DEVELOPMENT PROPOSALS TO THE WATER MONITORING AND MANAGEMENT OF HARTBEESPOORT DAM

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KOKKINEN SIRPA & SIRI MARIANNE:

Development proposals to the water monitoring and management of Hartbeespoort Dam

Ympäristötekniikan opinnäytetyö, 68 sivua

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TIIVISTELMÄ

Työn tarkoituksena on tukea Etelä-Afrikkalaista Harties Metsi A Me –kunnostusprojektia, jonka tavoitteena on Hartbeespoort Dam –patoaltaan kunnostaminen. Työssä keskitytään patoaltaan ongelmiin sekä monitoroinnin ja kunnostusmenelmien kehittämiseen. Monitoroinnin kehittämisehdotukset painottavat automaation hyödyntämistä monitoroinnissa. Kunnostusmenetelmiksi on ehdotettu menetelmiä, jotka pyrkivät vähentämään sekä ulkoista että sisäistä kuormitusta. Keskeisimmässä osassa on fosforikuormituksen vähentäminen. Työssä on käytetty esimerkkinä Lahden Vesijärven kunnostusta, jonka pohjalta pääosa kehitysehdotuksista on syntynyt.

Idea työhön saatiin Etelä-Afrikassa kesällä 2009 suoritetun työharjoittelun aikana Harties Metsi A Me –kunnostusprojektissa. Kunnostusprojektin monitorointitiimi oli kiinnostunut Vesijärven ja Hartbeespoort Damin tapauksien vertailuun keskittyvästä työstä. Varsinaista laajamittaista vertailua ei tehty vesistöjen ja niiden ympäristön erilaisuuden vuoksi, vaan työssä keskityttiin käsittelemään vesistöjen ongelmia sekä kunnostusprojekteja. Opinnäytetyön työstäminen aloitettiin syksyllä Suomen puolella, kun työn aihe saatiin rajattua selkeämmäksi.

Työssä on hyödynnetty työharjoittelussa saatua monitorointikokemusta, omia opintoja sekä käytetty kirjallisia materiaaleja Harties Metsi A Me -projektilta. Työharjoittelun aikana saatuja monitorointitutkimustuloksia ei käsitellä tässä työssä. Työn keskeisinä tuloksina voidaan pitää esiteltyjä kehitysehdotuksia.

Avainsanat: vesistön monitorointi, vesistön kunnostus, rehevöityminen

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ABSTRACT

The purpose of this Bachelor's thesis was to support a remediation project called Harties Metsi A Me in South Africa, which aims at the rehabilitation of the Hartbeespoort Dam. The study concentrated to developing the water monitoring and remediation methods of the Dam. The development proposals of monitoring emphasize the utilisation of automation in monitoring. The suggested remediation methods aim at decreasing both external and internal loads. The decreasing of phosphorus load has the most center part. In this study, the remediation of Lake Vesijärvi is used as an example, and a major part of the development proposals are based on it.

The idea of this study was born in summer 2009 while doing practical training for the Harties Metsi A Me remediation project in South Africa. The monitoring team of the project was interested in the study which would compare two remediation projects: Lake Vesijärvi and the Hartbeespoort Dam. Because of the differences of water courses and their environment, an extensive comparison was not made, but the concentration of the study was on the problems of water courses and on remediation projects. Working with the thesis started in Finland in autumn when the subject was specified.

For this study the practical training experience and the materials from the Harties Metsi A Me project, were utilised. Monitoring experience, environmental engineering studies and literature were also utilised. The monitoring research results obtained from the practical training is not included in this thesis. The presented development proposals can be considered as the results of this study.

Key words: monitoring, remediation, eutrophication

CONTENTS

Terminology

Catchment area = an area from where water is flown into a water course along the earth surface and waterways (rivers, streams etc.) of that particular area

Chlorophyll α = a pigment from the chloroplast of plant, which participates to photosynthesis, concentration is used to meter of eutrophication

Dissolved oxygen, DO = oxygen concentration in the water

Electrical conductivity = an amount of salts in water, increases when the concentration of electrolyte increases, unit mS/m

Epilimnium = the layer of warm water at the surface of the lake

Eutrophication = an increase in the concentration of nutrients in a lake that increases the primary productivity

External load = a nutrient amount which comes to a lake from outside of the lake

Food web = hierarchical entirety, formed by different organisms, which through energy flows from level to level

Hypolimnium = the dense, bottom layer of water in a thermally-stratified lake

Internal load = load from water course itself, appear especially when oxygen expires and nutrients from the bottom sediment are released back to the water mass

Secchi depth = the transparency of water, measured with a white plate. The depth where the plate can not be seen anymore is secchi depth

Sediment = solids which are stratified to the bottom of a water course

Turbidity = the cloudiness or the haziness of the water caused by little particles like clay material or algae, unit FTU (Formazin Turbidity Units)

Zoobenthos = small animals which live on or in bottom sediments

1 INTRODUCTION

South Africa is located in a semi-arid part of the world, and its water resources are globally considered scarce and extremely limited. Fresh water resources are already almost fully-utilised and under a stress, and water will increasingly become a limited resource. At present, many water systems are polluted by industrial effluents, domestic and commercial sewage, acid mine drainage, agricultural runoff and litter. The pollution of surface waters is generally more common and noticeable than the pollution of groundwater.

In spring 2009, we spent three months in Hartbeespoort, South Africa doing a practical training related to water monitoring. We participated in a remediation project called Harties Metsi A Me whose aim was to rehabilitate a badly polluted water reservoir Hartbeespoort Dam. The remediation project is one of the many projects of the Department of Water Affairs of the Republic of South Africa (DWA). We were suggested on behalf of the Hartbeespoort Dam monitoring team to do our thesis focusing in water monitoring and remediation in two water courses: Lake Vesijärvi and Hartbeespoort Dam. The remediation project of Lake Vesijärvi is well known around the world, and Harties Metsi A Me project has taken example of the Lake Vesijärvi remediation project, inter alia using food web remediation as one of the remediation methods. The monitoring team was interested to see some comparison between the two remediation projects, and to get a different perspective for the Harties Metsi A Me project.

1.1 Aim and Implementation of the Study

This thesis deals with the problems, the remediation methods and the water monitoring of a water reservoir called Hartbeespoort Dam in South Africa. Lake Vesijärvi is used as an example case, but the main focus is on Hartbeespoort Dam. The southern part of Lake Vesijärvi, called Enonselkä, has been the worst polluted part of the lake, and even nowadays the water quality is weaker there than in the rest of the lake. Therefore, in this thesis, mostly the Enonselkä area is studied in connection with Hartbeespoort Dam. The aim of this study is to support the development of water monitoring in Hartbeespoort Dam, and to suggest development proposals to the remediation methods.

Water monitoring and management of a lake is an extensive subject to deal with, and it belongs to the field of limnology, which is only a small part of our studies. Therefore, only few selected remediation methods are dealt with in this study, and in water monitoring the emphasis is placed on the utilisation of automatic measurement. Comparison between the two water courses is implemented mainly with examples taken from the Lake Vesijärvi rehabilitation project. The comparison between the rehabilitation of the water courses is an interesting idea, but difficult and prolonged to implement because of the differences: Lake Vesijärvi is a natural lake whereas Hartbeespoort Dam is an artifial reservoir. Also the climate and the environment are very different, as well as the functions of the two water courses: for example, water reservoirs in South Africa have a naturally bigger tolerance against nutrients than Finnish lakes, which are more disposed.

1.2 Background of the Study

The practical training in South Africa was based on the Environmental Cooperation project between the City of Lahti and the Bojanala Platinum District Municipality. Cooperation has been done since the end of 1990s, and the aim has been to strengthen and to develop environmental administration in both municipalities. The cooperation has dealt with issues such as the supporting of sustainable development, water conservation, environmental management, and waste management. The working methods have included common developmental projects, education, personnel interchange and peer review between both municipalities. In the beginning, the cooperation was implemented in Lahti by the Environment Center, and since July 2006, implementation was done by the Lahti Technical and Environmental Affairs. The program is funded by the Finnish Ministry of Foreign Affairs and coordinated by the Regional and Local Government Association of Finland.

Lahti Technical and Environmental Affairs donated a continuously measuring water station to the Harties Metsi A Me project on behalf of the Environmental Cooperation project. One of the assignments in South Africa was to get the station to work, and to set it to the measure water quality in Hartbeespoort Dam. The station has also been used in Lake Vesijärvi, and there are five similar stations working now around the lake. Based on the practical training experience, the measurement station was chosen for the primary development proposal to water monitoring in Hartbeespoort Dam.

2 REHABILITATION OF HARTBEESPOORT DAM

2.1 Overview of Hartbeespoort Dam

Hartbeespoort Dam is a 20 km^2 reservoir located in the Madibeng Local Municipality which belongs to the North West Province of South Africa. The dam is considered the most important dam in South Africa; the surrounding area is fast developing, and proximity to major metropolitans makes Hartbeespoort Dam an important recreational dam. Hartbeespoort Dam belongs to the Crocodile River catchment and receives its water from a 4100 km^2 area from Johannesburg via the Jukskei and Hennops Rivers that flow into the Crocodile River (see Figure 1. The Location of Hartbeespoort Dam). Land use within this drainage area is primarily a rural agricultural use, although wide areas along the Crocodile River system are highly urbanised. About 90 % of the annual inflow comes from the Crocodile River, and with it lots of waste from the three metropolitan areas Johannesburg, Ekurhuleni and Tshwane. During the dry season, more than 50% of the dam water is treated wastewater. (DWA, 2009)

The Hartbeespoort Dam was built mainly for irrigation purposes and was constructed during the 1920s and compeleted in 1923. Nowadays, roughly 80% of its water is used for irrigation, and the rest for domestic consumption and compensation flows. The 532 kilometres long network of canals provides water for farmlands within the watershed of Hartbeespoort Dam. The volume of the dam is 110 -

150 million m^3 of water per annum, depending on weather conditions. The shoreline is approximately 56 km when the dam is full. Turnover is 186 days. Madibeng Local Municipality depends totally on the water from the dam. The inhabitants around the dam, and large settlements downstream, including the Town of Brits, use the purified water from Hartbeespoort Dam for drinking. (DWA, 2009)

Hartbeespoort Dam is a hypertrophic dam, which has been the result of excessice nutrient loading coming into the dam. The dam has been in this state since the early 1970s. The water quality is poor, and the water smells bad and is partly green by color because of massive blue green alga populations in the dam. All this has effects on the recreational use of the dam and on the economy of the surrounding areas. The Town of Hartbeespoort is situated right next to the Hartbeespoort Dam. The dam and its immediate surroundings is a popular holiday resort area among the South Africans. Hartbeespoort is situated next to the big cities Pretoria, Johannesburg and Rustenburg which have their own influence on the continuous growth of the town. Many local people go to work to the big cities nearby.

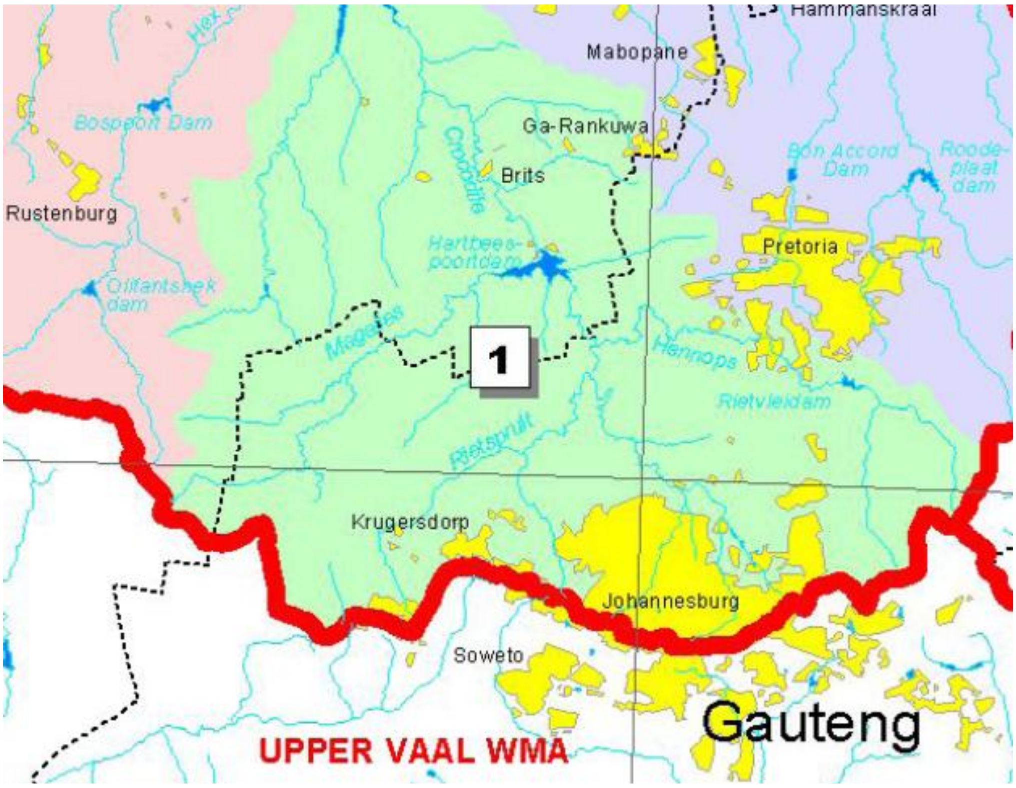

FIGURE 1. The Location of Hartbeespoort Dam (DWA)

FIGURE 2. Hartbeespoort Dam (DWA)

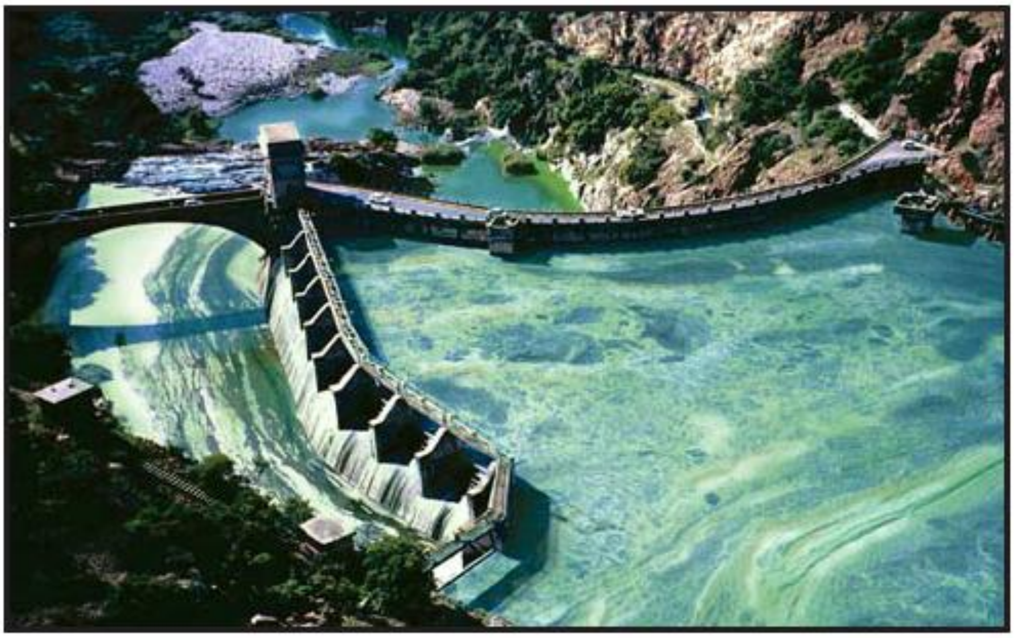

FIGURE 3. The Dam Wall of Hartbeespoort Dam Reservoir (DWA)

2.2 Problems of the Water Quality

In 1930, five years after the dam was built, the conditions were described as oligotrophic. But within 25 years, the situation changed dramatically to eutrophic. During the past 40 years, problems caused by the presence of dense blooms of toxicated cyanobacteria have placed restrictions to the supply of the raw potable and irrigation water, and the recreational use of the dam. (Action Plan – Volum 2 2004). Toxicated algal growth restricts water sports, and for example swimming is completely forbidden. The fishes of the dam are not considered eatable.

2.3 External and Internal Load

External load from the catchment areas is a major factor contributing the condition of Hartbeespoort Dam. Non-controlled activities, such as urbanisation, agriculture, industry and mining have had impacts on rivers and natural wetlands. Modified and destructed river banks, river beds and shrinking wetlands in the catchment have reduced the natural purification capacity of the rivers. Erosion of the soil and the destruction of riparian vegetation have increased the washing of nutrients and harmful substances to the rivers. The poor controlling of storm water increases the external load of the dam because of overflows from the sewage networks into the water courses. Along the storm water, surface pollutants, such as fertilisers, litter, animal waste etc. end up into the dam. Constricted infrastructure causes the washing of grey waters to enter the rivers. Also the properties of the river banks of the Hartbeespoort Dam are one source of the external load entering the dam (for example fertilisers used in lawns, and the lost of buffer zones).

It is estimated that more than 600 million litres of purified sewage per day is discharged by the wastewater treatment plants into the catchment. That means more than a 200 ton annual phosphate inflow to the dam. Most of the phosphorus loading to the Hartbeespoort Dam is conveyed via the Crocodile River. (DWA, 2009) Because of constantly growing urban areas and settlements, the capasity of the wastewater treatment plants is often insufficient. The application of the 1 mg per litre phosphorus standard to the wastewater treatment plants was implemented in 1986 with a view to reduce the amount of phosphorus. At first, the standard was only partly implemented and not used in all the treatment plants around the catchment area. Although the standard has proven effective in reducing the total load of phosphorus, there are still improvements to be made (see Table 1.) (Action Plan – Volum 2 2004). The maximum concentration of total phosphorus allowed in the

Kariniemi wastewater treatment plant of the City of Lahti is 0.5 mg/l. When compared to the values in Table 1, only one wastewater treatment plant in the Hartbeespoort catchment area was able to achieve the concentration of 0.5 mg/l.

Besides the external load, the Hartbeespoort Dam is also strained by an internal load which is typical for eutrophic reservoirs. Historic and present pollution loads are trapped in thick sediment layers of the dam. Additional nutrient loads are constantly released from the bottom into the water. (DWA, 2009) This yet natural nutrient cycle is unbalanced because of the poor water quality and distorted food web. For example, oxygen shortage, high pH and a high population of bottom feeder fishes are factors accelerating the releasing of phosphorus from the sediments.

TABLE 1. The Phosphorus Loading of Crocodile River by Wastewater Treatment Works (Action Plan – Volume 2 2004)

Works	Median phosphorus concentration in final effluent, mg per liter	Annual discharge, million m^3 per annum	Phosphorus loading, tons P per annum
Percy Stewart	6.1	5	30.5
Randfontein	5.0	2.5	12.5
Hartbeesfontein	0.8	13.5	10.5
Olifantsfontein	0.5	16.5	8.2
Verwoerdburg	No data provided by Tshwane Council		
Johannesburg N Works	0.6	120	66
Esther Park	1.4	0.2	0.2
TOTAL			**127.90**

2.3.1 Total Phosphorus in the Dam

Long term water monitoring has indicated that there are sufficient quantities of phosphorus in the Hartbeespoort Dam to sustain algal growth, as long as this phosphorus is biologically available. Data from water sampling in the dam (for the last 6 years) indicates an average of more than 0.2 mg P/l. According to various studies, as little as 0.002 mg P/l may sustain maximum phytoplankton growth. In the dam, the amount is 100 times more than the minimum required to sustain the maximum growth. It is, therefore, critical that the total phosphorus concentration is reduced in the dam. As the other limiting factors, such as sunlight, water temperature (linked to solar radiation) and carbon source is difficult or impossible to control, it is critical that the total phosphorus be reduced. (De Jager & Maré, 2009, 76)

The average concentration of total phosphorus in Lake Vesijärvi, during the years 2002 – 2007, was 25 mg/m3 (0.025 mg/l). The aim is to reduce the total phosphorus to the level of 18 mg/m3 whereby the need for the reduction of phosphorus load (12 600 kg/a) is 30 %. (Tavastia Regional Environment Center, 2009) The difference between the phosphorus amounts of Lake Vesijärvi and the Hartbeespoort Dam is huge, but it should be noticed that Hartbeespoort Dam has naturally a bigger tolerance to sustain nutrient loads. Still, it is obvious that the phosphorus amount in the dam must be radically reduced. Figure 4 shows phosphorus concentrations in Hartbeespoort Dam between 2002-2008. A similar graph showing the phosphorus results of Lake Vesijärvi is found in figure 5. (Notice the different concentrations and time periods of the graphs).

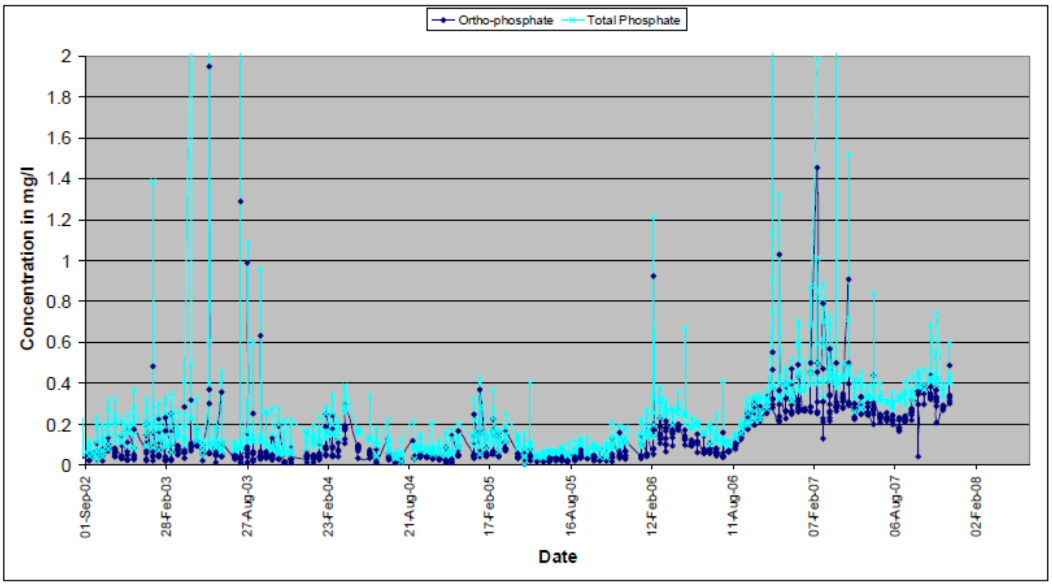

FIGURE 4. Phosphorus Concentrations in Hartbeespoort Dam (2002-2008) (De Jager & Maré, 2009)

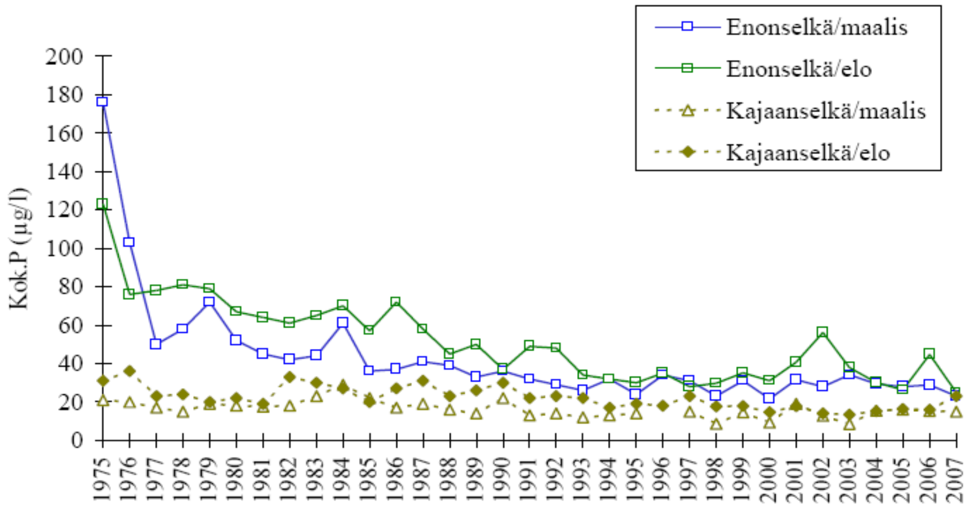

FIGURE 5. Phosphorus Concentrations (µg/l) elo = August, maalis = March. (The Lake Vesijärvi –Program, 2008)

2.3.2 Phosphorus Balance Model

Material balance models are used as tools to evaluete the amount of loading and the significance of different loading sources. With the help of balance models, it can be estimated whether it is priority to allocate management activities to the catchment area or to the internal load of a lake. (Lakso & Ulvi, 2005, 69)

In a phosphorus balance model, variables calculated include: the phosphorus load coming to the lake, sedimenting in the lake and leaving the lake. The load affecting the state of the lake is assumed to be the sum of external and internal load. The basic unit of a material balance model is a material flow rate, which is the result when the concentration and the flow rate is multiplied. For example, it can be calculated as follows: If the phosphorus concentration is 35 µg/l, it is the same as 0.035 mg/l and 0.035 g/m^3. What is the phosphorus flow rate leaving the lake?

$0.035 \text{ g P/m}^3 * 86.4 * 3.5 \text{ m}^3\text{/s} = 10.584 \text{ kg P/d}$

The number 86.4 is the result of division (86400/1000) in which 86400 means the amount of seconds per day and 1/1000 is a conversion factor which changes grams to kilos (Cranberg, 2006, 38). A balance model is usually calculated separately for each season. The external load is calculated as the sum of nearby catchment areas, far-off catchment areas and point source loads. The basis for the evaluation of an internal phosphorus load is a balance formula with five factors (Lappalainen & Matinvesi 1990). The calculations are based on observations which are supplemented with empirical estimates as needed. The phosphorus balance formula is: EL + IL = OF + GS + dP/dt in which:

EL = external load
IL = internal load
OF = phosphorus leaving the lake (along a river & fish catches)
GS = gross sedimentation
dP/dt = change in the material content of water mass
(Lakso & Ulvi, 2005, 69).

A preliminary phosphorus balance model is found on the web pages of Harties Metsi A Me project. An integrated Monitoring Program for the Hartbeespoort Dam and the upstream catchment is currently under development. Its objectives are inter alia to measure the effectiveness of the Harties Metsi A Me Bioremediation project, to identify the impacts and to develop existing water monitoring programs. (De Jager & Maré, 2009, 3) In the future, the phosphorus balance model will become more accurate when monitoring is further developed. As an example of an accurate phosphorus balance model, there is the balance model of Lake Vesijärvi in the Figure 7, which shows the different sources of external and internal loads.

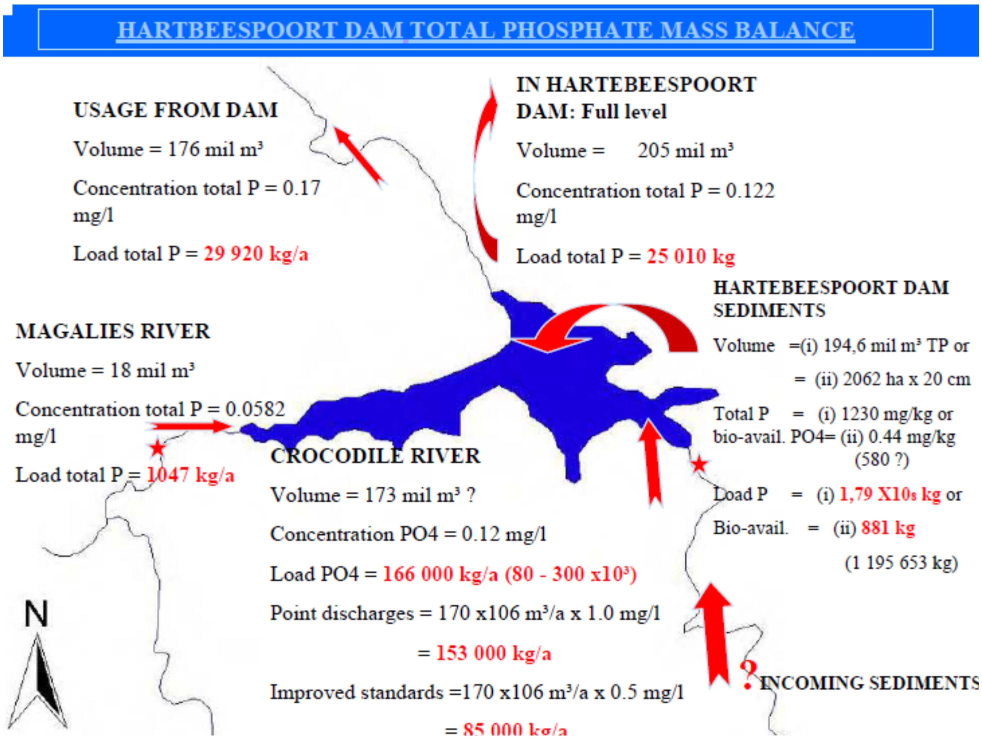

FIGURE 6. Hartbeespoort Dam Phosphate Balance kg/a (DWA, 2010)

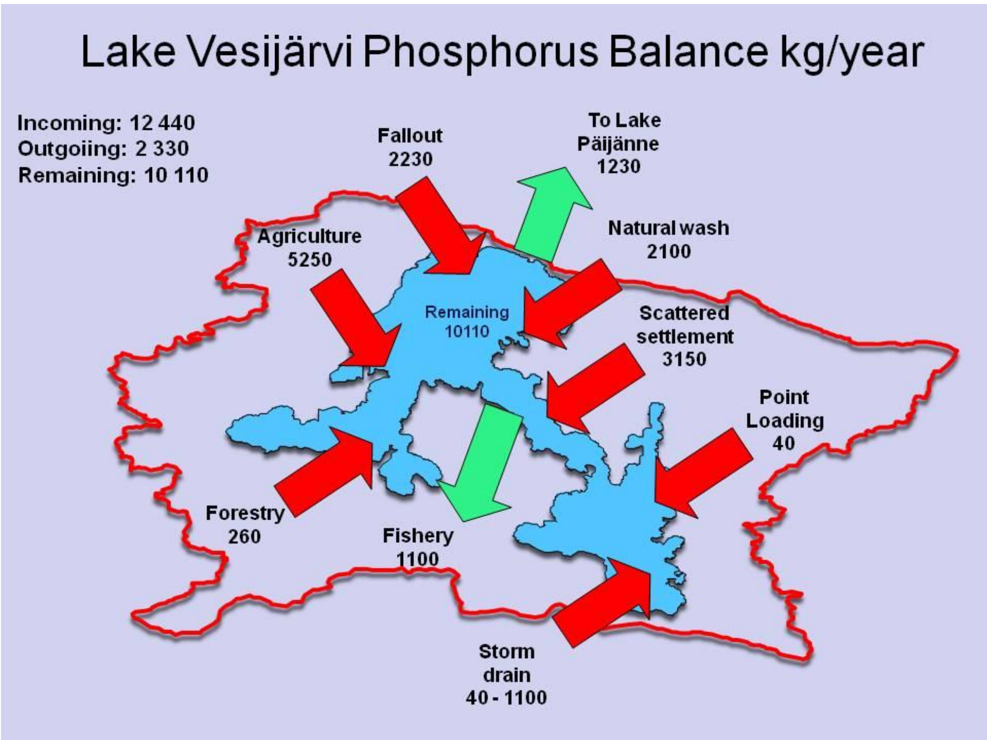

FIGURE 7. Lake Vesijärvi Phosphorus Balance kg/a (Malin, 2010)

2.4 Hypertrophic Dam

Dam water is excessively enriched by nutrients, such as phosphorus and nitrogen. There are several factors, for example high nutrient loading, high incident solar radiation, low wind speed or warm water that together make the Hartbeespoort Dam an ideal environment for the massive blue green algae growth. Toxic cyano-bacteria population grows to such a large level that the population self-shades itself, so the algal mass has a major impact on regulating light penetration to the water. (De Jager & Maré, 2009) Cyanobacterias tend to accumulate in large floating mats, and they are drifted throughout the dam along the changing wind. The high concentration of nutrients in the dam has also led to the uncontrolled growth of hyacinths (waterweeds). Water hyacinths produce a huge amount of dead roots and leaves which create great organic loads to the bottom. Besides the generation of anoxic conditions and the negative impact on production, the accumulation of organic material has favoured detrital feeding fish in the Hartbeespoort Dam (Action Plan – Volum 2, 2004). Especially during summer months, hyacinths and Microcystis blooms are accelerated when solar radiation and water temperature are high.

Algal blooms and hyacinths spoil the beautiful appearance of the dam, and especially rotten hyacinths cause unpleasant odours when they are drifted and accumulated to the waterside. In potable water, there is still distinguishable odour and taste left after the purification process. Algal blooms further affect on water treatment systems as they clog the filters and pumps, and reduce the carrying capacity of pipelines and canals. This means that the quality of the water is being affected, as well as the cost to purify the water for household use. Depending on the maintenance and the upkeep of the domestic water supply, the toxins could be collected in the system, and therefore be released into the domestic water. (DWA 2009)

FIGURE 8. Shoreline Govered by Algae (Kokkinen, 2009)

2.5 Distorted Food Web

Although algal production is high in the Hartbeespoort Dam, the zooplankton population remains small in relation to the primary producers of the dam. The fish population is distorted because of poor water quality, high pH, small zooplankton population and green blue dominant algal population. (De Jager & Maré, 2009, 5) The destruction of natural habitats, like the shoreline vegetation also contributes to the distorted food web, which results in the dominance of undesired fish species, such as common carp (*Cyprinus carpio*), cat fish (*Clarias gariepinus*) and Canary Kurper (*Chetia flaviventrix*). Besides small fishes, the destruction of shoreline vegetation also decreases the amount of the zooplankton and macro invertebrates when they are left without habitats and shelters from predators.

Although the carp and the catfish are omnivorous, they put the zooplankton population under pressure, for example their larvae are especially dependant on the availability of the large quantities of zooplankton. The mature catfish efficiently prays on the youngest of more desirable fish species. Both fishes also feed on the zoobenthos and disturb the ecosystem balance of the bottom by uprooting aquatic vegetation and by disturbing the bottom sediments in the search of food. (Action Plan – Volum 2, 2004)

FIGURE 9. The Carp (left) and the Catfish Are Part of Fishery Management (DWA, 2004)

2.6 The Rehabilitation of the Hartbeespoort Dam

The Department of Water Affairs (DWA) has implemented many efforts over the past 30 years in an attempt to recover the Hartbeespoort Dam. The symptoms of the dam have, however, prevailed and the dam is still in the same sick state. The implementation of the 1 mg per litre phosphorus standard coincided with the recovery of the dam, following the extensive drought conditions experienced between 1981-1982 and 1987-1988. The refilling of the dam resulted in further dilution of the extremely high phosphorus levels observed in the waterbody, reducing the in-lake phosphate-phosphorus concentration from nearly 0.50 mg ℓ-1 to 0.13 mg ℓ-1. Conversely, total nitrogen concentrations have increased, with a nitrogen-to-phosphorus ratio of 25:1 being reported in surface waters during 1988-1989. During that year, the blue-green algal *Microcystis aeruginosa*, was virtually absent from the system for the first time in more than a decade. (Action Plan – Volume 2, 2004)

For many years, the rehabilitation possibilities of the Hartbeespoort Dam focused on the controlling of phosphate at point source discharges, which was seen as the only solution. Biological rehabilitation means were ignored. Consequently, the condition of the dam has been deteriorating for years. In the absence of any remedial pilot study and action, also other dams of the North West Province continued to deteriorate (e.g. Bospoort Dam). As a result, already scarce water resources have become less suitable for drinking, irrigation and recreation over the years. Recently problems caused by eutrophication have been recognised in South Africa and dam remediation initiatives have now become priorities. (The North West Provincial Government, 2005)

In April 2003, DWA (DWEA at that time) and the North West Department of Agriculture, Conservation and Environment implemented the Hartbeespoort Dam Remediation Project (also referred to as the Harties Metsi A Me –project) to develop a management plan for the Hartbeespoort Dam. The action plan of the remediation project was received in November 2004. The study concentrated on providing a concrete and practical action programme based on the knowledge gained from the previous studies (inter alia The Limnology of the Hartbeespoort Dam, 1985). The study also reviewed international experiences from successful rehabilitations of lakes with similar problems, such as Lake Vesijärvi in Finland, Lake Delvan in the USA, and some Australian lakes. The Fish Community Study related to the Action Plan was finalized in March 2005. (The North West Provincial Government, 2005)

2.6.1 The Harties Metsi A Me Project

The aim of the program is to address the imbalances and unhealthy biological conditions in the Hartbeespoort Dam, and to simultaneously create job opportunities for the local people. The implementation will take place in two phases. Phase one will focus on establishing biological processes and mechanical harvesting of algae and hyacinths. Phase 2 will focus on the broader catchment impacts, such as improved storm water management, protection and remediation of wetlands and riparian and in-stream river habitats. The alternative is a costly process of pre-impoundment with in-stream treatment to remove the bulk of the phosphorus load. (DWA, 2009)

Harties Metsi A Me project has implemented a number of activities which aim at improving the condition around the dam. The project is busy developing biological and physical means to remove phosphorus from the dam and phosphates flowing into the dam. The recreational use of the dam is being studied, and ways found to manage these activities in order for everyone to participate in them. (DWA, 2009)

Management Activities for the Rehabilitation of the Hartbeespoort Dam

- The management of water quality including the reduction of fertiliser and pollution load from point and nonpoint sources within the catchment
- Controlling and removing of alga blooms and hyacinths
- Removing of accumulated sediments in a sustainable way
- The fish population must be re-established which involves a huge process and will create job opportunities for the local people
- Land use planning and management. The shoreline plant life must be restored for aesthetic purposes and to supply habitat to the fish enhancement of biodiversity in other valuable areas
- Recreational regulations for boating, angling and allowing public access
- Public awareness and education programmes
- Options to treat the water in the dam is being considered and will be implemented in the near future
- The wetlands need to be rehabilitated and artificial wetlands created to assist with water cleansing
- Control and force the wastewater treatment works in the catchment to comply the phosphate standard. All treatment plants should meet the 1 mg/litre maximum phosphorus effluent discharge standard, or do better
- Improvement of storm water management
- Develop a practical system through which the bulk of nutrient rich water could be diverted from the dam
- The water quality in the dam must be monitored on an ongoing basis to ensure long term benefits of the rehabilitation programme. For this, volunteer groups need to be established. (DWA, 2007)

2.6.2 Remediation Methods in Progress

The project has started the rehabilitation of riparian vegetation along the shorelines of Hartbeespoort Dam. Vegetation has been planted out in desolated waterfronts in an order to create buffer zones. Vegetation has also been planted in floating foundations which are called floating wetlands. There are also plans for the rehabilation of wetlands within the Hartbeespoort catchment but it is not known whether any activities have taken place yet. Hyacinths are collected to certain harvesting spots around the dam where they are removed. Also the alga mass is removed by pumping, and the mass is composed together with the hyacinths. Part of the total mass is decomposed using earthworms to convert the waste to humus. The worm project is called Vermiculture and it was started in 2007. When the removing of sediments will start, the aim is to add removed sediments to the compost to produce a soil conditioner. Besides biomass restructuring, there is also a pilot food web restructuring going on in the dam. Three undesired fish species, the carp, the catfish and the canary curper are under fishery. Fishing is done by using nets in the middle of the dam and seines are used near the shore.

FIGURE 10. Floating Wetlands in Hartbeespoort Dam (Kokkinen, 2009)

3 REHABILITATION OF LAKE VESIJÄRVI

3.1 Overview of Lake Vesijärvi

Lake Vesijärvi is a part of the Kymijoki water course which is located in Päijänne, in Southern Finland. In the south, Lake Vesijärvi is limited to the City of Lahti, and in the north the lake is connected to Lake Päijänne through the Canal of Vääksy. Lake Vesijärvi is the 43rd biggest lake in Finland, its area being 109 km^2, and the length of the shoreline covers 181 km. An average depth is 6 metres, and the biggest depth is 42 metres. The catchment area is 515 km^2, and 57 % of that is forests, 24 % fields, 6 % swamps and 11% build-up area. At the shoreline, several environmental protection areas are located. Lake Vesijärvi is known as a habitat for many endangered plants. (Lahti Region Environmental Services, 2009)

3.2 Rehabilitation of Lake Vesijärvi

Lake Vesijärvi used to be clear and there was still a healthy fish population in the 1950s. But, due to ever increasing nutrient loading, the water quality started to degrade, and the poor condition of the lake started to constrict recreational use. Lake Vesijärvi started to become eutrophic, and, in fact, it was one of lakes in the worst condition in Finland in the early 1970s. The lake has suffered decades from different kinds of problems, such as a massive cyanobacteria biomass and blooming, a distorted fish population, and a low oxygen concentration. Shores have become vegetated with reeds and other macrophytes. (The Lake Vesijärvi Project, 2008)

For decades, a big amount of untreated wastewater from the City of Lahti was discharged to Lake Vesijärvi, until 1976 when the new wastewater treatment plant was build. Since then, the treated effluent was discharged to River Porvoo. The lake was also exploited by industry, transport and timber industry. The artificial aeration of the lake was done between 1979 and 1984. These measures were necessary prerequisites for the recovery of the lake. (Kairesalo, Keto, Laine, Malinen, Suoraniemi 1998, 20) Phosphorus concentration decreased within two years after the diversion of sewage load and hypolimnetic oxygen depletions were prevented. The chemical quality of the water recovered a lot especially in Enonselkä, which was one of the most eutrophic parts of the lake. (The Lake Vesijärvi Project, 2008) In the beginning of the 1980s, the water quality in Enonselkä started to deteriorate again when the winter blooms of cyanobacteria reduced the conditions all over Lake Vesijärvi. In 1985, winter blooms declined, and the situation improved for a time, but soon deterioted again due to summer blooming cyanobacteria. (Keto, Malin, Tallberg, Vakkilainen & Vääränen, 2005)

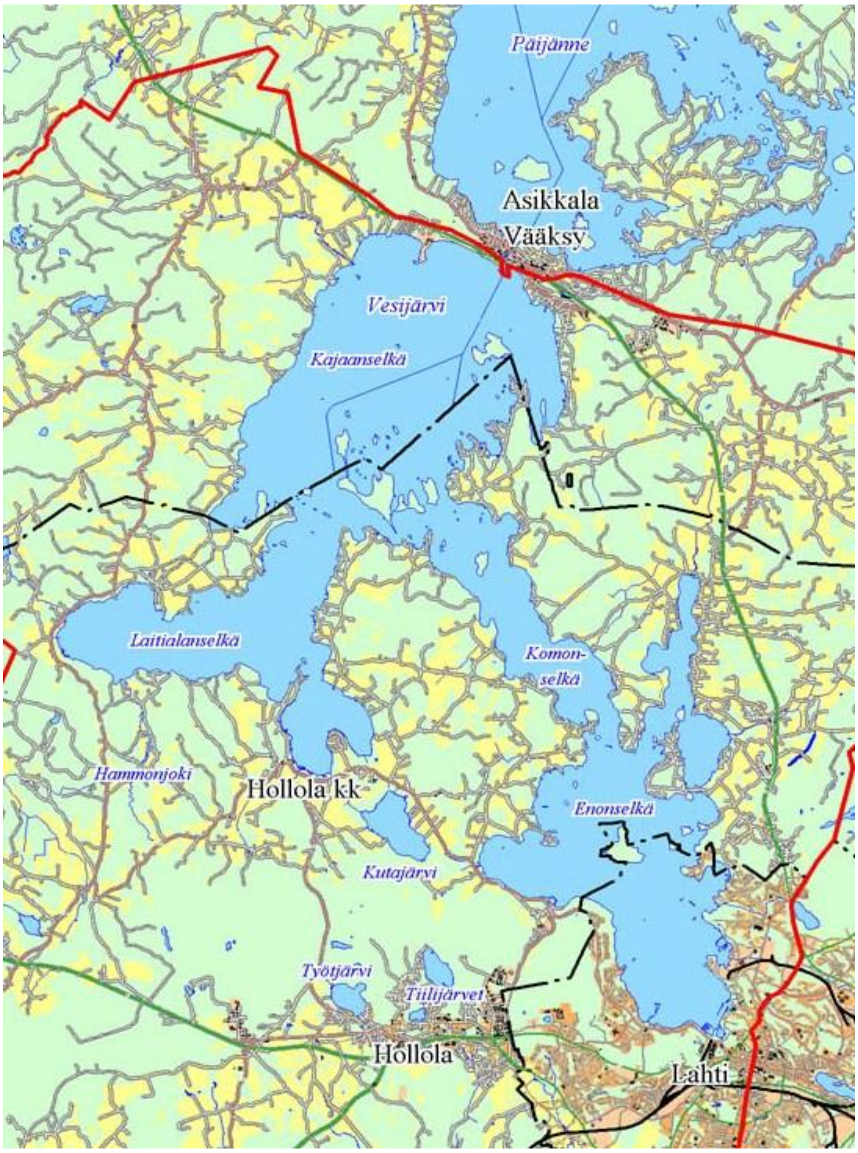

FIGURE 11. Lake Vesijärvi (Päijät-Hämeen Kalatalouskeskus ry, 2010)

3.2.1 Lake Vesijärvi Project 1987-1994

The City Council of Lahti realised in the early 1980's that addressing the problems affecting the lake required a new approach which should be more extensive. The Lake Vesijärvi project (the Ecological Management and Research of the Lake) was initiated in 1987. The goals of the program were to stop the eutrophication, to eliminate the toxic blooms and the mass developments of cyanobacteria, to rehabilitate the recreational values and to re-establish a sustainable fishery in the lake. (Kairesalo, Keto, Laine, Malinen & Suoraniemi, 1998, 21)

Fishery management, also known as biomanipulation, was started already in 1984 but the activity became more efficient when the Lake Vesijärvi project started. Research results revealed that the fish stock density of roach (*Rutilus rutilus*) increased the internal load, and it also affected alga blooming. 500 000 kilograms of roaches were removed from Lake Vesijärvi in five consecutive years. Also predatory fishes like pike (*Esox lucius*) and pikeperch (*Sander lucioperca*), which prey on roach, were restocked to the lake. At the same time with the biomanipulation, traditional water protection and the remediation of shorelines were done. The sewerline of the City of Lahti was also repaired to decrease external load. Environmental management plans were made to farms located in the catchment area, and settling pools were built to decrease the washing of nutrients from the fields. Due to pollution control and the biomanipulation, the blooms and the mass developments of cyanobacteria vanished since 1990, and the fish stock became more stable and water lighted up. The recreational values of Lake Vesijärvi were thus restored. (Lahti Region Environmental Services, 2009)

3.2.2 Lake Vesijärvi II Project 2002-2007

In 1997, the condition of Lake Vesijärvi started to become weaker again, and the need for water protection and the intensification of lake management was noticed. The state of the lake was especially bad when examined the cyanobacteria and oxygen situation during 2001-2003. The aim of the new Lake Vesijärvi project was to prevent the disadvantages of eutrophication, and to secure a recreational and fishery usage covering the whole surface of the lake. In the 2000s, fishery management has been further strengthened, and it has proven to be one of the most important issues in the prevention of eutrophication. Fishery management has improved water quality, which has had an influence on recreational purposes and on the usage, and livelihood of fishery and travelling. Other measures in the project were the remediation of catchment areas and shorelines, the mowing of aquatic plants, and the restoration of breeding grounds for fishes. Wastewater treatment systems in cattered settlements were inspected and updated. (The Lake Vesijärvi Project, 2008)

3.2.3 Current Situation of Lake Vesijärvi

In the beginning of the 21st century, oxygen concentration in Enonselkä has been varying strongly during summer times, and in 2005 and 2006, the oxygen situation was even worse than during the worst polluted period of Lake Vesijärvi in the 1970s. At the same time, warm weather has increased the temperature of hypolimnium. When the weather has been cooler, the oxygen situation has been better. (The Lake Vesijärvi Project, 2008) According to the results (year 2009 average values) given by the measurement stations in Enonselkä, the oxygen concentration measured from 10 m depth was at its lowest in August (4.75 mg/l), and at it highest in November (11.25 mg/l), before the ice-cover of the lake. Chlorophyll α was at its lowest in July (12.71 µg/l), and at its highest in November (18.63 µg/l). Blue green alga situation in the whole lake was at its best in May (0.64 mg/l), whereas the worst situation was in November (6.74 mg/l). (Lake Vesijärvi Foundation, 2009) Figures 12 and 13 show the water quality data collected over the years in Enonselkä and Kajaanselkä. All values are average values of at least 20 measurements.

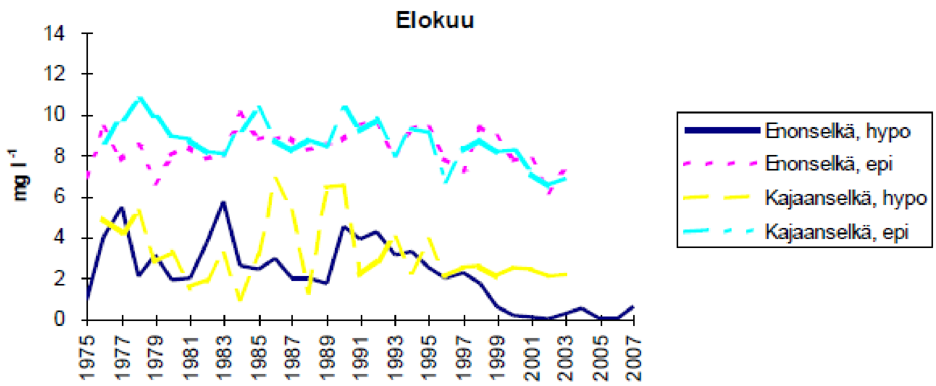

FIGURE 12. Oxygen Concentrations in August (mg/l) hypo = hypolimniun, epi = epilimnium (The Lake Vesijärvi Program, 2008)

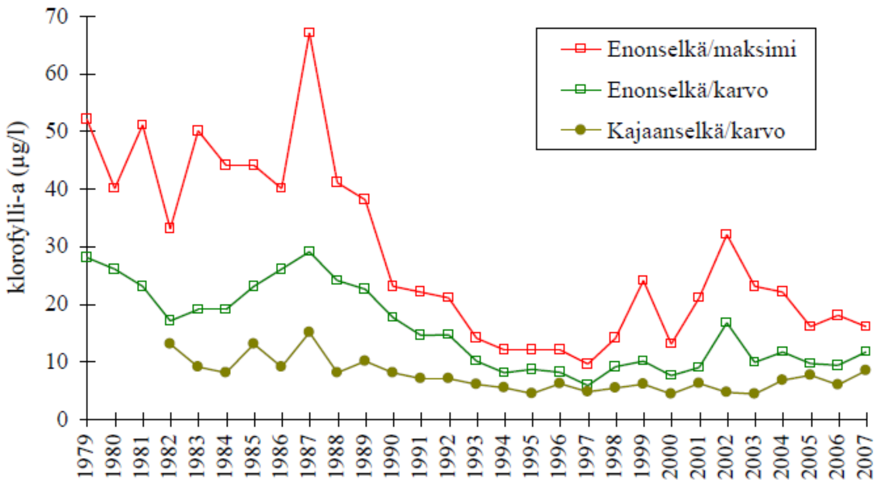

FIGURE 13. Chlorophyll α Concentrations Red line indicates a maximum value, other two indicate average values. (The Lake Vesijärvi Program, 2008)

The two Vesijärvi projects taught that Lake Vesijärvi will not stay in a proper state without continuous management. In 2008, the Lake Vesijärvi Foundation was established to ensure a continuous follow-up and research of the lake. The founder members of the foundation were the City of Lahti, the municipalities of Hollola and Asikkala, the Lahti Industry association inc., Esan Kirjapaino Ltd., and Kemppi Ltd. The Lake Vesijärvi Foundation has managed to get cooperation partners who are each committed to fund at least 10 000 euros annually to the management of the lake in the following three years. Besides the main cooperation partners, there are other partners (e.g. parties from industry, business and media) who support the foundation with a varying amount of money. The Lake Vesijärvi Foundation has directed a planning document, The Lake Vesijärvi program, whose aim is to plan the water management of Lake Vesijärvi and other lakes nearby. The current Lake Vesijärvi program covers the years 2009 – 2011. The program is being updated every autumn (or often if the circumstances change, or new research information is revealed) and continued a year ahead. (Lake Vesijärvi Foundation, 2009)

In the European Union countries, the EU Water Framework Directive forms a basis for water protection. The directive concerns both surface waters and groundwaters. The idea is to prevent deterioration in the water quality, and to achieve a good state of all waters within the EU area by 2015. For waters classified as less than good, required actions are needed to achieve a good ecological and chemical status. According to the definition given by the directive, the ecological state is comparable to the consequences caused by human activities. Ecological status is determinated according to the appearance of organisms living in the water, the abundance ratio, and the structure of the species. When evaluating the state of surface waters, also the assessment of hydrological and morphological state are required besides the assessment of ecological and physico-chemical state. (Finland's Environmental Administration, 2010)

When the ecological status of Lake Vesijärvi was evaluated, the lake was divided into two sections; the southern part and the northern part. The southern part mainly considers the Enonselkä area (see Figure 11. Lake Vesijärvi Catchment Area) which still remains the most problematic part of the lake, and therefore it was classified as acceptable by its ecological state. The average concentration of total phosphorus in Lake Vesijärvi during 2002 – 2007 was 25 mg/m^3. The concentration of 18 mg/m^3 has been set as a target for the total phosphorus, whereby the need for the reduction of phosphorus load (12 600 kg/a) is 30 %. The reduction demand for chlorophyll α is also 30 % and for nitrogen it is 10 %. The northern part was classified good by its ecological state, therefore no special actions were required on behalf of the EU. Still the area must be kept an eye on. (Tavastia Regional Environment Center, 2009)

4 DEVELOPMENT PROPOSALS TO THE REMEDIATION METHODS OF HARTBEESPOORT DAM

This chapter suggests few development proposals to the remediation methods of Harties Metsi A Me project, mainly on the basis of the case of Lake Vesijärvi experience. The rehabilitation of Lake Vesijärvi is well known around the world, and similar rehabilitation efforts have been done elsewhere. Local people and active citizens, experts, water and other authorities, schools and companies were involved into the rehabilitation. The cooperation of different parties had an important role in the recovery of the lake, and the cooperation is still needed. Although Lake Vesijärvi has recovered significantly from its worst state, it will not stay in a proper condition without continuous management. External load is still bigger than the tolerance of the lake. In the management of Lake Vesijärvi, the decreasing of external load is the main object, as well as keeping the inner load of the lake under control by fishery management and oxidation.

The rehabilitation of the Hartbeespoort Dam is a large scale remediation project, and many great efforts have already been done in an order to improve the state of the dam. As always, there are still sectors to be improved, and new remediation methods can be considered as potential options for the Harties Metsi A Me project. Likewise, in the case of Lake Vesijärvi, reducing the external load is also the main object in the Hartbeespoort Dam. If nutrient loading to the dam is uncontrollable, other remediation methods in the dam are almost cosmetic. The situation could be compared to a comatose person lying in a hospital bed who is kept alive with the help of artificial respiration. The person is not really cured but kept alive.

There are some big differences in the sources of external load, if Lake Vesijärvi and the Hartbeespoort Dam are compared. Large unofficial settlements around the Hartbeespoort catchment are one of the major sources of phosphorus load of the dam, and the lack of sanitation is an important matter which should be interfered in, if the phosphorus load is wanted to get under control. Therefore, the issue of sanitation is dealt in this study, focusing on composting dry toilets. Other suggested development proposals are buffer zones and the intensification of phosphorus removal and fishery management. The main object has been to consider methods which will lead to the decreasing of phosphorus in the system. When suitable remediation methods were considered with the Hartbeespoort Dam, the management activities of Harties Metsi A Me project (in the chapter 2.4.1 Harties Metsi A Me Project) were kept in mind. The most central were:

- The fish population must be re-established, which involves a huge process and will create job opportunities for the local people
- Water quality management including the reduction of fertiliser and pollution load from point and nonpoint sources within the catchment
- Options to treat the water in the dam is being considered, and will be implemented in the near future
- The wetlands need to be rehabilitated, and artificial wetlands created to assist with water cleansing
- All treatment plants should meet the standard of 1 mg/litre maximum phosphorus effluent discharge, or do better

In some rehabilitation cases, after the reduction of external load, the state of lake is not improved, and in that case the reason lies in the lake itself. Therefore, the controlling of inner load of the dam is at least as important as the controlling of the external load. In the reduction of the inner load of the lake, fishery management has proved an effective method in many rehabilitation cases. Still, fishery management alone can not necessarily solve the problem, because a part of the inner load is caused by factors like the lack of oxygen in bottom waters, high pH or the movement of sediments caused by wave actions. Fortunately, unlike in the case of comatose patience, there are many possibilities to improve the state of a polluted water reservoir. Still, the rehabilitation of a reservoir requires long term management and enough resources, as well as cooperation with different parties. Most of all, water monitoring is needed to support successful recovery. Water monitoring is dealt separately in chapter 5 Development of Water Monitoring.

4.1 Buffer Zones and Sedimentation Basins

Buffer zones have already been constructed around the dam by the Harties Metsi A Me project. Management plans have been made for the catchment of the Hartbeestpoort Dam as well, but it is not known (for this study) what activities have been planned or already implemented. Usually problems that cause the need for rehabilitation activities, are mainly caused by the loading from the catchment. Thus, it is important to define the external load coming into a lake and implement management activities for the catchment areas. This chapter introduces two methods aiming to reduce nutrient loads flowing into the dam caused by agriculture, industry, mining and settlements. The first method is to create buffer zones along the rivers of the Hartbeespoort Dam catchment. The second method is to create sediment basins which also function as buffer zones.

A buffer zone is a zone aside lake, river, main ditch or brook which is usually at least 15 metres wide and covered by perennial vegetation. Buffer zones are usually located between a water course and fields. Zones are kept free from fertilisers and pesticides to minimise nutrients entering the water with runoffs. Buffer zones decrease solid matter and nutrients drifting to the water, and reduce shoreline erosion. It has been stated that the buffer zone decreases 30 – 40 % of the phosphorus load coming from fields to the water course, and 60 % of the solid matter load. The buffer zone must be cared for by mowing or grazing, so that it would work effectively. (Lakso & Ulvi, 2005, 144) The buffer zone offers more habitats for animals and plants providing food, shelter and shade, and this way increases nature's biodiversity (Pirkanmaa Environment Centre, 2009).

Natural wetlands play a role as buffer zones but nowadays wetlands are shrinking and disappearing because of human actions. Natural wetlands can be rehabilitated or new wetlands can be founded. A proper wetland can adsorb a third of the nitrogen load and over the half of the phosphorus load annually. The functioning of the wetland can be strengthened by placing an automatic phosphorus precipitating machine to a ditch or a river flowing to wetland, so soluble phosphorus from the mass of the water can be adsorbed to the sediment. The wetland can also be used for example as an irrigation basin. (Lake Vesijärvi Program, 2010)

Sedimentation basins can also be used to remove sediment and nutrients from runoff. Earlier there were differently sized and shaped basins usually along the ditches of fields of which some were full of water around the year, and some mainly controlled flow rates caused by flooding. Modern agriculture has demolished those natural sediment basins and wetlands. The functioning of the sedimentation basin is based on the stratification of sediment when the flow velocity decreases. The longer water stays in the basin, the smaller particles manage to settle and the better the basin works. According to the surveys, the surface area of the basin should be at least 1 % of the surface area of upper catchment in agricultural area. (Lakso & Ulvi, 2005, 146)

The best place to the sedimentation basin is a hollow of ditch or brook where the excavation of ground is avoided. The sedimentation basin can be founded by damming water to the hollow, and that way the edges of the basin are already surrounded by natural vegetation. If the basin has to be excavated, it will load to the water course for months, sometimes years, because of erosion. (Lakso & Ulvi, 2005, 146) The sedimentation basin is excavated in the place where the flow of water naturally slows down. Basins are placed enough far away from an outlet ditch to avoid the effects of floods. The banks of the sedimentation basins are excavated as gently as possible to avoid erosion and to help animals to get out if they accidentally end up there. (North Ostrobothnia Regional Environment Centre, 2005)

The sedimentation basin has to be emptied from sludge occasionally, like once a year, and everytime if ditching is done in the catchment area. Many little sedimentation basins in the top of the catchment are much better than the single big basin in the lower part of the catchment. That makes management much easier. Emptying little basins from sludge can be made for example by using a tractor-mounted excavator. Removed sludge can be utilised in fields. (Lakso & Ulvi, 2005, 146)

FIGURE 14. The Sedimentation Basin of Purailanviepä (Lahti Region Environmental Services, 2010)

4.2 Intensification of Phosphorus Removal

Major part of the phosphorus load flowing to the Hartbeespoort Dam originates from the discharge of treated effluent from wastewater treatment plants located in the catchment area. If a persistent change in the phosphorus load of the dam could be seen, the efforts of decreasing the phosphorus amount should be targeted to the sources of phosphorus loading, and thereby the wastewater treatment plants are good targets to get started. The 1 mg/l phosphorus standard, which was discussed in the chapter 2.2.1 External and Internal Load, is a good objective which should be made to work in all the wastewater treatment plants. Yet, some treatment plants are not even close to the concentration of 1 mg/l, so the phosphorus removal process should be made more efficient. In the Kariniemi wastewater treatment plant of the City of Lahti, the maximum permissible total phosphorus concentration is 0.5 mg/l, but usually the concentration has been even smaller (in 2008, the average concentration was 0.14 mg/l).

Phosphorus removal in wastewater treatment plants can be done in three ways, chemically or biologically, or these two prosesses can be combined. In Finland, the most common way is the combined way, in which orcanic particles are removed biologically and phosphorus is chemically removed by using chemicals to precipitate the phosphorus. By using this method, the phosphorus removal has been approximately 95 %. (Finland’s Environmental Administration, 2009) Biological phosphorus removal is used in South Africa. Unfortunately, more detailed information about the phosphorus removal process in wastewater treatment plants was not found for this study.

In chemical phosphorus removal, a chemical is added to wastewater, and it reacts with soluble phosphorus and forms a phosphate sediment. The sediment is removed by using a settling. Chemical precipitation includes three different stages. *Quick mix*, where chemical is mixed to wastewater efficiently for 20 seconds and the first sediments are formed. During *flocculation*, sediment particles grow and become more descenting. This stage takes 20-30 minutes and during it the waste water is mixed slowly. During *settling*, sediment descents to bottom or it is raised to the surface by using a flotation. Sediment is removed to sludge treatment. Different precipitation chemicals are ferrous sulphate, ferric sulphate, ferric chloride, aluminium sulphate or polyaluminium chloride. (Finland’s Environmental Administration, 2009)

4.2.1 The Intensification of Phosphorus Removal Project in Saint Petersburg

The City of Saint Petersburg in Russia is the biggest single polluter of the Gulf of Finland and the Baltic Sea. Still 15% of the city’s untreated wastewater is led to the Gulf of Finland. The Ministry of the Environment of Finland and Saint Petersburg’s treatment plants started an experimental chemical phosphorus removal in 2005. The purpose is to combine chemical phosphorus removal with an existing biological phosphorus removal process in the most cost-effective way as possible. The experiment has made the phosphorus removal more efficient already at six wastewater treatment plants, and the aim is to achieve 1.0 mg/l for the phosphorus

concentration of treated wastewater by 2015. The project is supported by the Ministry of the Environment of Finland and it is implemented by Saint Petersburg's treatment plants, John Nurminen Foundation and Kemira Oyj.
(Finnish Ministry of the Environment, 2009)

Chemical phosphorus removal in three wastewater treatment plants of Saint Petersburg will reduce nearly 27 % of the phosphorus load usable to algae which is coming to the Gulf of Finland. The Keskinen wastewater treatment plant treats a half of the wastewaters of Saint Petersburg, and it is estimated that more efficient phosphorus removal in the treatment plant would decrease the phosphorus load 600 tons a year which is 10-12 % of the total phosphorus load coming to the Gulf of Finland. According to the Finnish Environment Institute, the project provides the most cost-effective and fastest way to improve the state of the Gulf of Finland when compared to all the possible water protection actions that could be done in Finland and Russia. (John Nurminen Foundation, 2010)

Before 2005, none of Saint Petersburg's wastewater treatment plants used any chemicals for the precipitation of phosphorus. This means that even though the majority of Saint Petersburg wastewater is conveyed to wastewater treatment plants nowadays, only a part of the phosphorus is removed in purification processes. Earlier, the aim of the purification prosesses was only to remove solids and biochemical oxygen demand. The Finnish Ministry of the Environment has supported the purchase of dosage equipment for the precipitation chemicals to Saint Petersburg. (Kemira Water, 2007)

4.2.2 Phosphorus Precipitation on the Dam

Phosphorus precipitation straight on Hartbeespoort Dam or in rivers is an alternative to the intensification of phosphorus removal implemented in wastewater treatment plants. However, this method is not very cheap, and thus, the aim is not to spread precipitation chemicals to cover the whole surface of the dam. The chemical precipitation of phosphorus is a method whose aim is to adsorb soluble phosphorus, which is usable to plants, to the sediment from the mass of water by using different kinds of chemicals. The precipitation also improves the sediment's own capability to adsorb phosphorus. Chemicals like ferrosulphate, aluminium sulphate or aluminium chloride are normally used. The precipitation decreases the concentration and the circulation of phosphorus between the mass of water and the sediment. As a consequence, internal load decreases. (Lakso & Ulvi, 2005, 191)

Chemical precipitation is suitable for smallish and badly eutrophic lakes, and it is easy to put into practice. The benefits of this method are fast impacts (the results are shown up immediately) and a quite low cost when implemented in small lakes. Phosphorus concentration decreases rapidly, alga blooms decreases significantly or can even disappear, water will become brighter, and secchi depth increases. Undesired effects are possible fish deaths and a short duration of action. Fish deaths can be avoided by using a right dosage and the right spreading of chemical. (Lakso & Ulvi, 2005, 193) If the fish stock keeps up and maintains eutrophication, like in the Hartbeespoort Dam, fish deaths could even be wanted and planned. This is called chemical biomanipulation. It has been used inter alia in Lake Kirkkojärvi in Finland.

The period that water stays in a lake has its effect to the duration of action of the precipitation. If the period is short, under one or two years, the water in the lake will be replaced by new water from the catchment. A part of the total effect is caused when phosphorus is absorbed to the bottom sediment which prevents internal load. This can make the duration of action of the chemical longer than would be the time that water stays in the lake. One way to make the duration of action longer is to convey the chemical straight to the bottom water, in which case the quality of epilimnion is not changed. In this way, the chemical dosage is bigger to unit volume when no chemical is used to precipitate the phosphorus in upper water layers. The durability of effects depends on the characteristics of lake, the chemical used and its dosage. Usually, it is necessary to repeat the chemical treatment after a few years of the first prepitation. (Lakso & Ulvi, 2005, 194)

In the case Lake Kirkkojärvi, the lake was very badly eutrophicated and it suffered strong algal blooming. The average phosphorus concentration was 240 µg/l in 1996-2001. Phosphorus was precipitated with aluminium chloride in two different times in 2002. At the first time, phosphorus concentration decreased from the starting level of 190 µg/l to the level of 53 µg/l but pH did not decreased because of strong buffer capability. The water did not get bright enough and fishes did not die so the manipulation was decided redo. At the second time, pH decreased and killed almost the whole fish stock. The water got brighter and the phosphorus concentration decreased to the level of 14 µg/l. Monitoring has shown little increasing in the phosphorus concentration level after precipitation, but all in all, the concentration has decreased 70-80% from the starting level and blue green algal bloomings have disappeared. (Lakso & Ulvi, 2005, 201)

The need for the chemical, when doing precipitation, is 10 – 100 g/m^3 depending on the buffer capacity of a lake. The prize level of aluminium chloride and ferric chloride is 250 – 300 €/tons (2005) depending on the usage amount. Lake Kirkkojärvi is an example of very intensive treatment method which aims at removing the fish stock and phosphorus with precipitation at the same time. In other words, the chemical biomanipulation takes place. The cost of precipitation was 55 000 €. Chemicals were used 75 g/m^3 (90 tons in total) in the first stage, and 83 g/m^3 (100 tons) in the second stage. The surface area of Lake Kirkkojärvi is 42 ha, average detpht 2.8 metre and volume is 1.2 million m^3. (Lakso & Ulvi, 2005, 195 - 201) The surface area of the Hartbeespoort Dam is 20 km^2 and the volume is 110 - 150 million m^3. Therefore, the surface area of the dam is 47 times bigger than the surface area of Lake Kirkkojärvi and the volume is 100 times bigger.

If phosphorus precipitation was considered to be used in the Hartbeespoort Dam, it should be done only in the basins of the dam, not in the whole dam. Otherwise, the treatment would be too expensive because of the large size of the dam. Other options of phosphorus precipitation are to convey the precipitation chemical just to the hypolimnium or to precipitate phosphorus in the rivers flowing to the dam (e.g. the Hennops River, the Juksei). The City of Lahti is using a phosphorus precipitation station in one brook that automatically doses a certain amount of precipitation chemical to the water. In this way, the chemical supply is kept optimal all the time.

4.3 Ecological Sanitation - Composting Dry Latrines

The lack of sanitation and undeveloped sanitation forms are polluting the environment, especially surface and ground waters. Latrine waste includes lots of nutrients, organic oxygen consuming substances and pathogens. Latrine waste is also a health risk when ended up to nature. In waters, the pathogens will stay alive from few days to few months, and several months in soil. All over South Africa, as well as in the Hartbeespoort Dam catchment area, informal settlement areas can be found, which do not belong to any sewer network and therefore have improper sanitation. Ecological sanitation is a good option to be used in South Africa because the scarce water resources of the country can be preserved and the further pollution of the waters can be prevented.

Ecological sanitation is based on a nutrient cycle and latrine waste is considered as a valuable resource and not a cast-off waste. Latrine waste is not mixed with water and conveyed elsewhere, but composted in situ. The ecological sanitation solution prevents diseases, protects the environment and is simple and economical. Out of biological waste treatment methods, the composting of latrine waste is the best method when making latrine waste hygienic. Compost soil is suited to be used as fertiliser, soil enrichment material and earth filling material. At the same time, the use of artificial fertilisers is avoided. (Järvelä 2009, 15-16)

Successful decomposition demands optimal moisture ratio, temperature and enough oxygen. Humidity can be controlled by dewatering and watering, by mixing –up dry litter with latrine waste and by using ventilation. Dry litter should be carbonic organic material so that the optimal carbon – nitrogen ratio 25:1 would be achieved. Materials such as different grass, wood and peat –rich materials (such as leaf litter, sawdust, peat, kitchen waste or even plain soil) are suitable to be used as dry litter materials. (Järvelä, 2009, 17) Many composting dry latrines do not achieve the optimal temperature (+45-55ºC) but the temperature stays under +37ºC. In that case, the hygianization of waste has to be made more effective by increasing the storage time. (Järvelä, 2009, 17)

The basic rule for the safe use of compost soil can be considered a year of composting. During that time, fresh latrine waste can not be mixed up with old latrine waste. The separate collection of urine and excrement decreases the volume and the smell of compost material and prevent possible runoffs to soil and surface waters. Dry excrement includes fewer pathogens than the wet mix of excrement and urine. After one month storage time, plants that are not eaten raw can be fertilised with urine, and after six month storage time, urine can be used as fertiliser to all plants. (Järvelä, 2009, 18)

Not all the ecological sanitation solutions are cheap, but they are cheaper than building a drainage system and its maintenance. Various types of composting latrines can be found around the world. Composting pit latrine is a cheap and simple option but demands a moving of the place of latrine when the pit is filled up. Pit latrine consists of a metre deep pit and a lid. It is not suitable for areas where ground water is very high or the soil is hard or porous. (Huuhtanen & Laukkanen, 2005, 27) Composting dry latrines were choosed to be studied in this thesis due to many benefits of the solution. There is also a composting dry latrine project going on in the city of Ho in Ghana. The project is a part of the Environmental cooperation project between the City of Ho and the City of Lahti.

4.3.1 Dry Latrine Technique

There are many kinds of dry latrine models, so suitable solution for every culture can be found. A common factor for the models is that latrine waste is composted completely or partially in a waste container. When latrine waste is composted only partially, a latter composting is needed. (Järvelä, 2009, 19) In a single container latrine, the waste is moved to the separate container to be composted after the waste container has been filled up. There are also waste containers with wheels, which are changed to new ones after the former has filled up.

In order to compost the waste in the latrine in situ, and the separate latter composting and the constant moving of waste could be avoided, dry latrines with two containers have been developed. Their function is based on rotation. After the first container has filled up, it is closed and left to compost. Meanwhile, the second container is in use. Containers should be dimensioned so that one container would be adequate for the waste amount produced per annum. The material of the containers can be any watertight material like a concrete or a brick. There are also so called carrousel latrines, whose waste container is divided into four sections and each one is used in turns. The benefits are that the user does not have to be in contact with raw latrine waste and the emptying of the containers happens seldom. Still, the same benefits can be achieved more economically with twin container latrines, when there is no need to pay extra for the movable container. (Järvelä, 2009, 20)

In dry composting latrines, the handling of urine can be done in three ways. *Composting urine together with excrement*: there is a risk that the waste mass will became too wet and may start to decay. This can be prevented by making the ventilation more effective, or installing solar panels to the lid of the container, so that the dehydration of waste would accelerate. *Separating urine and composting excrement*: demands a designed seat or a "squat mould" which is developed for the squat position. *Filtering urine and composting excrement*: does not require the specific seat. Urine is filtered through excrement to the separated container. Because urine has been in contact with excrement, it must be stored before the use to destroy the pathogens. (Järvelä, 2009, 21)

4.3.2 Sanitation Project

A thorough background survey (social, economical, cultural and economical factors), and the consideration of local circumtances are requisites for a succesful sanitation project. The project should be based on the own needs of the users and the users should be taken along into planning and implementation. (Järvelä 2009, 24). Composting dry latrines have to be maintained regularly, so that people would use them and the latrines would be hygienic. Cleaning should be done every day. When cleaning the latrines, the floor and the hole for excrement can be cleaned with a brush or washed with water, but in that case, it must be careful not to pour much water to the latrine. Ash can also been used to make the floor hygienic. (Järvelä, 2009, 40)

The sanitation project would create valuable job opportunities for local people and support domestic or local economy, and therefore, the project would accomplish one of the management activities of the Harties Metsi A Me project: job creation. All materials needed, could be provided from the domestic market. The project would employ several people in a building state, and after the completion, some people would be employed for the maintenance of the latrines. There must be certain people in charge of the maintenance, because otherwise, it will not work out if each user is supposed to do the cleaning in ones turn in a certain day. Besides the cleaning, there are duties such as the emptying and the moving of the waste containers or the replacement of full urine tanks with the empty ones. There should also be training to all users about how to use the latrines appropriately and how to maintain the cleanliness.

4.4 Intensification of Fishery Management

With fishery management (other terms: food web remediation, biomanipulation), the aim is to improve the state of waters by reducing undesired fish species developed due to eutrophication with an intensive fishery. Besides, intensive fishery, fishery management can also mean management fishery, which is not as effective as intensive fishery. The fishery management project of a lake starts with intensive fishery, and when an optimal fish structure is obtained, the fishing is continued as management fishery. With management fishery, the aim is to maintain the current level of fish populations and to prevent the further deterioration of water quality. The undesired fishes targeted under the removal are those who feed on zooplankton, or are whirling up bottom sediments releasing nutrients back to the water.

The reduction of smaller fishes can lead to a remarkable improvement of secchi depth and the decreasing of inner phosphorus load. In clearer water, light is able to penetrate to greater depths, enabling the colonization of macrophytes on deeper bottoms. The colonization of submerged macrophytes plays an important role in the recovery of a lake. Macrophytes stabilise the bottom sediment, bind nutrients and offer refuges and feeding areas to zooplankton and fishes, thereby preventing the algal blooms and contributing the recovery of the lake. (Kairesalo, Keto, Laine, Malinen, Suoraniemi, 1998, 37) With intensive fishery, the complex interactions of the food web can be changed to be less favourable for the blue green algal blooms.

Lots of nutrients are accumulated to the fish stock of eutrophic lake, and thereby, the amount of fishes has its influence on the water quality. It is estimated that 10 % of the total phosphorus in Lake Vesijärvi is removed along the undesired fishes (Riihijärvi, 2010). Last year, the management fishing catch in Lake Vesijärvi was 219 000 kg, of which the half was caught by professional fishers, and the other half was caught by the staff of Lahti Region Environmental Services and voluntary fishers. Approximately 0.6 % of phosphorus absorbs in a fish, so last year, 2.1 tonnes of phosphorus was removed among the fishes from Lake Vesijärvi. For example, the same amount of phosphorus is ended up to the lake along natural washing or along the deposit from air. (Kaupunkilainen, 2010)

The recovery of Lake Vesijärvi is a great example of the efficiency of fishery management in the prevension of problems caused by eutrophication. In the first Lake Vesijärvi project, experiments to test the suitability of seine and fyke net fishing for intensive fishery were started. Methods were discovered cost-effective and even very young roach fishes were caught with them. (Lakso & Ulvi, 2005, 186) Later on, fishing with trawls was left out and used only in the fish population surveys. Nowadays, in winter fishing, more fish traps are used instead of seines. The fish traps developed for management fishing have proved effective in the niche fishing of roach fishes. Seine, fyke net and fish trap fishing enable releasing valuable predatory fishes undamaged back to the lake. (Lahti Region Environmental Services, 2010)

Nowadays, as intensive fishing as in the 1980s and in the 1990s is not needed anymore because the water quality is much better and the structure of the fish population have improved much. The utilisation of smelt and European perch has grown as big as the utilisation of vendace. Besides before mentioned, also roach is utilised nowadays, and opportunities to export have opened up to the different parts of Europe. (Lahti Region Environmental Services, 2010) The stocking of fishes – value fishes for recreational fishing and predatory fishes for the biomanipulation purpose - is still continued. The aim of the stocking is that growing predatory fishes would feed on the undesired smaller fishes, and thereby would contribute the balance of the food web, and, at the same time, act as biomanipulators decreasing the intensity of management fishing. According to Lake Vesijärvi program (2008), the aim for the fishery in Enonselkä for the next five years, is to collect 30 kilograms of undesired fishes per hectare, altogether considering 78 000 kg/a. For the whole lake, the level of management fishing is set to 20 kg/ha which considers 200 000 kg of fishes.

Currently in Hartbeespoort Dam, three undesired fish species carp, catfish and canary curper are under the fishery. The fishing is done by using nets in the middle of the dam, and seines near the shoreline. A total of 65.8 tonnes of fish has been removed between February 2008 and December 2009. In order to achieve the desired bioremediation effect, it is recommended that the fish community should be restructured by the removal of 200-300 tonnes of coarse fish (carp and catfish) during the first year of the fisheries exploitation project, and to continue the reduction of the standing crop to 20% during the second year (DWA, 2010). To reach the target set for the fish catch, the fishing should be intensified - the average catch per year (till December 2009) being currently 35.9 tonnes. The amount is very low, for example, when compared to the catches of management fishing in Enonselkä between 2000 – 2005 (See Table 2).

TABLE 2. Fish Catches in Lake Vesijärvi and Enonselkä (Päijät Hämeen Kalatalouskeskus ry, 2007)

	Enonselkä	Lake Vesijärvi
2000	68 620 kg	110 600 kg
2001	48 110 kg	84 385 kg
2002	59 645 kg	94 311 kg
2003	60 710 kg	234 249 kg
2004	38 300 kg	158 909 kg
2005	38 150 kg	184 427 kg

In the beginning of the fishery management project, it is important to catch fishes as efficiently as possible. In the second or the third year of the project, it must be repaired to remove the younger age class of the fishes, which often are born after the first intensive fishing period. Otherwise, the lake is about to fill up rapidly with the new age class of roach fishes. Some cases are known in which the preying aimed at zooplanktons has increased after the short-term intensive fishing. (Lakso & Ulvi, 2005, 180) In Lake Vesijärvi, the roach population was succeeded to retain clearly smaller than earlier by doing five-year intensive fishing, and by doing management fishing after that. Between 1989 – 1993, 1 100 tonnes of fish (mainly roach and smelt) were caught with trawl fishing from the area of 26 km^2 in Enonselkä. The total catch was 423 kg/ha and the average annual catch was 84 kg/ha. (Lakso & Ulvi, 2005, 186) But as it can be seen in the Figure 15, the first two years in Lake Vesijärvi, went for searching enough efficient fishing methods, and therefore fish catches were small.

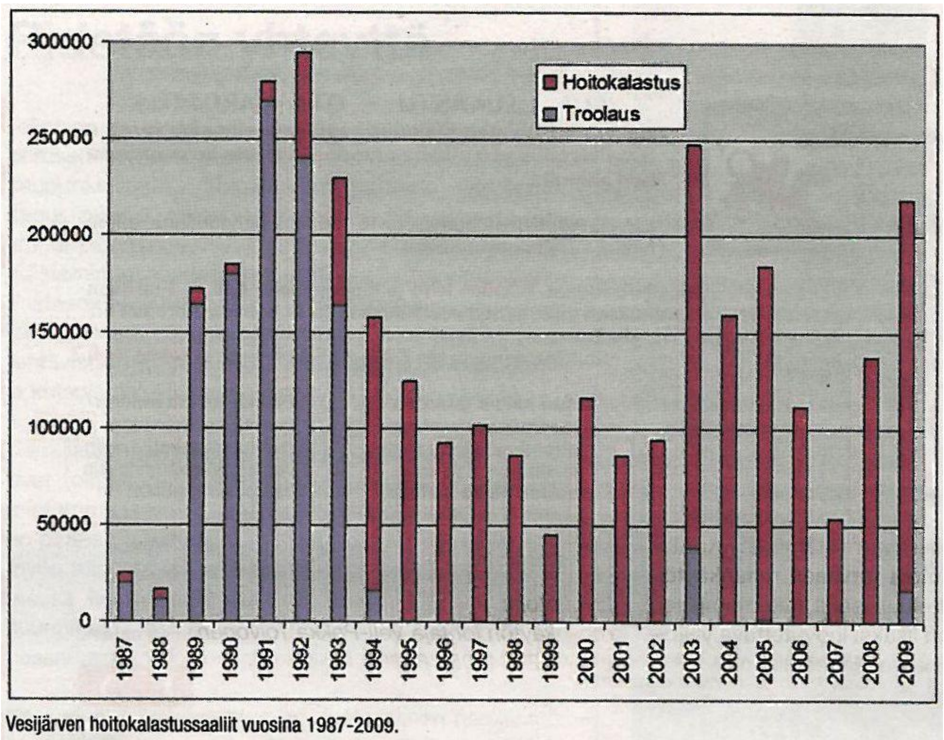

FIGURE 15. The Fish Catches of Lake Vesijärvi in 1987 – 2009. Blue columns show intensive fishing and red columns show management fishing. (Kaupunkilainen, 2010)

Also the fish catches of Hartbeespoort Dam are very likely going to increase considerably when more optimal and efficient fishing methods and equipment are discovered. However, decent fishing equipment and methods do not ensure big fish catches yet, if the fishing is done in wrong locations. “The fishing project should be supplied with a pH and dissolved oxygen level meter. It is postulated that fish will only be found in areas where the conditions are optimal, namely areas where dissolved oxygen levels are the highest.” (De Jager & Maré, 2009, 121) Also the fish surveys must be carried out regularly to point the fishing into right spots and to assess achieved results.

FIGURE 16. Local People Repairing a Seine (Pyydystalkoot) (Lahti Region Environmental Services, 2010)

The rehabilation of Lake Vesijärvi is largely based on a voluntary work continued more than 20 years. In Lake Vesijärvi projects, the methods of fishery management have been developed over the years. Voluntary fishers have been trained to adopt new methods and to use new equipment. Training has also been done in an event called Pyydystalkoot, which has been organized annually already over 15 years time. The event lasts few weeks and during the event, new seines and traps are done and old ones are repaired by voluntary people, mainly fishers. At the same time, a lecture –day is held to give information to people what has happened and what is happening in Lake Vesijärvi.

In the fishery management of the Hartbeepoort Dam, different possibilities of the utilisation of cooperation in fishery management could be considered. However, examples like the voluntary based work from the Case Lake Vesijärvi can not necessarily adapt as such to the rehabilitation of the Hartbeespoort Dam because of the differences in cultural and social backgrounds. In South Africa, unemployment rates are high, and one of the objectives of Harties Metsi A Me –project is to create job opportunities to local people. For that purpose, the fishery management project suits very well.

One remarkable difference in contrast to the Case Lake Vesijärvi is that the fishes of the Hartbeespoort Dam are not eatable. That was the situation also in Lake Vesijärvi, when the lake was in its worst state. Nowadays, fishes from Lake Vesijärvi can be utilised in many ways than just composting, and fish catches bring incomes to parties involved. Later on, when the water quality will improve in the Hartbeespoort Dam affecting favourably to the fish structure and allowing the utilisation of fishes more versatile way, there will be more possibilities to utilise voluntary work and the cooperation of different parties in fishery management.

5 DEVELOPING OF THE WATER MONITORING OF THE HARTBEESPOORT DAM

Information is an essential part of water management. Without a reliable and long-term monitoring data it is impossible to manage a water course in a right way. Information is required on water quality, volum, seasonal variation and changes happening in water due to weather conditions, aquatic animals and flora. Besides subaquatic functions, also the functions of surrounding environment has to be known, especially the sources of external load must be located. Water monitoring plays an important role when planning and implementing water remediation project. With the help of monitoring data required remediation methods can be selected and pointed to right places. With monitoring, the effectiviness of already made remediation methods can be examined. Water monitoring brings its own expensives to water management but it can also help to assess the cost-effectiveness of a remediation project, for example, in a case, when a certain remediation method or several methods are discovered wrong or inefficient.

Nowadays, the monitoring of Lake Vesijärvi is the combination of automatic and traditional monitoring. The use of measurement stations adds enormously information required on water quality and physiological changes happening in the water. Water courses are constantly changing because of their dynamic character, therefore, when using a continuous automatic measurement, more representive picture is obtained than with single samplings. The sampling done in certain spots can give distorting results, if measurements are done in spots which are not representive, or wrong intervals or timing is used. Continuous and dense monitoring data can be utilised in the development of water system model for example nutrient balance model (Finnish Environment Institute, 2009).

In this thesis, the development proposals to the water monitoring of Hartbeespoort Dam were formed on the basis of the monitoring practises done in Lake Vesijärvi and the practical training experience gained from South Africa. The aim of the study is not to interfere in the monitoring practises done in the dam and the catchment, but to consider how water monitoring could be further developed, and therefore, a special emphasis is placed on the utilisation of automatic monitoring. Before dealing with the development proposals (5.5 Development Proposals of Water Monitoring in Hartbeespoort Dam), monitoring practises in Hartbeespoort Dam, Bospoort Dam and Lake Vesijärvi are discussed.

5.1 Background of Monitoring in Hartbeespoort Dam

Integrated Monitoring Program for the Hartbeespoort Dam and upstream catchment is currently under a development. Its objectives are inter alia to measure the effectiveness of the Harties Metsi A Me project, to indentify impacts and to develop existing water monitoring programs. The Hartbeespoort Dam catchment includes more than 30 monitoring points that are managed by DWA. Although, the catchment area is under the monitoring, there is little information available on the dam itself. (De Jager & Maré, 2009, 3) Besides monitoring done by DWA, there are companies such as AECI, Kelvin Power Station and Chloorkop or mines such as Mogale Gold, who are doing water monitoring as a part of compliance requirements for their licences. (De Jager & Maré, 2009, 79) The Figure 17 shows the sub-catchments of the Hartbeespoort Dam; wastewater treatment plants, surface water monitoring points and flow monitoring points are marked on the map.

Before 2008, the only monitoring in the dam was done by RQS (Resouce Quality Services), which works under the Policy and Regulation Branch of the Department of Water Affairs. Monitoring is done every two weeks at one site only and it has been conducted for a number of years. (De Jager & Maré, 2009, 95) Intensive sampling of the Hartbeespoort Dam has only taken place since September 2008. Samples are taken in a monthly basis from 14 monitoring points around the dam. The monitoring team uses the YSI 6600-V2 Sonde -instrument for water quality monitoring, and readings are taken at the surface, at the depths of 1 m, 3 m, 5 m, and also a reading every 5 metres until the bottom is reached.

The instrument measures the followings: depth, temperature, electrical conductivity, turbidity, pH, oxygen reduction potential, chlorophyll α, blue green algae and dissolved oxygen. In addition, ordinary samples are taken with a sampler at different depths (usually 1 m, 3 m, 5 m, 10 m and bottom) and samples are analysed in a laboratory. Laboratory analysis consists of surface samples (ortho-phospate, total phosphorus, ammonium, ammonia, nitrite, nitrate and suspended solids), samples taken at 3 m and 5 meter (total phosphorus and suspended solids) and all other samples (total phosphorus). In every monitoring point, a secchi depth is measured. (De Jager & Maré, 2009, 96) Besides water quality sampling, algal and invertebrate samples are taken monthly.

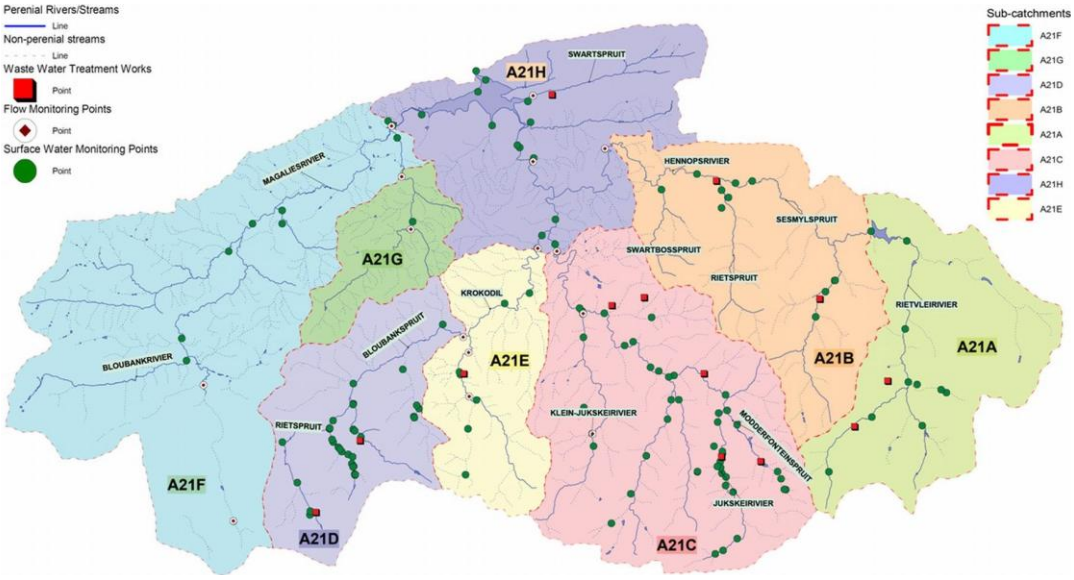

FIGURE 17. Monitoring points and wastewater treatment plants (De Jager & Maré, 2009)

Current indications are that the dam is extremely dynamic, temperature changes constantly during the day and wind significantly alters algal localities. Monthly monitoring through the year will provide data on how the dynamics of the dam change due to weather conditions and inflow compared to the previous years. It is considered, that variables such as solar radiation and available carbon dioxide are the limiting factors during the instances of algal blooms. A multiyear program is therefore essential to determine the significancy of each of these factors (for example rainfall and wind turbulence increase available carbon dioxide). Sampling during night, as well as directly after heavy rainfalls is considered important. Dissolved oxygen concentrations can also be used to indicate algal activity, and therefore it is critical to do monitoring in the dam on a weekly basis during months of November, December and January. (De Jager & Maré 2009, 97)

5.2 Monitoring Station in Hartbeespoort Dam

In summer 2004, Lake Vesijärvi II project donated continuosly working measurement station to Lake Vesijärvi. The station was placed to Lankiluoto and it measured temperature and dissolved oxygen at six different depths (5m,10m, 15m, 20m, 25m, 30m) and chlorophyll α and turbidity at three different depths (2m, 7m, 12m) every three hours around the clock. Results went to the internet via GSM connection. The station collected valuable information on the conditions of the lake four years until it broke in November 2007 due to the freezing of the lake surface. (Lahti Region Environmental Services, 2009) After the breakdown, the station was repaired and simplified by removing some parts of it. The station was given as a present to Harties Metsi A Me project on behalf of Lahti Region Environmental Services in spring 2009.

One of the practical training assignments in South Africa was to get the station to work and set it to measure water quality continuously in the Hartbeespoort Dam. There were several problems to get the station to work. In the beginning, the connection between the station and a laptop was not abled to be formed because of the wrong type of phone cards. It was also discovered, that the modem of the station was damaged (probably during the flight from Finland) which added difficulties to form the connection. When proper phone cards and the new modem were purchased, the measuring station started to work and was ready for a calibration. The calibration of oxygen probes were done in a big bucket full of aerated water. The chlorophyll α –probe was ment to be calibrated with a calibration program using a special cable between the probe and the laptop. For some reason, the cable did not match with the laptop, and it took over a month to get a right cable for the calibration.

Finally in June 2009, the monitoring station was ready to be installed. The station was placed to a platform which was build for that particular purpose. The platform was placed near the dam wall behind a barrier which keeps hyacinths away from the wall. The placement was chosen because it was the only place in the dam being deep enough (30m) and it was a safe place being difficult to reach. Since then, the station has been measuring water quality continuously every hour through day and night. There are six probes at 5, 10, 15, 20, 25 and 30 metres depth and each measures both dissolved oxygen and temperature. There are also a probe labeled as SCUFA® (Turner Designes) which measures chlorophyll α and turbidity at 1 metre depth. Readings given by the station are transferred to the computer via GSM –link. The probes need to be calibrated at least on a weekly basis to ensure accurate readings. There is a solar panel installed on the station that gives energy to the modem which is on at all times. In future, the intention is to show the measurement data given by the station in the web pages of the Harties Metsi A Me project.

After the installation, the station seemed to be working well, but later on, it was discovered that dissolved oxygen readings measured by the probes did not match with the readings measured by the YSI –instrument of the monitoring team. The probes were appropriately cleaned, so the problem was not due to an incomplete maintenance. According a Finnish retailer of measurement stations, the fault may lie in the probes which should be replaced to new ones, because the lifetime of the probes is propably near its finish. In addition, one of the probes was lost (the 30 metre probe) when it got entangled with something in the dam. For this thesis, the data given by the station of the Hartbeespoort Dam were meant to be collected into graphs, and then a little comparison would have been made with the results measured from Lake Vesijärvi. But due to the uncertain functioning of the station, the measurement results from the station of the dam are not included in this study.

5.3 Water Monitoring in Lake Vesijärvi

Monitoring the state of Lake Vesijärvi is largely based on the integrated water surveillance program of Lahti Aqua and Lahti Energy (obligated by the Water Act), whereby water quality samples are taken altogether at ten points in Enon-selkä, Komonselkä and Kajaanselkä. The aim of the surveillance is to examine effects to the water quality caused by Lahti Aqua’s dilution water and cooling water taking, and effluent discharging from Lahti Energy’s Kymijärvi powerplant. Samples are taken two times a month from May to August and three times from September to April. Also one fish farm is obligated to monitor the water quality in the River Sepänpuro which flows to Lake Vesijärvi. (The Lake Vesijärvi – Program, 2008) Lahti Aqua is also obligated to do fishery monitoring in Enonselkä and Kajaanselkä. The Fishery Research Institute is doing Lahti Aqua's fishery monitoring as a part of its own fishery surveys in Lake Vesijärvi. (The Lake Vesijärvi –Program, 2008)

Lahti Region Environmental Services also monitors the water quality in Lake Vesijärvi by taking samples in March (in the end of winter stratification) and in August (in the end of summer stratification) (The Lake Vesijärvi -Program 2008). Besides occasional samplings, the water quality is monitored continuously with five measurement stations by Lahti Region Environmental Services. Each station measures oxygen, temperature and chlorophyll α. In Ruoriniemi, also cyanobacteria is measured. Measurement depths for temperature and oxygen are in Myllysaari and Paimenlahti 5, 10 and 13 metres, in Ruoriniemi 5 metre, in Lankiluoto 10, 20 and 30 metres, and in Enonselkä 10, 20 and 32 metres. Chlorophyll α is measured at 2 metres depth in every station and cyanobacterias at 2 metres depth. Measurements take place every hour and results are moved to the internet server each day at 12 p.m. Because of cold winter, measurement stations are taken away before the freezing of the lake will start. (City of Lahti, 2009) The sixth measurement station will be placed soon in Lake Vesijärvi. As a new feature, there is a weather station included. The station will measure temperature, wind speed and direction, air pressure, humidity, rainfall and total solar radiation. (Malin, 2010)

The rivers and streams flowing to the lake are also monitored four to five times a year. Parameters to be analysed are total phosphorus and nitrogen, *colon bacillus*, *streptococcus*, temperature, smell, appearance and flow rate. Samples are taken from the storm drains of the City of Lahti. Plankton societies and the fish population are monitored all around the lake. Also the monitoring of bottom animals is done in Enonselkä. In Enonselkä and Laitialanselkä, bottom surveys are done to examine the history of the lake, and the surveys cover diatom populations, algal pigments and the physical and the chemical features of the bottom sludge. The Figure 18. shows what kind of monitoring is happening in the lake and where it is taking place. Besides water monitoring, there are fallout collecting stations near the shoreline which are collecting air pollution loading. (Lahti Region Environmental Services, 2009)

The oxidation experiment, started in year 2007 in Enonselkä, has expanded to eight oxidation instruments covering experiment this autumn. Because of the extensive oxidation, fishery surveys are done three times a year between 2009 – 2013. The aim of the allocated fishery survey is to find out if the oxidation has any effects to the fish population. Surveys were done before the installation of oxidation instruments (autumn 2010) and surveys are carried on several years forward. Effects to the food web and bottom sediment are studied as well.

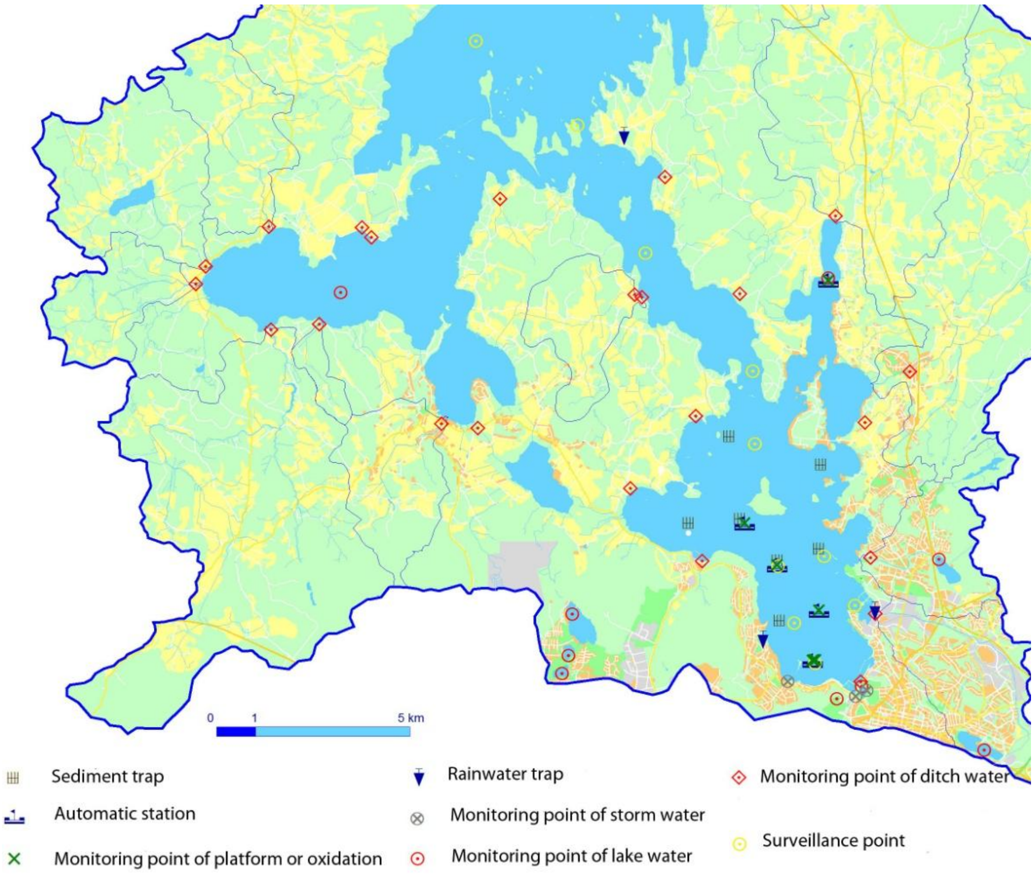

FIGURE 18. Different Monitoring Points in Lake Vesijärvi (Malin, 2010)

5.4 Monitoring in Bospoort Dam

During the practical training, water samples were taken around the Bospoort Dam, which is located near the City of Rustenburg in the North West Province (see the location in the Figure 1. the Location of the Hartbeespoort Dam). The land-uses in the catchment are divided into urban developments, intensive mining areas and agricultural activities. The Bospoort Dam is classified as hypertrophic dam like the Hartbeespoort Dam, and the dam has similar problems with water quality. Monitoring in the Bospoort Dam was based on the environmental cooperation between the City of Lahti and the Bojanala Platinum District Municipality. The reason why the Bospoort Dam was chosen under monitoring was to support the previous studies of the Bospoort Dam done by a Finnish student of limnology.

There were six sampling points in the Bospoort Dam, of which five were located along the Hex River and one point was located at the dam. Three points were located in an area with a lot of mining activity and two points were located further away upstream in an agricultural area, and the two points were taken along after two samplings were done. The aim of the extra points was to compare two different areas and see if there were differences. Sampling was done once in two weeks. Samples were analysed with a portable colorimeter by Hach in a same day as the sampling was done. Analysis included phosphorus, nitrogen and turbidity. At first, pH was measured with pH sheets and afterwards with the YSI-instrument by the monitoring team of the Hartbeespoort Dam. Temperature was measured at the field. One time, samples were sent to a laboratory in Finland.

According to the analytical data, the water quality was very bad in the lower course of the river and in the dam. But as it was expected, the samples in the agricultural area were much cleaner than the samples taken from the mining area. To get better picture about the water quality, also the flow rate should have been measured together with the sampling, but it was not possible due to time limits. In the middle of the practical training period, it was found out that phosphorus reagents were expired which made the results measured uncertain.

However, the results obtained can be considered as indicative results, and with the help of the results the problem area was able to be defined (the variation between the lower course and the upper course being considerable). In water monitoring, it is important to locate problem areas but also do the sampling in a clean or less critical area. By comparing the results together, more comprehensive picture is obtained and changes in water quality can be observed in a wider area. This helps in defining the sources of pollution loading and to find out the point source loads of a catchment. If samples from cleaner area are abruptly getting high concentrations indicating pollution, a new discharge outlet has occured - and most propably an illegal discharge is in question.

5.5 Development Proposals of Water Monitoring in Hartbeespoort Dam

5.5.1 Automatic Measurement - Measurement Station

The first measurement station in Lake Vesijärvi gave comprehensive information about physico-chemical quality and its development in a real time. Station enabled to identify turnovers and times when there was a lack of oxygen. A real-time and continuous measuring of the station gave more comprehensive information than infrequent and random traditional water sampling. The station measured water quality, even when it was not possible to do sampling due to weather conditions. (Värttö 2008, 51) The utilisation of automatic measuring in water monitoring increases enormously information with a relative scarce expensive, for example, when compared to the cost caused by frequently repeated traditional sampling. (Finnish Environment Institute, 2009)

Due to continuous and dense measurement, information can be obtained from unexpected processes (e.g. nutrient loading peak during the heavy rains) which otherwise would stay without notice with traditional sampling done at long intervals. Automatic measurement has great benefit when developing different water system models. For example, the problem in the development of nutrient washing models has been that the water quality observations have been done only from 2 to 20 times a year in many monitoring places. Automatic measurement gives uninterrupted data, and the frequence of measurements and the data transfer can be freely adjusted to the level wanted. (Finnish Environment Institute, 2009). With automatic measurement, the resources of traditional sampling can be reduced, but that does not make traditional sampling less important. Traditional sampling is still needed to get a bigger picture about water quality and to ensure the quality of the results given by the stations.

In 2009, the report Development of Methods for Monitoring the Environment - Automation and Other New Possibilities was published by the Finnish Environment Institute (SYKE). The present state of automatic measurement and water system modeling and their possibilities in environmental monitoring were discussed. The longest experience from automatic monitoring SYKE has collected from following parameters: surface level, temperature (air and water), conductivity, pH, oxygen and turbidity. Nowadays, mentioned parameters can be measured quite accurately and for a reasonable price. Acknowledged probe manufactures are for example YSI, S:can, Keller and OTT. When planning the investment of probes, it is important to find out information about an operational experience of different probes and to purchase only properly tested probes which are discovered reliable. (Finnish Environment Institute, 2009)

5.5.1.1 Expensives of the Measurement Station

The initial costs of measurement stations are quite expensive (30000-50000 €) and the usage requires a well done maintenance. The expensives of the measurement station are caused from prime cost, the platform of the station (if not included to the price), data transfer and the power source of the station. The probes have to be changed to new ones occasionally. Other expensives include the cost of labor when the maintenance work is done, and when the results are collected from the station and further processed. In the Hartbeespoort Dam, the modem and the data logger of the station get energy from a small solar panel, which is ideal for the circumstances of South Africa where the sun is shining through the year.

The cost of data transfer depends on whether the data is transfered via GSM link or via GPRS service. In simple, only few parameters measuring stations, the data transfer can be done reasonably with GSM data or with a text message. Tense and versatile data transfer can be done best with the GPRS service. The greatest benefit of the GPRS service is that the connection can be on at all the time, and that burdens the GSM net only when the data is being transferred. GPRS is the most profitable when transfering huge amounts of data because the bill is caused according to the amount of data transferred. GSM data transfer is charged according to time, just like an ordinary phone call. (Finnish Environment Institute, 2009)

When considering purchasing the measurement station, it is important to pay attention to the durability of the station and to the operational costs. Cheap prime cost can turn out more expensive than expected, for example, if the life time of the station is short or the probes are not automatically self-cleaning. It is difficult to know beforehand whether the life time of the station is three or ten years, but nowadays, good and bad long-term experiences in the usage of many instruments can already be found. In addition, the total cost-effectiveness of the station is significantly affected by the guaranty and the maintenance of the station. (Finnish Environment Institute, 2009)

The following things will save the working time of the monitoring team: contact with the supplier of the instrument is fast and fluent and there is a change to meet personally, troubles are solved and fixed as fast as possibly, and after the guarantee period also with a reasonable prize. (Finnish Environment Institute, 2009) The cleaning and the calibration of the probes are done once in two weeks in Lake Vesijärvi. Because of the huge amount of algae, the probes should be cleaned at few day intervals in the Hartbeespoort Dam to ensure representative results. Therefore, the station should be provided with self-cleaning probes (e.g. compressed air-cleaning system) which considerably would reduce the maintenance costs.

5.5.1.2 The Existing Station and Further Development

The measurement station in the Hartbeespoort Dam measures four parameters: temperature, turbidity, dissolved oxygen (DO) and chlorophyll α. Although, the station is simplified version from the original, useful information can be obtained with the help of the parameters. The variations of oxygen concentration in time and in different depths, give a good overall picture about the state of a water course. DO concentration defines the composition and the quantity of species living in the water at each time. The low concentrations of dissolved oxygen indicate the pollution of water. Oxygen results are shown as mg/l, and besides that, the saturation percent of oxygen is reported, which tells how much dissolved oxygen is found in the water in relation to the biggest possibly concentration which could be in the water of that temperature. (Häme Regional Environment Centre, 2010) Primary production (photosynthesis) increases DO concentrations and an opposite process “the respiration of algae” consumes oxygen.

Oxygen is also consumed in the decomposition process of organic matter caused by heterotrophic bacteria. By comparing the maximum and the minimum concentration of DO measured during 24 hours, it can be seen whether the lake is eutrophic. The bigger the difference is, the more eutrophic the lake is. (Kettunen, 2008, 20-21). Temperature has a great influence on the solution of oxygen and it is needed in the analysis of oxygen results. By monitoring the temperature, the factors (e.g. the increasing of turbidity) behind the changes of temperature can be evaluated. The increasing of temperature can drive away fishes which prefer cool waters. It can also accelerate photosynthesis which has effects on the zoobenthos population which further affects to the nutrition of fishes. (North Ostrobothnia Regional Environment Centre, 2004) There is one metre long chlorophyll α –probe in the station which measures also turbidity. Chlorophyll α –concentration describes the abundance of plankton algae. It is comparable to the eutrophic level of the lake.

To gain greater benefit from automatic measurement, the Harties Metsi A Me project would need more advanced measurement station than the existing station at the moment. Other parameters of the water quality measured by water monitoring probes in the market are inter alia pH, electrical conductivity, nitrogen, organic carbon, blue green algae, redox potential, ammonium, nitrate, nitrite, total phosphorus and iron. The measuring station can also be equipped with a weather station and the measurement of a flow rate and the surface level as well. According to SYKE, pH and electrical conductivity can be measured accurately and with a reasonable prize nowadays (mentioned in the chapter 5.5.1 Automatic Measurement – Measurement Station). Electrical conductivity and pH would bring more information about the state of the dam. Different reactions happening in water are affected by pH. Eutrophication increases the variation of CO_2 concentration during the day. High pH values occur in eutrophicated water courses where photosynthesis consumes the free CO_2 out of the water. Electrical conductivity indicates the amount of dissolved salts, and with the help of it, the drifting of wastewater to a water course can be examined. (North Ostrobothnia Regional Environment Centre, 2004) Besides before mentioned, other parameters can be considered depending on the resources and the needs of the Harties Metsi A Me project.

For the water monitoring of the Hartbeespoort Dam, it is essential to plan the monitoring to support solving the reason behind algal blooms, and with the help of the monitoring data provided, nutrient balance –models should be calculated more accurately. The measurement station provided with the weather station would give meteorological data, such as wind direction and speed, temperature, air pressure, humidity, rainfall and total solar radiation. Therefore, besides nutrients, other variables which may control the algal growth in the dam could also be identified and investigated. The measurement of flow rate supplements meteorological data and helps in analysing the other results given by the station. The flow rate has its influence on water quality, so the results measured are constantly changing along the flow rate. When calculating nutrient balance model, the information about the flow rate in the dam would be a great help. To gain better understanding about water quality, there could be several stations measuring in the Hartbeespoort Dam. The dam is approximately the same size as Enonselkä in Lake Vesijärvi where are five stations altogether. At first, it would be good to start with two or three measurement stations and they could be located in the basins of the dam.

5.5.1.3 Water Flow Station

It is important to monitor rivers and streams to figure out the extension of external load flowing to a lake and to identify the sources of pollution load. Even a tiny brook can have a remarkable effect to the water quality of the lake if the brook carries a lot of impurities and nutrients with it. A water flow station suits well for the monitoring of different kind of streams. Water flow stations are not as expensive and complex as ordinary measurement stations, and there are also more manufactures around the world. Water flow can be defined in a discharge curve. The water flow station can also be set to measure different parameters, such as water level, pH, electrical conductivity, oxygen, nitrate and phosphorus. (Keto, 2010).

5.5.2 Portable Colorimeter

There are different fieldmeters available for the measurement of water quality: some of the instruments are provided with probes which do the measurement of parameters straight from the water, and some instruments require reagents mixed with water to analyse the samples. In this thesis, only a portable colorimeter is discussed, while other fieldmeters are limited off. There are many portable fieldmeters by different manufactures in the market, but the colorimeter of Hach was chosen to be an example due to the usage experiment of the instrument in the monitoring of the Bospoort Dam. The same instrument is also used by the Friends of Vesijärvi association in their voluntary based monitoring in Lake Vesijärvi. At present, two Hach portable colorimeters are in use in the communal water works of the municipal of Moses Kotane in South Africa. The fieldmeters were donations from the City of Lahti and they have been a great support in the monitoring of water quality.

The portable colorimeter is practical in water monitoring in many ways. The meter is moveable, easy-to-use and cheap. Because of single packed reagents, the analysis of samples can be done right away in a field if wanted. Distilled water is needed for the cleanliness of test tubes and to ensure the representativeness of the results. The analysis expensives of the colorimeter, which include new reagents and the cost of labor, are minimal compared to expensive analysis done in a laboratory. Occasionally, it is advisable to take reference samples and analyse them in the laboratory to ensure the accuracy of the results. The portable colorimeter supplements other water monitoring but it is not enough to be used alone if considered a complex remediation project of a water course. One of the benefits of the portable colorimeter is that the usage does not require skills in an analytical chemistry. More important is the planning and the completion of sampling and the observation done in the field. Strict diligence must be obeyed when taking the samples and the samples must be representatives. To get more representative picture about water quality, flow rate should also be measured at the same time with the sampling.

With the portable colorimeter many different parameters can be measured. For water monitoring, suitable parameters include for example turbidity, nitrogen, ammonia, phosphorus, total orcanic carbon (TOC), pH, pesticides/herbicides, oxidation-reduction potential (ORP), dissolved oxygen, iron, *Escherichia coli*, conductivity, CO_2 and bacteria. According to Hach Company, its DR800 -serie colorimeters are preprogrammed to test 20, 50 or 90 parameters. The portable colorimeter by Hach is calibrated by chemists using multiple of reagent, standard, and multiple instruments and are independently verified to ensure accuracy (Hach Company, 2010). Because of that, the colorimeter is reliable but the calibration can be done with standard solutions if wanted. With the standard solution, an existing calibration curve can be verified in the instrument. If the correct result is obtained with the standard solution, the colorimeter is functioning right. (Hach Company, 2010)

5.5.3 The Measurement of Deposit

Air pollution is hazardous to health but also to the environment. Pollutants cause eutrophication to water courses and can cause harm to animals and plants. Particles can move hundreds of kilometres with wind from the source. In this chapter, a simple method to measure the amount and the quality of air pollution is introduced. Finnish Standards Association, SFS, has done a standard called the Measurement of Particulate Fall Out by Horizontal Deposit Gauge. With the help of the standard, defining air pollution load is very easy and inexpensive.

Deposit considers particles which fall from air to land or to water. Usually, the deposit includes sulphur or nitrogen compounds which cause eutrophication. The majority of the harmful deposit is caused by traffic and industry. The deposit can be wet, coming with the rain or dry deposit, which is in the form of small particles. (Finnish Meteorological Institute, 2009)

The collector of the deposit is a flat bottomed cylinder which inner diametre is 200 ± 5 millimetres and depth is 400 ± 10 millimetres. The cylinder has to be a material which does not react with the deposit and keeps its shape when moving the cylinder full of water. The collector will be placed to a stand (See Figure 19). The stand is made to keep the collector horizontally in all circumstances. Corrosion resistant metal wire will be placed around the stand to avoid birds to sit on it.

The collector should be placed to an open spot as horizontal place as possible. The collector has to be set in height of 1.8 ± 0.2 metres of its immediate surrounding area. To avoid incorrect results, the collector should not be placed too near to dust sources, suc as chimneys, traffic lanes or dusting lands.

0.5-2.0 litres of water is put inside the collector when the collecting period starts. After that, the collector should be taken care of to prevent it for drying. Water is added when needed, and it is advisable to write down the amount of water added in each time. Collecting period is 30 ± 2 days.

The collector is rinsed with distelled water to capture all particles after the collecting period. Bigger particles are filtered with a filter which density is 1 mm. Insoluble matter is separated for analysis by filtering, centrifugalizing or by using other separation method. The sample is dried in 105 ºC to a standard weight. The mass of collected deposit is reported per 30 days interval and unit of g/m^2 is used.

Total deposit is counted in the following way:

mA = m ÷ A x 30 d ÷ t

mA = deposit of month, g/m^2

m = weight of collected deposit, g

A = cross-sectional area of collector, m^2

t = collecting period, d

(SFS 3865).

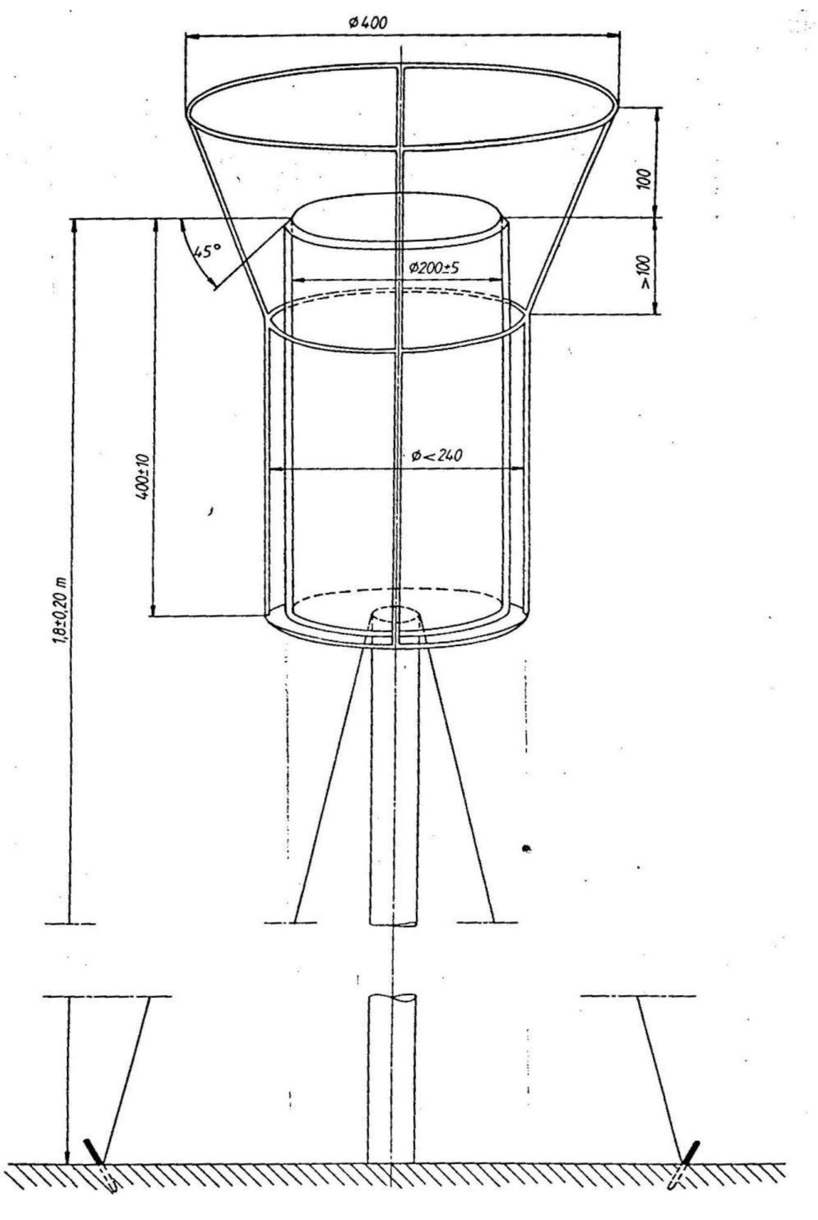

FIGURE 19. The Collector of the Deposit (SFS 3865, 2009)

5.5.4 Cooperation of Different Parties in Water Monitoring

The rehabilitation of Lake Vesijärvi is a good example how important the co-operation of different parties is for the successful rehabilitation of a water course. The co-operation of experts, local people, authorities, organizations, schools and companies is also needed in water monitoring. In this chapter, two examples of cooperation in water monitoring in Finland are introduced: the monitoring obligated by law and the voluntary based monitoring done by local citizens. Also possibilities of cooperation in the Hartbeespoort Dam are considered.

In 2006 founded voluntary association called Vesijärven Ystävät (Friends of Lake Vesijärvi) is using portable colorimeters in their water monitoring around Lake Vesijärvi. Water monitoring is done officially few times a year and during the year casually as the need arises. Portable meter is also used to educational purposes. The aim of the Friends of Lake Vesijärvi association is to keep up the conservation spirit of the lake and to support the management and the recreational use by being active in communication, campaigns and fund raising. Nowadays, the association is doing cooperation with the Lake Vesijärvi Foundation by raising funds and doing a grass roots activity. The Friends of Lake Vesijärvi association is run by ordinary citizens who are interested in keeping the lake in a good state.

In the Information center of Harties Metsi A Me project, an education about the problems and the rehabilitation of the dam are given to students of different ages. Students from upper secondary schools or higher level of education could be considered to be involved in the rehabilitation project of the dam. For example, students could be involved in the monitoring done in streams by using cheap portable colorimeters (discussed in the chapter 5.5.2 Portable Colorimeter). The benefit of the meters is their easy-of-use and there is no need for expensive laboratory equipment and laboratory experience. When participating in water monitoring, students could learn about water management in practise and help Harties Metsi A Me project at the same time. The monitoring could be targeted to the areas not covered by monitoring yet. Potentials monitoring spots could be those close to some potential loading source (e.g. wastewater treatment plant, industrial company or mine). Samples could be taken in upstreams and downstreams and in a discharge point.

Polluters like wastewater treatment plants, mines and factories, should participate in the costs of water monitoring and management. The biggest polluters have to be responsible for their actions. In Finland, all remarkable polluters of water are obligated by the Water Act and the Environmental Protection Act to monitor the state of water systems they are polluting. For example, communal waste water treatment plants, industrial plants, fishery plants, power plants and huge hydraulic engineering works need an environmental permit for their action and the permit nearly always include the obligation to monitor the load and impacts of the water course. (Ministry of Environment, 2007) This act became valid already in year 1962, but only ten years after the act was being supervised by officials.

Also in South Africa, compliance monitoring is done by wastewater treatment plants, industry and mines (De Jager & Maré, 2009, 79-81). No information was abled to be found how the compliance monitoring system is working in reality. It would be ideal if the Harties Metsi A Me project could make the wastewater treatment plants in the catchment area to take part in the expensives of monitoring – at least those treatment plants not complying with the phosphorus standard yet. Also the industry and the mines discharging their treated wastewater to the rivers flowing to the dam should support the monitoring project.

6 CONCLUSIONS

During our practical training in South Africa a year ago, there were many rehabilitation methods going on and new management activities were planned. We do not know how the project has proceeded after the practical training, but we hope this study will be useful for the Harties Metsi A Me project, especially the development proposals. Hopefully, the suggested development proposals will not be too unrealistic because many of the proposals demands big financial investments and cooperation between different parties, such as policymakers. On the other hand, the purpose of the study was not to consider how the proposals would work in practice but to think about ideal remediation and monitoring methods suitable to the situation of the Hartbeespoort Dam. The purpose was to connect the development proposals to the aims of Harties Metsi A Me project, like the decreasing of phosphorus load, the standard of 1 mg/l phosphate, effect on employment, the remediation of wetlands and the monitoring of water quality on an ongoing basis.

The original aim of the study was to concentrate on the development of monitoring the Harties Metsi A Me project, and not to deal with remediation methods so that the study would not become too extensive. However, during the study, development proposals to remediation methods were decided to be taken along because remediation was seen as important as monitoring when supporting the Harties Metsi A Me project. When considering the development of remediation methods, external load was seen the primary problem of the dam, so therefore the majority of the proposals aim at decreasing the external load, especially the phosphorus load. Also the internal load is a problem in the Hartbeespoort Dam, and to make it decrease, the intensification of fishery management is an effective remediation method. Intensive fishery also decreases the amount of phosphorus in the dam because it is removed along unwanted fishes.

In the development proposals of monitoring, the utilisation of automation in monitoring is seen most useful to the Harties Metsi A Me project. The utilisation of automatic measuring in water monitoring increases information enormously, and enables to save the expensives caused by samplings and analyses. Due to continuous and dense measurement, information can be obtained from unexpected processes which otherwise would stay without notice with traditional sampling done at long intervals. Besides the existing measurement station of the Hartbeespoort Dam there could be two or three more stations that are more developed measuring also parameters like pH and electrical conductivity. The functioning of the existing station has not been trouble-free but misfortunes can be avoided with the next stations, because new and unused stations can be customised directly for the circumstances of the Hartbeespoort Dam. Accurate results can be guaranteed by choosing right and trustful probes and doing careful maintenance.

The building of composting dry toilets and the intensification of phosphorus removal in wastewater treatment plants (which requires renewals in the existing system) require the biggest investments from the development proposals. However, the intensification of phosphorus removal was seen as a feasible option, and it would be a good subject to a follow-up research. In this study, the existing techniques of wastewater treatment plants are not examined so combining chemical phosphorus removal to biological phosphorus removal could be examined as a case-specific in the follow-up research. If development proposals are seen feasible to the Harties Metsi A Me project, the other subject for the follow-up research would be the costs of development proposals because in this study those have not been calculated.

In the remediation of Lake Vesijärvi, fishery management has been done together with oxidation. At first, oxidation was considered to be suggested to Hartbeespoort Dam because lots of phosphorus has been accumulated in the bottom sediments, and oxidation could help the sediment's holding capacity of phosphorus. One of the Harties Metsi A Me project's management activities is the removal of sediment, and with successful oxidation that would not be necessary. It is not known how extensively sediment removal has been planned but a dredging even for a smallish area requires a lot of work considering the preparation works and the treatment of removed sediments. However, oxidation was left out because there was not enough time to consider its suitability to Hartbeespoort Dam and there were not any graphs to show the dam's oxygen situation.

The subject of this thesis would suit better to be the subject of Master's degree because development proposals could have been dealt with more completely than now. Also writing the study in English slowed down the working and therefore the subject was kept at an easy level. Development proposals can be considered as proposals, not as actual results. This kind of study would require more information obtained from careful background research done in the Hartbeespoort Dam and the catchment area. Finding the information concerning South Africa and the Hartbeespoort Dam remediation was sometimes difficult, and the study would have proceeded more rapidly, if we had in South Africa. However, a lot of useful information was obtained from the Harties people concerning the remediation project, and we saw the rehabilitation and monitoring done on-the-spot which cave us a good start to write this thesis.

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