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ADDENDUM 11.1

THE 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.

PART I : BIOLOGICAL ASPECTS

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

(Romanenko et al 1980)

CONTENTS

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.

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.

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 which being unable to survive in flowing water decomposes and causes 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 instumental 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.

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, the excessive algal or macrophytic growth should be controlled.

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

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

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. This is discussed in more detail in the section on chemical aspects.

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 swimming ability in currents and 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).

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.

4. CONCLUSIONS FROM THE LITERATURE SURVEY

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

The survey has shown that the main 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.

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.

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