification methods.

Cyanophytes can develop in canals containing stagnant water, but are usually introduced with the source water. This is more likely to be a problem in canals receiving water from an impoundment than those receiving water directly from a river. During periods of algal bloom in reservoirs, large amounts of algae may enter canals and being unable to survive in flowing water the algae decomposes causing a marked decline in water quality (12,13, 16-19).

In Israel, the annual Peridium algal bloom on Lake Kinneret (The Sea of Galilee) causes hundreds of tons of organic matter to settle in storage reservoirs in the Israel National Water System. This organic material decomposes causing oxygen depletion in the reservoir sediments and the release of nutrient minerals. Under these conditions the filamentous algae Oscillatoria chalybea develop. Oscillatoria impart an unpleasant musty taste and odour to the water supplied by the water carrier. This is an example of an algal bloom in the source water indirectly affecting the water quality in the carrier (5-9).

3.1.2.2 DIATOMS

With favourable conditions diatom blooms develop and substances released during the decomposition of these blooms can cause taste and odour problems. In the Ukraine, the annual development of a planktonic diatom bloom of the species, Stephanodiscus hantzchii, causes a sharp deterioration of water quality in the Severskiy-Donetz-Donbass canal (15-18).

3.1.2.3 FILAMENTOUS GREEN ALGAE

The most serious algal problem in lined canals is that of filamentous green algae which develop preferentially on the sides of canals lined with a hard facing such as concrete. To flourish these algae require a hard substrate, clear water, a moderate flow rate of 0,2 m/s - 0,7 m/s (17) and sufficient concentrations of dissolved nitrogen and phosphorus (14, 16-20, 33-36).

In the Transvaal, filamentous algae have caused problems in irrigation canals leading water from Hartebeespoort, Roodeplaat and Grootdraai Dams (33-36). Cladophora, a filamentous algae, reduced the flow rate in these irrigation

canals to such an extent in summer, when the demand for irrigation water was greatest, that the water supplied was insufficient and crop losses resulted (34). The attached algal strands of between 11 and 30 m increased the roughness coefficient of the canal resulting in a reduction of maximum water supply capacity from 5,7 m^3/s to as low as 2,7 m^3/s. The reduced supply capacity resulted in the submergence of longweirs, an underestimation of water supplied due to increased water levels at calibrated pressure weirs, and water losses due to spillage out of the canal (35)(36).

In the Ukraine, the Donetz-Donbass Canals show a clear quantitative relationship between water quality deterioration (measured as the concentrations of organic matter and heterotrophic bacteria), and the amount of filamentous algae growing on the side of the canal (14,16-20).

3.1.3 ZOOLOGICAL PROBLEMS

Zoological problems in water transfer systems are caused by both aquatic and terrestrial animals. Most of the literature obtained deals with the ecological and health hazards of artificially linking different watersheds. A few articles document the effect of canals on game migration and mortality (32, 52,53), and only one dealt with animals (snails) causing a physical obstruction to flow in pipelines (22).

The main zoological problems are the introduction of alien species, disease transmission, game mortality and flow obstruction.

3.1.3.1 THE INTRODUCTION OF ALIEN SPECIES

Pipelines, canals and tunnels which link different catchment areas are often instrumental in the introduction of plants and animals to new environments. Such introductions are frequently, but not necessarily detrimental to the invaded systems. But even if no detrimental consequences can be foreseen, the inadvertant transfer of aquatic animals via man-made routes remains undesirable both ecologically and conservationally.

Fish are able to enter carrier systems similar to the ENWC, even through apparently devastating physical pumping and screening processes (60). This is evident from case histories such as the Orange - Fish Tunnel (59-62) and the Israel National Water System (7). A local example is in Owambo where fish entered the Olushandja Dam from the Cunene River via the screened Calueque inlet, (parallel bars 50 mm apart) pumping station and canal system (65). Fish are more likely to survive this short pumping main than the much longer proposed Rundu-Grootfontein one.

Fish can enter a carrier at any life-stage i.e. egg, fingerling or adult. Eggs and fingerlings probably constitute the major source of introduction to carrier systems (63). It is generally assumed that larval fish are passively transported by currents, but recent work in the USA has shown that the active movement of fingerlings is also an important consideration at water intake points (64).

No information is available at present on the entrainment and transfer of eggs and larvae of Southern African freshwater fishes. However some experiments are being done on adult fish entrainment in the Orange-Fish Tunnel which allows Orange River species accesss to the Great Fish and Sunday River Systems (59-62).

Similarly the Okavango-Grootfontein link could aid the southward dispersal of Okavango fish species. A separate study on the possible introduction of Okavango fish into the ENWC was conducted by this section in 1984. The results confirm that the river supports a large and diverse fish community within a variety of habitats and that the Okavango fish species are distinctly different from those occurring in waters in the interior of South West Africa/Namibia. Although the ecological tolerances and preferencs of most of the Okavango species are not conducive to their becoming established in the ENWC, a few rheophilic (current-loving) species could enter the carrier, and several more generalized fish could establish viable populations in the receiving and intermediate components of the ENWC (54,66).

3.1.3.2 DISEASE TRANSMISSION

Should the source water contain organisms which are detrimental to the health of man or his livestock, the resultant water-borne diseases may be transmitted to previously uninfected areas via an artificial water carrier.

The spread of waterborne diseases in developing countries can be linked to irrigation schemes. The construction of the Aswan High Dam and its network of irrigation canals, increased the prevalence of bilharzia-carrying snails from 5% to 80% (26, 27). The Volta Lake impoundment in Ghana, and the Sennar Dam in Sudan which serves the two million acre Gezira Irrigation Scheme are further examples where major water schemes increased the incidence of bilharzia despite attempts at control (29,30,49,50). It is feared that the 360 km Jonglei canal presently being constructed in Sudan to divert the White Nile past the Sudd swamps will aid the spread of bilharzia (32).

a) BILHARZIA

The water-borne disease most likely to be transmitted via the ENWC is bilharzia or to use the medical term schistosomiasis. Bilharzia affects more than two hundred million people in 71 countries and is considered one of the five most prevalent tropical diseases by the World Health Organization. This disease which infects various mammals, including man and domestic animals, is caused by blood-flukes of the genus Schistosoma. The two species, infecting man, which occur in the Okavango River are, Schistosoma haematobium which causes bladder or urinary bilharzia and S. mansoni which causes intestinal bilharzia, they are carried by the intermediate snail hosts, Bulinus globosus and Biomphalaria pfeifferi respectively (49,57).

The transmission of bilharzia to previously uninfected areas depends on the life-cycle of the parasite and the establishment of suitable habitats in the new region.

The life-cycles of these blood flukes are characterized by two parasitic stages, one occuring in a molluscan intermediate host (a snail), and one in a mammalian primary host (man), and two free-living larval stages, the miracidia and cercaria stages which occur exclusively in water.

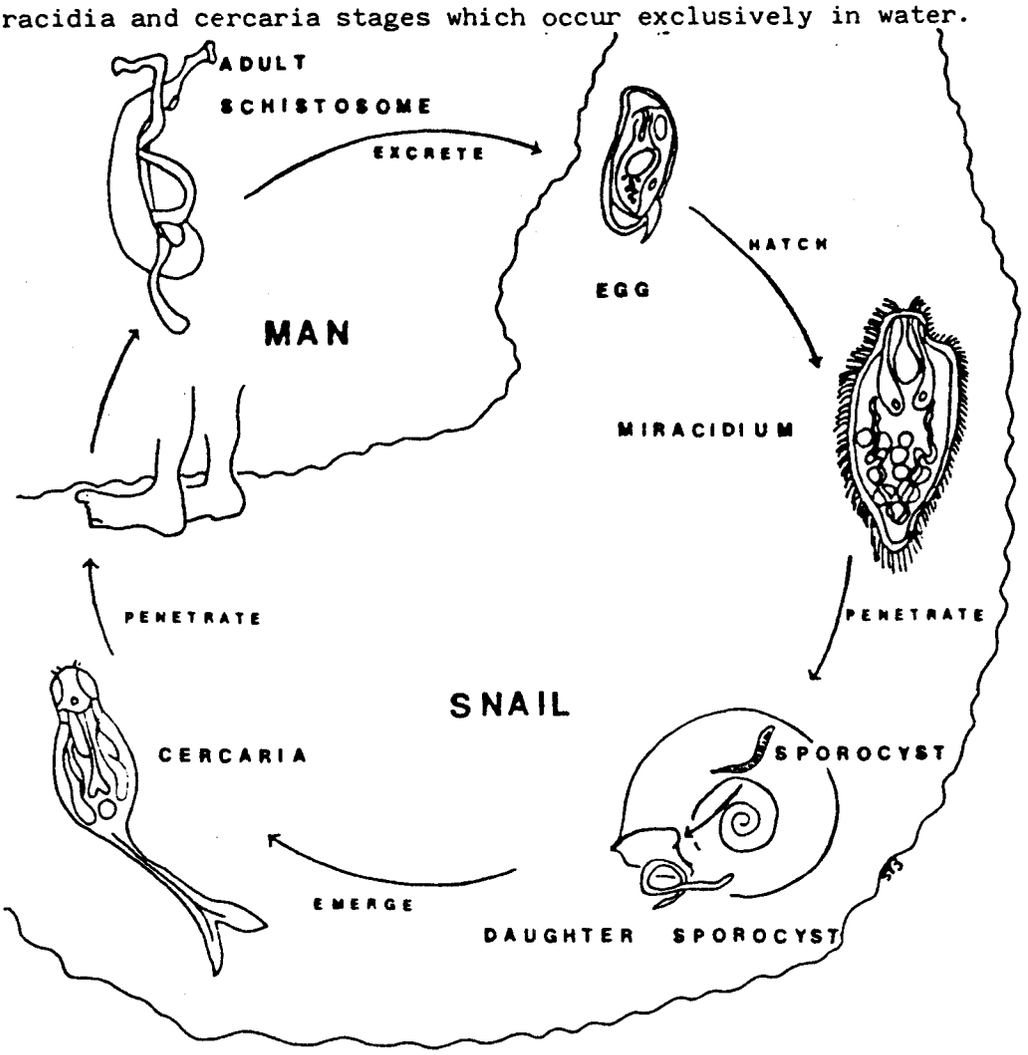

Figure 1. A diagram of the Life-Cycle of Schistosoma mansoni.

Figure 1, illustrates the life-cycle of Schistosoma mansoni, which occurs in Kavango and causes intestinal bilharzia. The adult thread-like parasites live in the blood vessels in the walls of the small intestine, hence their name "blood-flukes". The females lay between 300 and 3 000 eggs daily. These spined eggs erode through the intestinal wall, in severe cases this causes bleeding, and are passed out with faeces. On contact with water the motile meracidia hatch. This larval stage can only survive for 24 hours in the absence of its specific host snail, Bulinus globosus. On encountering susceptible snails the miracidia penetrate their soft bodies and form local sporocysts, which by asexual reproduction produce thousands of redia which migrate to the internal organs where they encyst. These cysts can remain in the snail from 17-36 days in summer and for as long as five months in winter.

The release of the cercaria is triggered by temperature, usually when the water temperature reaches 22°C. The cercaria stage can only survive for 48 hours after emerging from the snail. Upon making contact with human shin, the cercaria penetrate the skin by the secretion of proteolytic (protein-destroying) enzymes and vigorous movement. Immediately on entering, the parasites are changed into schistosomules which are carried in the bloodstream to the liver, from where they migrate against the flow of blood to the small blood vessels in the intestinal walls (49, 50, 51)

Although Bulinus globosus is also the intermediate host of Schistosoma mattheei which causes bilharzia in livestock and several species of game, this parasite has not been found in Kavango (70).

When considering the likelihood of bilharzia transmission to previously uninfected areas it is important to know what the habitat preferences of the host snails are. For example, when the Tugela - Vaal scheme was planned the possibility that bilharzia snails might enter the Vaal - Orange system was investigated and it was found that the temperatures in the pipeline and the receiving Sterkfontein dam would be too low (below 15° C) for the snails to reproduce (37-41,56).

There have been many studies both in the laboratory and in the field to establish the relationships between the ecology of the host snail habitats their life-cycles and behaviour.

Biologically the ideal snail habitat has few snail predators and plenty of vegetation. Plants serve as a food source, provide a site to lay eggs, provide shelter and to some extent prevent snails from being swept downstream. Studies in Ghana indicate a strong correlation between the presence of Bulinus snails and Ceratophyllum, a submerged aquatic plant growing in the marginal water of Volta Lake (46).

The abiotic (non-biological) factors which determine the suitability of a particular snail habitat are current velocity, water temperature and to some extent water chemistry.

Host snails have a remarkably narrow tolerance to current velocity. They tend to occur in quiet waters or very slowly flowing waters (velocities not greater than 0,3 m/s). At this critical limit of 0,3 m/s the snails require all their metabolic energy to oppose the current and at greater velocities they are dislodged and swept downstream.

The effects of water chemisty and temperature, together with the biological ability to withstand dessication can best be shown by comparing the environmental tolerance levels of the two host snails, Bulinus globosus and Biomphalaria pfeifferi. The former is generally better suited to temporary waters and the latter to more stable waters. In general snail species associated with temporary water have a greater tolerance to fluctuating chemical conditions than species occuring in permanent waters. B. globosus is tolerant of a wider range of calcium and bicarbonate concentrations than B. pfeifferi (56).

B. globosus reproduces best at 25°C, whilst B. pfeifferi reproduces well at any temperature between 20°C and 27°C. This means that B. globosus can multiply rapidly under optimal conditions, however brief. This is a selective advantage which enables the snails to make the most of short periods of favourable conditions in temporary waters. In contrast B. pfeifferi reproduction remains constant over a 7° C temperature range suggesting an adaptation to the stable thermal conditions in more permanent waters.

Studies done in Egyptian irrigation canals show that both the genera Bulinus and Biomphalaria could survive a drying period of 40 - 50 days and that they laid viable eggs immediately after the canals were refilled (58). Further studies elsewhere show that Bulinus is able to withstand longer periods of dessication (of up to a year) than Biomphalaria, although no Southern African B. pfeifferi have been recorded aestivating thus under natural conditions (56).

Both intestinal and urinary bilharzia are prevalent in the Kavango. The free-living stages would be unlikely to survive the Rundu-Grootfontein pumping main, but the infected host snails might. There is little chance that these snails will become established in either the canal or in the dams

of the ENWC. The snails cannot tolerate water velocities greater than 0,3 m/s, whilst the rate expected in the canal on the ENWC will be nearer 0,9 m/s. Further, the snails require plenty of aquatic vegetation, any plant growth in the canal will be discouraged whilst the fluctuating water levels in the dams will effectively prevent the establishment of marginal vegetation. As the free-living stages are unable to survive chlorination, there is no risk of infection to the consumer once the water has been purified. It is not as easy to predict the chances of bilharzia transmission to the intermediate or storage components of the ENWC, here stock-watering points in Hereroland present a possible foci of infection.

b) FASCIOLIASIS

The only other confirmed snail-borne disease which occurs in the Kavango is fascioliasis. Fasioliasis is a stock disease which can cause financial loss to farmers as abattoirs reject infected cattle livers. Fasciola is a liver-fluke which inhabits the bile-ducts and gall bladders of grazing animals which become infected by ingesting vegetation carrying encysted metacercariae. Eggs are passed out with the faeces and can remain viable for several months, their development is dependent on at least a surface film of water and an adequate temperature. The stimulus of light appears to be necessary for the successful emergence of the miracidia which swim freely and require a suitable snail host of the genus Lymnaea in which to develop further. Within the snail, asexual multiplication occurs through successive larval stages, sporocyst, rediae and finally cercariae. The cercariae are shed after 21 days at 27° C, but development takes longer at lower temperatures. The subsequent behaviour of the cercariae is in striking contrast to that of schistosome cercariae, for within an hour of emergence from their snail host they encyst on a suitable plant surface and play no direct role in locating a mammalian host (49).

Both the snail host, Lymnaeae natalensis and the parasite Fasciola gigantica are present in the Okavango river (57). Figure 2 illustrates the life-cycle of this liver-fluke.

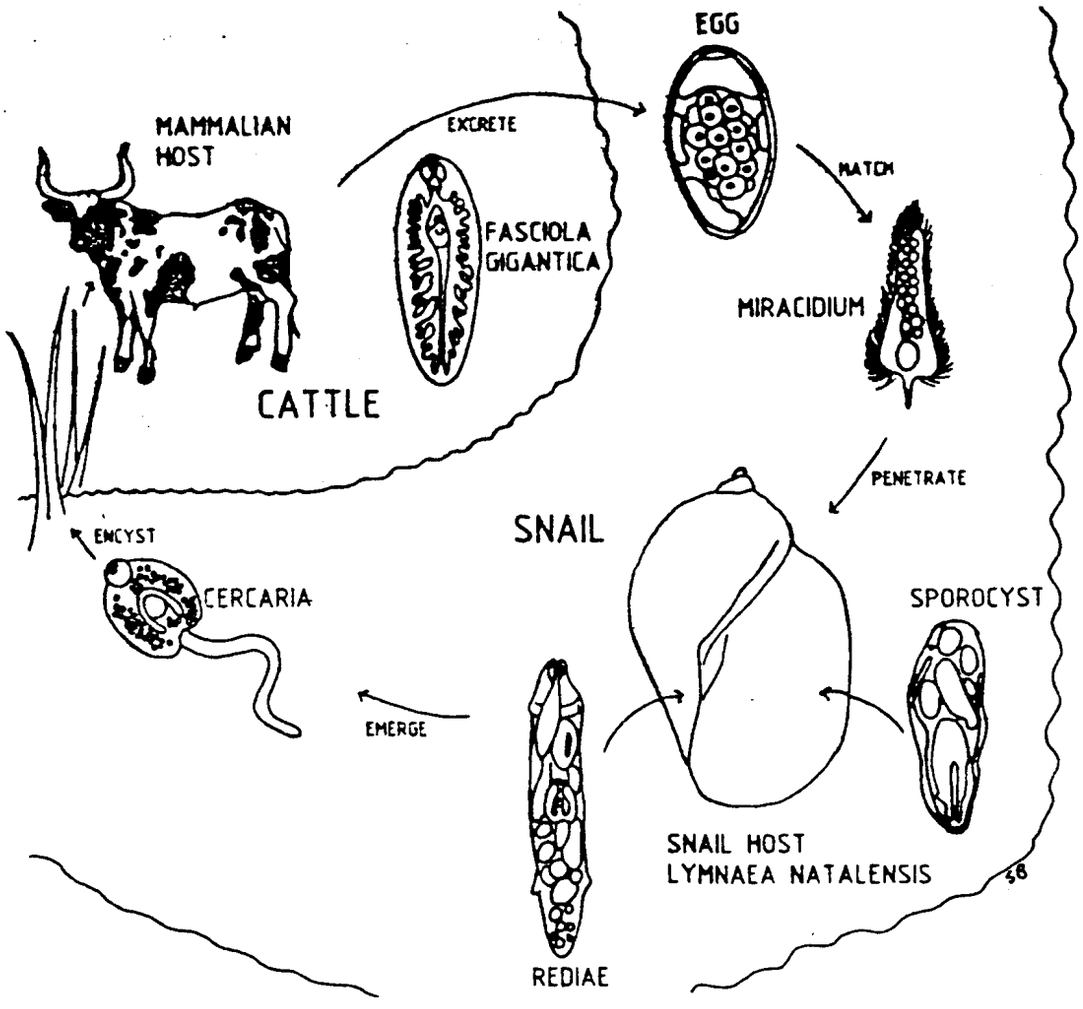

FIGURE 2. A Diagram of the life-cycle of Fasciola gigantica.

3.1.3.3 GAME MORTALITY AND MIGRATION

Long open canals are often an artificial barrier to seasonal animal migration (32, 52, 53). In East Africa canals cause animal losses. In Tanzania, a canal which crosses a section of the Serengeti Game Reserve disrupts annual game migrations, causing animals to drown in the confusion of crossing and young to be separated from the adults. Further, there have been recent reports of mass drownings of both game and domestic stock in the Jonglei Canal in Sudan.

Nomadic tribes need to cross the Jonglei canal with their herds twice a year in search of grazing and the wild taing horses also have to cross the canal twice during their annual migration, once at the start of the dry season when the females are pregnant and again four months later with young calves (32).

In the Federal Republic of Germany, an investigation of the drowning of wild animals in navigation canals showed that although all the game species tested could swim sufficiently well to cross the canals, they drown because they are unable to climb out (52,53). Although the canal on the ENWC is much narrower and not as deep as the "Mittellandkanal" in Germany, the steep sides still make it an effective animal trap.

The ENWC canal is fenced off to prevent domestic stock entering the area. To some extent this fence will also serve to keep out wild animals. Since construction began, several reports have been received of animal mortalities in completed sections of the canal. This, and the possible influence of the canal on game migration routes, are being investigated.

3.1.3.4 FLOW OBSTRUCTION

Living organisms may become established inside pipelines and cause an obstruction. In the Ukraine, Dreissena snails invaded irrigation pipelines, and by their physical presence reduced the carrying capacity of the pipes. This resulted in crop losses, increased pumping costs, and the shells of dead snails blocked filters and sprinklers (22). Similar problems have occured in South Africa, but have not been documented.

3.2 CONTROL METHODS

There is much literature dealing with various control methods for problems related to long distance water transfer. The particular method used depends on the urgency of the problem, the funds available and the seriousness of the problem.

Biologists and engineers must carefully select a control strategy that will effectively eliminate, or at least reduce to acceptable levels, any biological problems encountered on the ENWC. Before such a control strategy can be incorporated into the design and operation of the ENWC, further research is necessary to determine its effectivenes under local conditions.

3.2.1 BIOLOGICAL POLLUTION

The degree of biological pollution likely to occur in a long distance canal can be predicted to some extent.

Based on long-term observations (15 years) Russian scientists have drawn up a biological classification of canals (Table 1). This classification takes into account the water source, the design and hydrology of the canal and is used to predict the development of plants and animals in the canal, the rate of organic decomposition and the self-purification potential of the canal.

The self-purification potential of a canal depends on the balance between the water-purifying action of plants and their role in causing biological pollution. As mentioned earlier, the quality of water often deteriorates significantly when algae and higher plants develop abundantly and then die and decompose, so increasing the amount of suspended organic matter, decreasing the amount of oxygen in the water and causing unpleasant tastes and odours to develop.

According to the classification reproduced in Table 1, the canal on the ENWC obtains water from a lowland, nutrient-poor river, has a cement lining and a flow rate greater than 0,7 m/s. Therefore the water quality should not deteriorate significantly with distance, filamentous algae may develop, but the rate of self-purification should balance the rate of decomposition, there should be little silting, no rooted aquatic plants and a limited fauna in the canal. This means that provided the canal is flowing, there should be no need to control biological pollution in the ENWC.

If the canal on the ENWC is operated on a continous flow basis, it is unlikely that there will be significant biological pollution, at least in the initial years of operation. But any future increase in agricultural activity in the catchment area of the Okavango River, could cause an increase in the nutrient concentrations in the runoff from fertilized fields, such enriched source waters could promote algal blooms and the establishment of filamentous algae.

However at flow rates less than 0,2 m/s or if the canal should remain stagnant for several months, when there is no immediate demand for water in the storage impoundments, the situation alters drastically. Silt will accumulate in the canal, both planktonic and benthic algae will be abundant especially in the summer, bacteria will be abundant but zooplankton densities will remain low, submerged aquatic macrophytes will develop (the number of plants will depend on the degree of silting), and the rate of decomposition of organic matter will remain moderate, but the amount of organic material available for decomposition will increase due to the improved conditions for growth. Thus if water is stored in a non-flowing canal, the water quality can be expected to deteriorate with time and massive algal blooms may occur in spring and autumn. In lined canals the amount of filamentous algae is expected to increase in summer and as this is accompanied by their death and decay, will cause marked water quality deterioration (17).

The most effective method of control would be to avoid keeping stagnant water in the canal for long periods of time. If this is not practical from an engineering point of view, it may become necessary to control excessive algal or macrophytic growth.

TABLE 1 : CLASSIFICATION OF CANALS IN TERMS OF HYDROLOGICAL CONDITIONS CONTROLLING WATER QUALITY CANALS ORIGINATING IN LOWLAND RIVERS

WATER FLOW	HYDROBIOLOGICAL FACTORS	LINED	
		SILT-FREE	SILTED
Slow	Phytoplankton	Very abundant over entire route	Very abundant; moderate during heavy summer overgrowth
	Bacterioplankton	Abundant	
	Zooplankton	Low	
0,2 m/s	Phytobenthos	Abundant	
	Higher aquatic plants	Occasionally, isolated thinned clumps, mostly of submerged plants.	Abundant; belt of submerged vegetation down to depth of 2m; fragments of aerial-aquatic plant groupings
	Zoobenthos	Moderate	
	Rate of mineralization of organic matter	Low	
Moderate	Phytoplankton	Very abundant over entire route	Very abundant; moderate during heavy summer overgrowth
	Bacterioplankton	Abundant	
	Zooplankton	Low	
	Phytobenthos	Very Abundant	
0,2-0,7 m/s	Higher aquatic plants	Occasionally, isolated thinned clumps, most of submerged plants.	Abundant, belt of submerged vegetation to depth of 1,5 m; fragments of subaerial-aquatic plant groupings
	Zoobenthos	Moderate	
	Rate of mineralization of organic matter	Weak	
Fast	Phytoplankton	Abundant at beginning of canal, then becomes depleted	
	Bacterioplankton	Moderate	
	Zooplankton	Very Low	
	Phytobenthos	Moderate; microphytobenthos dominates	No silting
0,7 m/s	Higher aquatic plants	Occosional aerial-aquatic plants	
	Zoobenthos	low	
	Rate of mineralization of Organic matter	Moderate	

3.2.2 EXCESSIVE PLANT GROWTH

3.2.2.1 FILAMENTOUS GREEN ALGAE AND AQUATIC MACROPHYTES

In a cement-lined canal such as the ENWC attached filamentous green algae are a potential problem. Similar methods are used to combat both filamentous algae and macrophytes.

a) PHYSICAL CONTROL

Manual removal of algae is time consuming and labour intensive. This method was used on the irrigation network from Hartebeespoort Dam which consists of two main canals, 78 and 56 km long, of 118 km of secondary branch canals and 290 km of distribution canals. To clear these of Cladophora required a labour force of 40 unskilled workers for about four months of the year at a cost of R40 000 per annum (34).

It might be appropriate to consider such a labour intensive method for the ENWC canal. As the water is not enriched, any plant growth would be slow and could be effectively controlled by regular manual clearing by an unskilled maintenance team.

The research team at the Hydrological Research Institute in Pretoria found that Cladophora in irrigation canals could be controlled effectively, if the canal is allowed to dry out for eight hours each month. In the case of the irrigation canals in the Transvaal this was not a practical solution as the water supply to the lands would be reduced at a time of maximum demand (32).

On the ENWC periods of desiccation followed by manual clearing would be an effective and relatively cheap means of controlling plant growth at times when there is no immediate water demand.

b) CHEMICAL CONTROL

Chemical control using sulphuric acid and copper sulphate proved to be an effective short term solution in the canals below Hartebeespoort Dam.

The Cladophora could be successfully controlled by simultaneously lowering the pH of the canal water from pH 8,3 to 6,5 with commercial sulphuric acid and dosing with copper sulphate to a final concentration of 0,5 mg/l copper in the canal water for a period of eight hours. Dosing operations were effective for six weeks and resulted in an annual saving of R5 000 per year compared to manual removal (34).

Chemical control should only be used on the ENWC as a short-term solution under emergency conditions. The ecological after-effects of chemical manipulation cannot always be predicted and may be detrimental to the limnology of other components on the ENWC. Further, the addition of sulphuric acid can cause deterioration of the concrete lining in the canal.

c) BIOLOGICAL CONTROL

In many countries, herbivorous fish are used to control aquatic plant growth in canals. On the Israel National Water System, grass carp (Ctenopharyngoden idella), are used to combat submerged plants in the reservoirs. Potamogeton, Najas (saw weed) and Chara were effectively eliminated and no secondary effects such as colouring of the water nor an increase of nutrients were observed.

In Eqypt, grass carp are specially breed at Ismailia University to combat aquatic weed problems in the irrigation canals in the Nile Delta (28). A further example is in the Everglades in Florida where grass carp are used as biological control agents to check the invasive weed Hydrilla (668).

In South Africa, researchers at the Hydrological Research Institute are experimenting with various fish species to control Cladophora in the Grootdraai Canal (33). Initial experiments were unsuccessful and more research is required to formulate a long term biological control programme.

From a management point of view it may be desirable to selectively introduce fish to the ENWC to serve as biological control agents. Should this need arise, it would be better to use Okavango fish species, than to risk introducing an alien such as grass carp, as both the canal and the Omatako Dam fall within the Okavango drainage system. The recent Okavango fish survey has identified several fish species which may be suitable for particular problems. For example Tilapia rendalli (Northern redbreast bream) which feed exclusively on aquatic macrophytes would possibly be suitable weed control agents in the canal. This would depend on their feeding behaviour and swimming ability in currents. At present there is a lack of data available on the swimming performance of Southern African freshwater fishes. In its natural habitat T. rendalli prefers a gentle current and shallow flooded areas with plenty of vegetation.

Further research is necessary on the biology of both the problem plant and the control agent before a biological control programme could be implemented on the ENWC and before any recommendations can be made on the optimum current speed which should be maintained in the canal system if fish are to be used. If well researched and properly implemented, biological control is the most effective long-term, ecologically sound method of controlling plant growth in canals.

3.2.2.2 BLUE-GEEN ALGAE

In the Israel National Water System, cyanophyte problems are controlled by an intergrated control strategy. The water is required for agricultural, industrial and domestic use and must thus be of a potable water standard. The treatment involves partial settling out of suspended matter in a settling reservoir, screening through 4 mm mechanical screens between the reservoirs and pipelines and chlorination allowing 0,2 - 0,3 ppm residual chlorine. This effectively removes all coliform bacteria, reduces turbidity and the concentration of suspended solids but does not prevent the growth of algae in the system. To combat the taste and odour problems caused by the blue-green algae, Peridium and Oscillatoria, three fish species are used, Tilapia aurea, Hypophtalmichtys molitrix (Silver carp) and Mugil capito (Grey mullet), to harvest the algae in the reservoirs (7).

3.2.3 ANIMAL-RELATED PROBLEMS

3.2.3.1 ALIEN INTRODUCTIONS

Recent surveys of the Okavango River by the Department of Water Affairs have identified several fish and mollusc species which could be detrimental if introduced to inland waters via the ENWC. These problems were discussed earlier in this report.
No literature could be found dealing directly with mechanisms used to prevent the entrainment of aquatic organisms, but some suggestions appear in departmental reports (54, 57).

To prevent animals entering the ENWC, grid-screens of appropriate mesh size to keep out fish, snails and water-borne debris can be used at all inlets to the water carrier. It is difficult to provide absolute recommendations on the screen-mesh size without knowing what hydrological constraints might apply. Complete effectiveness can only be achieved if the mesh is small enough to exclude fish eggs, fingerlings and young snails, but this would require a mesh size of less than 1 mm diameter. Such a small mesh size would be both impractical and easily blocked. As a compromise a mesh of 1-5 mm diamter would probably exclude the bulk of aquatic fauna including juvenile and small specimens, but would not totally eradicate the problem.

Similar screens at the entrance and exit points of each major component of the ENWC might be required to minimize inadvertant introductions at these points.

3.2.3.2 DISEASE TRANSMISSION

Recent work on the Okavango River confirmed that three snail-borne parasites and their host snails are present in the river. These are Schistosoma haematobium and Schistosoma mansoni which cause human bilharzia and Fasciola gigantica which infects cattle (57).

The spread of these diseases to other areas in South West Africa/Namibia depends on snails and parasites entering the ENWC, their survival in new habitats, the intensity of infection and whether their specific mammalian hosts have access to infected waters. These factors are influenced by both the life-cycle of the parasite and the retention time of the water in the Okavango-Grootfontein pipeline. The survival times of the free-swimming miracidia and cercaria life-stages are shorter than the expected water retention time in the pipeline, thus, in theory, the parasites should not survive in the closed pumping main. Conversely, the snails can survive centrifugal and hydraulic pumps (41), and remain infectious (carrying the parasite), inside the pipe for several weeks. Therefore it it is possible that infected snails can emerge unharmed from the proposed Okavango-Grootfontein pumping main and enter the canal and impoundments.

The control of schistosomiasis falls into four main categories, social, chemical, environmental and biological control.

a) SOCIAL CONTROL

As human behaviour plays an important role in the transmission of parasitic diseases, the ideal method of preventing the spread of bilharzis is to keep people away from the water. This is possible only if an alternative water supply exists. This method was recommended by Dr Pitchford when the problem of bilharzia in the Owambo canals was considered (43,44), but experience has shown that this is not always feasible, especially not in areas with high rural populations.

b) CHEMICAL CONTROL

The use of selective poisons to kill snails is the most widely used method of bilharzia control. In recent years the two molluscides, "Niclosamide" and "N-tritylmorpholine" proved to be particularly effective and are the chemicals favoured for snail control in Africa (49). Copper sulphate in concentrations of 15-20 ppm can also be used, but is ineffective in hard water and all vegetation has to be cleared before application (40).

In the Gezira Irrigation scheme in Sudan, the slow flow rates and abundance of aquatic weeds in the minor distribution canals provide an ideal snail habitat and site for bilharzia transmission. The molluscide, "Trifenmorph" was added to the main canal and the minor canals were hand sprayed. A concentration of 0,015 mg/l was sufficient to kill all the snails within a week (29). Several applications may be required for chemical control to be effective. In Brazil, the type of molluscides used failed to control the snail populations due to recolonization from temporarily dry adjacent breeding sites, which were overlooked during treatment (47). In Ghana chemical control, combined with mechanical clearing of weeds, reduced bilharzia transmission to an acceptable level in areas of human activity on Volta Lake (46).

Molluscides may have adverse side-effects on the environment unless they are thoroughly screened under local conditions and evaluated.

c) ENVIRONMENTAL CONTROL

Environmental control measures are aimed at creating a habitat which is unfavourable to either the schistosomes or their hosts. Slow-flowing, well vegetated irrigation canals provide an ideal snail habitat, whereas a rapid-flowing (greater than 0,3 m/s), narrow deep canal, with smooth concrete or plastic linings and no aquatic vegetation would be unfavourable to snails (48). Pipes too are usually effective in preventing snail colonization. Snails will not colonize areas without suitable vegetation, thus methods preventing plant growth in canals and impoundments will indirectly control bilharzia. In Volta Lake, regular fluctuations in water level are used to prevent the establishment of marginal vegetation and so control bilharzia transmission (46).

It is unlikely that bilharzia carrying snails will become established in either the canal or the dams of the ENWC. The flow rate in the canal is too rapid and the fluctuating water levels in the dams prevent the establishment of marginal vegetation.

d) BIOLOGICAL CONTROL

Natural enemies of disease-carrying snails include the Open-billed Stork, many African freshwater fishes and several invertebrate predators including ostracods, crabs, crayfish and insect larvae. Little work has been done in assessing their effectiveness as biological control agents (49).

On the Israel National Water System, two species of freshwater fish are used to eliminate snails, Myllopharyngodon piceus (Black carp) and Cyprinus carpio (Common carp) (7).

It is preferrable to use local biological control agents. The two mollusc-eating fish which occur in the Okavango River, Clarias ngamensis (Blunt-tooth catfish) and Serranochromis giardi (Pink bream), could possibly be used in the canal on the ENWC and in Omatako Dam (66). Further south, the common carp, although not indigenous, might be used as this fish already occurs in the Von Bach Dam (54).

3.2.3.3 SNAILS IN PIPELINES

In the Ukraine, snails blocking the pipelines were controlled chemically, using a concentration of 400-500 mg/l ammonium nitrate solution, sealing the pipeline for six days and then flushing the dead snails out (22).

3.2.3.4 GAME MIGRATION AND MORTALITIES

In the Federal Republic of Germany, shallow sloping vegetated bays and a variety of ledges and ramps are built at regular intervals on the canals to allow game to cross safely (52,53).

On the ENWC there are livestock crossings at regular intervals along the canal, but as these bridges are fenced off, there is no provision for game crossings and no means by which trapped animals can get out of the canal. This problem is being investigated with the co-operation of the Directorate of Nature Conservation. If warranted, structures such as crossings and ramps could be built into the canal (67).

4. PHYSICAL AND CHEMICAL ASPECTS OF WATER TRANSPORT

4.1 PROBLEMS IDENTIFIED BY THE LITERATURE SURVEY

Non-biological problems envisaged can be divided into two groups, viz: physical aspect sand chemical aspects.

4.1.1 PHYSICAL ASPECTS

The two most important physical parameters which affect water quality in long distance water carriers are suspended matter and temperature.

4.1.1.1 SUSPENDED MATTER

Soft water with little suspended matter may be corrosive to both metal and concrete surfaces of pipelines and canals. Turbid water i.e. water carrying a fairly high load of suspended sediment will not be corrosive, even if the water is soft, because of the protective layer which forms when the sediment particles deposit on the aquaduct surface (83). This does not apply to extremely high sediment loads of aqueous slurries where physical abrasion by the sediment can cause significant wear, for example in tests on steel pipes it was found that a 20% aqueous slurry of silica sand caused a high rate of wear, and electrochemical measurements confirmed that abrasive erosion was the main cause of metal loss (72). However, the water to be pumped in the ENWC system contains only very small quantities of suspended matter so that the loss of wall material through abrasion is not seen as a potential problem.

4.1.1.2 TEMPERATURE

Temperature can affect both the water quality and the aquaduct materials, through physical change due to temperature variation as well as dependence of chemical activity on temperature.

A problem can occur when concrete pipes are exposed to sunshine, rain and relatively high temperature variations which cause differetial expansion of the various components of the concrete resulting in weakening and possible cracking of the concrete. To counteract these effects it is recommended that the steel reinforcement content of the pipes should be 0,15% of the gross concrete area. Temperature variations should be limited to 13°C using insulation if necessary.

Higher temperatures enhance gas release reactions, chemical attack and precipitation reactions. For example, the solubility of calcium carbonate is temperature dependent as can be seen from its solubility product:

$$pK = 0{,}01183t + 8{,}03$$

where $pK = -\log K$

K = solubility product

t = temperature in °C

An increase in temperature causes an increase in pK or a decrease in K (120). This means that an increase in temperature will cause precipitation of calcium carbonate from a saturated solution.

4.1.2 CHEMICAL ASPECTS

Water transported through an aqueduct for relatively long distances is in contact with conduit material for an extended period of time and can result in an interaction between the water and the conduit material which is sufficiently strong to alter the chemical quality of the water.

The susceptibility of the pipe or canal wall material to chemical attack depends on the type of material used (concrete, steel, etc) and the water quality.

4.1.2.1 BACKGROUND

Over the years a varity of indexes have been formulated to "predict" scale formation, corrosion and water stability. (74,75). No ideal indexes have yet been formulated (76 - 81). None of the indexes indicate corrosion directly, but they do relate water quality to calcium carbonate i.e. the formation or dissolution of scale.

(a) Langerlier Index

$LI = pH - pH_s$

where pH_s = pH saturation

$pH = (pK_2^1 - pK_s^1) + pCa^{2+} + pALK + S$

where $(pK_2^1 - pK_s^1)$ = dissociation constant estimates

pCa^{2+} = - log (calcium ion in moles per litre)

p ALK = - log (total alkalinity in equivalents of CaCO per litre)

S = salinity correction term = $2,5\ \mu\ /(1 + 5.3\mu + 5.5\ \mu)$

and μ = ionic strength

For total dissolved solids (TDS) of concentration less than 500 mg/ℓ, the ionic strength may be estimated by 2.5 x 10 x TDS

The Langelier Index is a measure of the degree of calcium carbonate saturation in the water.

If the index is zero, the water is in equilibrium.

Ll 0 indicates oversaturation and a tendency to lay down a protective coating in the pipe

Ll 0 indicates undersaturation or a tendency to be aggressive to the pipe interior.

(b) Ryznar Index:

$R\ I = 2pH_s - pH$ RI $>$7.0 scale dissolution

RI $<$ 6.0 scale forming.

Scale deposition increases as the index drops below 6, and corrosion increases as it rises, with extremely aggressive conditions for values of 10 and above.

(c) Aggressiveness Index:

AI = pH + log (TAlk x CaH)

TAlk - total alkalinity as $mgCaCO_3/1$

CaH - calcium hardness as $mgCaCO_3/1$

AI $\geqslant$12 indicates nonaggressive water

10 $\leq$ AI $\leq$ 11.9 shows moderately aggressive conditions

AI $<$ 10 indicates extremely aggressive conditions

(d) Water quality of ENWC waters

The water quality of each water type along the Eastern National Carrier and its different indexes are as follows:

CHEMICAL COMPONENT	OKAVANGO RIVER	GROUND WATER (KARST AREA)	OMATAKO DAM	VON BACH DAM
Total dissolved solids	37 - 40	415 - 477	115 - 200	117 - 137
pH	6.8	7.3 - 7.5	6.8 - 7.7	7.3 - 8.1
Sulphate	0	4 - 10	4 - 10	0 - 2
Chloride	2 - 3	3 - 12	3 - 15	5 - 6
Total Alkalinity	20 - 25	412 - 451	78 - 150	100 - 132
Total Hardness	17 - 18	418 - 445	71 - 109	94 - 109
Calcium	5 - 13	195 - 200	50 - 55	75 - 80
Magnesium	4 - 13	208 - 250	21 - 54	19 - 29
Langelier Index	-3.0 /-2.5	0.1 / 0.9	-1.4 /-0.2	0.5 /-0.2
Ryznar Index	11.7 /12.7	6.5 / 9.6	8.1 / 9.6	7.8 / 8.3
Aggressiveness Index	8.8 / 9.3	12.2 /12.4	10.4 /11.6	11.3 /12.0

Total dissolved solids, sulphate and chloride are expressed in mg/ℓ. Total alkalinity, total hardness, calcium and magnesium are expressed in mg/ℓ as $CaCO_3$

4.1.2.2 LEACHING EFFECT OF SOFT WATER

The waters of lakes and rivers tend to be soft and low in dissolved solids. The hardness of river water is influenced by the geology and plant cover of the catchment area. Carbonate hardness is due to calcium and magnesium hydrocarbonate. For maintaining these compounds in solution an appropriate amount of dissolved free CO_2 must be present. Plants use CO_2 for respiration which results in the low carbonate content typical for shallow lakes and slow water courses.

Soft water can cause two related problems:

(a) Structural deterioration as a result of the dissolution and leaching of calcium salts from the concrete.

(b) Water quality changes within the distribution system due to the dissolution of wall materials, viz:

(i) the pH of the system will increase because the dissolution of calcium hydroxide provides hydroxyl ions;

(ii) the levels of calcium, aluminium and silicon will increase with time or distance through a pipeline, unless threshold conditions for saturation are met;

(iii) the alkalinity of the system may increase with the hydroxyl ion concentration.

e.g

A 10 Km reinforced concrete pipe incurred 5 mm of wear through leaching over a three year period.

Water passed once through this pipe showed the following water quality changes (85):

pH	6.9 - 8.6
Total Alkalinity	60 - 100 mg/ℓ as $CaCO_3$
Ca	120 - 200 mg/ℓ

Okavango water is soft and calcium carbonate deficient. Analyses show that this type of water can dissolve 10 mg/ℓ lime (as $CaCO_3$) before saturation is reached. Furthermore all indexes indicate that it is aggressive to concrete and corrosive to metals.

4.1.2.3 SCALING EFFECT OF HARD WATER

The borehole water in the Karst Area has a total dissolved solids concentration tenfold that of Okavango river water. The major chemicals are calcium and magnesium bicarbonate. Both hardness and alkalinity are high, yielding a high buffering capacity. All indexes indicate a scale forming tendency. On site measurements at boreholes at Berg Aukas, Brandwag and Rietfontein revealed very high carbon dioxide levels.

Brandwag water contains 542 mg/ℓ total CO_2 which includes 143 mg/ℓ free CO_2 (WW 25950). In the presence of carbon dioxide, calcium carbonate will remain in solution. When ground water previously under pressure emerges to the surface or seeps into surface water, the pressure is relieved and CO_2 escapes from the water until equilibrium with the air is reached. The loss of CO_2 causes the simultaneous precipitation of carbonates. Analyses show that these waters can potentially precipitate between 83 and 255 mg/ℓ $CaCO_3$ before equilibrium with the air is reached. The average for twenty one Karstland boreholes is 173 mg/ℓ $CaCO_3$ i.e. 173 000 kg/10^6 m^3 of calcium carbonate can precipitate in the canal.

4.2 POSSIBLE SOLUTIONS TO PROBLEMS INDENTIFIED

Depending on the concentration of calcium ions, carbonic species and pH, water may either tend to precipitate calcium carbonate, or to dissolve solid $CaCO_3$. The adjustment of these parameters by chemical additives is called conditioning.

Conditioning of water to remove hardness is called softening and conditioning of water to make it "non-corrosive" is called stabilization.

According to the literature, well-conditioned water has the following characteristics (120):

(i) the water should be oversaturated with $CaCO_3$. The theoretical $CaCO_3$ precipitation potential should be 4 - 10 mg $CaCO_3$ /ℓ;

(ii) calcium and alkalinity values should each be at least 40 mg/ℓ as $CaCO_3$;

(iii) the ratio alkalinity/(chlorides and sulphates) should be at least 5.

According to a different source, well conditioned water should have a Langelier index of between 0,2 and 0,5 (68).

4.2.1 WATER STABILIZATION

It can be seen from 4.2.1.4 that water stabilization on Okavango water would be required before pumping as it is aggressive to concrete and corrosive to metals.

4.2.1.1 LIME TREATMENT

The simplest and least expensive method of water stabilization is the addition of hydrated lime. However, it has the disadvantage that in most cases, not all the abovementioned criteria for well conditioned water can simultaneously be met.

The addition of lime has the following effects:

- it increases Ca content
- it increases Alkalinity
- it increases precipitation potential and Langelier's index

Referring to the example in Table 2, it can be seen that the addition of sufficient $Ca(OH)_2$ to increase the calcium content and alkalinity to 40 ppm as $CaCO_3$ produces water with a precipitation potential and Langelier index far in excess of given criteria for well conditioned water. (Interim water I).

However, because of the simplicity and low cost of this method, it is well suited to the ENWC situation. Table 3 shows an example of how Okavango water can be conditioned using only hydrated lime so that a compromise can be made between the raw water and well conditioned water. Practical experience has shown that this water should not be excessively aggressive as it is oversaturated and will form a protective coating on the pipe surface.

Assuming a lime purity of 90%, the amount of lime required is 9 867 kg/10^6 m^3.

TABLE 2: LIME TREATMENT AND CARBONATION OF OKAVANGO WATER

PARAMETER	RAW WATER	EFFECT OF CHEMICALS ADDED	INTERIM WATER I	EFFECT OF CHEMICALS	INTERIM WATER II	SATURATED STATE
Chemicals added mg/ℓ as $CaCO_3$		27 $Ca(OH)_2$		30 CO_3		
pH	6.8	–	10.04	–	8.82	8.84
Ca mg/ℓ as $CaCO_3$	13	+27	40	–	40	36
Alkalinity mg/ℓ as $CaCO_3$	25	+27	52	–	52	48
Acidity mg/ℓ as $CaCO_3$	43	–27	16	+30	48	48
Saturation state	undersaturated	–	oversa= turated	–	oversa= turated	saturated
pH	–	–	8.48	–	8.48	8.48
$CaCO_3$ precipitation potential	0	–	28	–	4	0
Langelier's Index	–2.5	–	1.56	–	0.34	0
Ryznar's Index	11.7	–	6.92	–	8.14	8.48

TABLE 3 : OKAVANGO WATER TREATMENT WITH LIME

PARAMETER	RAW WATER	EFFECT OF CHE= MICALS ADDED	INTERIM WATER	SATURATED STATE
Chemicals added mg/ℓ as $CaCO_3$		12 $Ca(OH)_2$		
pH	6.8	–	9.1	8.83
CO_2 mg/ℓ as $CaCO_3$	13	+12	25	23
Alkalinity mg/ℓ as $CaCO_3$	25	+12	37	35
Acidity mg/ℓ as $CaCO_3$	43	-12	31	31
Saturation state	undersaturated	–	oversaturated	saturated
pHs	–	–	8.83	8.83
$CaCO_3$ precipitation potential	0	–	2	0
Langelier's Index	-2.5	–	0.27	0.0
Ryznar's Index	11.7	–	8.56	8.83

4.2.1.2 Lime treatment and carbonation

This method involves the simultaneous addition of hydrated lime and carbon dioxide. The effect of the carbon dioxide is to transform calcium to the bicarbonate form, thus lowering the precipitation potential.

Table 2 shows how the addition of CO_2 decreases the precipitation potential of lime treated Okavango water without affecting the alkalinity and calcium concentration. (Interim water II).

It is possible to use coke, gas or oil burners for the generation of carbon dioxide. The quantities required to produce 1 kg of CO_2 are as follows:

coke - 350 g
fuel oil - 450 g

Alternatively commercial liquid CO_2 would produce a high purity product.

Assuming a 90% purity, 16 800 kg/10^6 m^3 of lime and 132 000 kg/10^6 m^3 of carbon dioxide would be required in this example.

Lime treatment and carbonation "produces" well conditioned water having the requirements for well conditioned water but requires expensive contacting equipment and skilled labour.

4.2.1.3 Limestone treatment

Percolation of water through a bed of limestone is another method of treatment. The material must contain 98 - 99% $CaCO_3$ and be free of iron oxides. In addition sufficient contact time must be allowed for the reaction to take place (79). In the past marble was used but because of its slow rate of reaction other products such as "Neutralite", "Magno" and "Akdolit" are now preferred.

1 m^3 of "Neutralite" is required to treat 3 to 10 m^3 of water per hour, depending on the concentration of CO_2.

4.2.2 WATER SOFTENING

Softening of hard waters is often necessary to reduce scaling problems in distribution system. Softening can be done by the elimination of calcium and magnesium ions.

4.2.2.1 Lime treatment

Carbonate removal by lime is the most common precipitation treatment. The temporary hardness can be eliminated by reaction of lime with calcium and magnesium bicarbonates and precipitation of calcium carbonate and magnesium hydroxide which settle in a clarifier. The theoretical average amount of lime required to lower the concentration of calcium to 60 mg/ℓ as $CaCO_3$ for water, from twenty one Karstveld boreholes, is 200 mg/ℓ as $CaCO_3$. The amount of lime required would be 164 444 kg/10^6 m^3.

4.2.2.2 Caustic soda treatment

Precipitation with caustic soda (NaOH) leads to calcium carbonate and sodium carbonate formation. Sodium carbonate reacts on the permanent hardness of water. Total hardness can be reduced to 30 mg/ℓ as $CaCO_3$.

4.2.2.3 Soda ash treatment

Sodium carbonate can also be used for water softening by calcium carbonate precipitation.

4.2.2.4 Softening by ion exchange

A cation exchanger regenerated with NaCl solution can be used to soften drinking water. Disadvantages of this method are the large amounts of salty waste liquid, the big increase in the sodium content of the water and the high cost, especially for large installations.

4.2.2.5 Carbonate removal by CO_2 elimination

Calcium carbonate can be precipiated by CO_2 removal in a degasification column. The precipitate must be separated in a sedimentation tank. It is normally considered that for reasonable stability water should have a slightly positive index of about +0,2 but not more than +0,5, and no tendency to redissolve calcium carbonate from the pipe (86).

4.2.3 CONCRETE PROTECTION

Concrete is commonly used for building resorvoirs, pipelines, canals and water processing tanks. Surface treatment of concrete can be considered as an alternative to water treatment. In some cases where high quality concrete is used, the water will not be affected by being in direct contact with the concrete. In practise, however, most concrete products require some form of protective lining.

Coating materials for concrete include sealing-slurries, plastic linings and bituminous linings. Slurries react chemically with the carrier surfaces whereas passive protectors such as plastic and bituminous linings act merely as covers which separate the two media.

4.2.3.1 A sealing slurry based on cement

Slurries must be of high quality because they react chemically with the surface of the carrier and the water in it. Slurries are sold as a mixture of cement and sand (1:1) which only requires mixing with water to be ready for application. Coating thicknesses of 3 - 4 mm are sufficient.

Aggressive water will attack a cement slurry but at a much slower rate than unprotected concrete.

The rate of chemical reaction depends on the density of the coating.

It is very important to have a carefully prepared base. In a number of applications carried out in Germany, Switzerland and Austria it was found that bad preparation caused severe problems later. The surface before coating should be sound and free of wide cracks and surface irregularities. Surfaces must be cleaned mechanically, preferably by sand or combined sand/water blasting. The surface should be free of bitumen, oil grease and paint. It should be prewatered well in advance, so that it is slightly damp when the coat is applied. Various tests have proved cement slurry products to be suitable and to have certain advantages over organic-based products.

4.2.3.2 Plastic linings

In general linings used on concrete have proved disappointing as peeling of the lining and deterioration of the concrete occured. There are several likely reasons, including application errors and the diffusion of gases or liquids from outside.

Some German-made paints based on PVC and PE appear to work well (95). PVC and PP (polypropylene) linings are reported to give long service. Plastic lined pipes tolerate flow speed between 1.2 and 1.8 m/s. Above these, ripping of the plastic lining occured (99, 100, 103, 74, 73). A flow speed of 5 m/s was found to strip PVC-lining from concrete pipeline, despite the assurance that the problem of weak bonding between PVC and concrete had been overcome (98).

4.2.3.3 Bituminous linings

Lining pipes with bitumen can only be considered a short term solution. Its disadvantages are:

(i) The layer is not uniform.

(ii) Tuberculation can occur. In one pipeline tuberculation occured after five years and two years later the lining had disappeared completely.

(iii) The solvent commonly used (dichloromethane) is considered unhealty and even toxic.

(iv) Bitumen as well as coal tar, gives off certain compounds, which affect both taste and smell (106), others are known carcinogens but are not reported to occur in lethal quantities (74, 107, 109).

Various linings (bitumen, chlorinated rubber, PVC, epoxides, etc.) provide a carbon source for slime-producing bacteria and other organisms (110, 111, 112, 113, 74). Micro-organisms require attention because of their ubiquity. The first water running through newly installed pipe showed very high bacterial counts, and even after much flushing with highly chlorinated water, very large bacterial populations were noticed in the pipe joints (119).

More expensive, cement linings last longer and provide better and more uniform layers than bituminous linings (104, 105).

5. CONCLUSIONS FROM THE LITERATURE SURVEY

This literature survey has pin-pointed the various problems which could potentially affect the water quality supplied by the ENWC.

The survey has shown that the main biological problem in cement-lined canals is excessive algal growth, particularly filamentous green algae. Spores and plants can be introduced with the source water or by wind. The nutrient concentrations and the flow rate of the water in the canal largely determine the extent of algal growth and decay.

The main cause of water-quality deterioration in long distance water transfer schemes is the decomposition of biological matter. This can originate from the source water, e.g. as plants and animals which cannot survive the altered, often adverse conditions in the carrier, and from terrestrial sources e.g. migrating game and small animals drowning in the canal and

wind-blown plant debris. Organic decomposition reduces water quality by increasing the amount of dissolved organic matter (enriching the water), decreasing the oxygen concentration and increasing the number of heterotrophic and coliform bacteria.

When different drainage systems are artificially linked there is the ecological risk of introducing alien species. Studies in the literature confirm that several species have the potential to enter and survive in carrier systems and that these can have detrimental consequences on the invaded systems. Water-borne diseases, in particular bilharzia, are often spread by large water transfer schemes and can endanger the success of development projects unless effective control is implemented.

The literature study documents many different control methods applicable to the various problems associated with long distance water transfer. Several of which could be applicable to the ENWC.

To prevent water quality deterioration caused by biological pollution, steps to control excessive algal growth might be required especially in cement-lined canals. This problem is less likely to occur in a rapidly flowing canal than in one containing standing water. Of the methods available, manual control and biological control are probably best suited to conditions on the ENWC. A biological control programme would require further research.

To minimize the possible introduction of biological material from the source water, sieves could be used at all inlet structures. Further research in close consultation with engineers and hydrologists is necessary to establish the design features of such grids.

To prevent the health hazard of bilharzia transmission, either an environmental control programme aimed at creating unfavourable snail habitats in the components of the ENWC, or a biological control programme should be considered. Both methods would require further research under local conditions before implimentation.

Further research is also needed to establish the need and feasibility of game crossings and structures to allow animals trapped in the ENWC canal to climb out.

The water sources of the ENWC offer clear water all year round, occasionally the Okavango river may be turbid, but the silt load will probably not be enough to form a protective layer on the concrete surfaces of the water carrier.

From a chemical point of view the Okavango water is aggressive towards concrete and has the potential to dissolve 10 mg/ℓ $Ca(OH)_2$ as $CaCO_3$. Theoretically 10^6 m^3 of Okavango water can cause leaching of 10 000 kg of lime or other calcium salts before equilibrium state is reached.

The Karst-water which is oversaturated with $CaCO_3$ has the potential to precipitate between 0 and 60 mg $CaCO_3$ /ℓ in a well sealed system (where there is no exchange of CO_2 between the water and the air), and 173 mg $CaCO_3$/ℓ i.e. 173 000 kg/10^6 m^3 in an open canal.

The deposition of calcium carbonate is apparently dependent on the linear flow speed. At a velocity of less than 0.3 m/s a porous layer of calcium carbonate is deposited, a more adherent layer is obtained at velocities greater than 0.6 m/s.

There are many different methods for water conditioning. The most effective method for Okavango water stabilization is lime treatment and carbonation.

The chemical costs for water softening increase from lime to caustic soda and soda ash treatment. Another method of carbonate removal can be CO_2 elimination.

Although the literature survey has identified several potentially serious problems which long distance water carriers are subject to, it must be remembered that the severity of these problems depend on the design and operation procedure of the water carrier and on local environmental conditions. From what we know of present conditions on the ENWC, we do not

expect serious biological problems, in the initial stages of operation. But any changes, for example in operating procedure, can have adverse side effects. To combat future biological problems the carrier should be monitored on a regular basis and suitable control options should be investigated. The chemical problems envisaged are a more serious threat to water quality at present. Further research will be necessary to determine the most effective control measures required and to re-assess these under local conditions.

A literature survey alone is not sufficient to determine a future management policy for the ENWC. Thus baseline studies are being conducted on the source waters and components of the ENWC, to establish the existing environmental conditions of these waters. A monitoring programme will also be necessary to detect and identify any changes in these waters. Finally a control programme must be formulated so that, if necessary, timely remedial action can be taken.

6. RECOMMENDATIONS REGARDING THE ENWC BASED ON THE LITERATURE SURVEY

6.1 That the stabilization of Okavango water and the treatment of Karstland borehole water the further investigated to determine:

(a) the necessity of treatment
(b) treatment methods
(c) cost of treatment

6.2 That a monitoring programme be initiated to determine biological and chemical quality changes of the water, once the system is in operation.

6.3 That in order to combat probable biological problems a definite control programme should be drawn up after further research and evaluated under local conditions.

COMPILED BY: _____ AND : Shirley Bethune

DATE: 22 April 88

7. APPROVAL OF RECOMMENDATIONS

This report has been read and approved for submission to the Director Investigations.

HEAD: WATER QUALITY

DATE: _____

I support the recommendations set out in this report and submit it to the Secretary of Water Affairs for approval in principle.

DIRECTOR: INVESTIGATIONS

DATE : _____

The recommendations in this report have been decided upon as follows:

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SECRETARY: WATER AFFAIRS

DATE : _____

8. AKNOWLEDGEMENTS

Our thanks is due to Mr R M Roeis who obtained many of the articles referred to in this report and who did much of the initial research. We also wish to thank Mr W Ravenscroft, Mr J Lambrecht and Ms V R Wallis for critically reading the manuscript.

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TAWWA, Management and operations, November 1977, pp 592-599.