

Reduction of anthropogenic environmental influences by advanced and optimized technologies

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Thesis submitted for the degree Doctor of Philosophy in
Environmental Sciences at the Potchefstroom Campus of the
North-West University

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November 2011

Everything has got an initiative and an end
- a destination -
the initiation is accomplished
the goal further converged ...

**This is acknowledged to all my supporters and loved ones who always
accepted and supported me to fulfill my wildest thoughts ...!**

Abstract

Sustainable development and resource efficiency are the common global strategies of the 21st century. The actual global natural resource consumption of humankind went far over the limit and to cover this worldwide resource consumption the productivity of 1.5 earths is now necessary.

The work *“Reduction of anthropogenic environmental influences by advanced and optimized technologies”* discussed the problem of advanced resource efficiencies with mining activities in South Africa as an example. Related strategies to reverse anthropogenic impacts to such an extent that it resembles former natural conditions were also discussed. Heavy metal contaminated soil and water were treated with natural techniques and different natural media to reduce and eliminate contamination and to provide a market value for former unusable material. Specially developed soil ameliorants and natural filter media could increase the total quality of soil and water. Even plants could be established in these changed conditions. Applied to the natural environment an overall upgrade of mining activities could be achieved.

To optimize these laboratory and field results support was generated by using evolutionary algorithms as part of the artificial intelligence. By combining applied technologies with the evolution strategy an optimization tool could be developed to simulate, optimize and forecast procedures of anthropogenic impact reversion. With this tool a transfer of solutions to other similar applications in under-developed and developing countries could be shown.

The trans-disciplinary scientific approach of balancing the trigger element carbon proved that the reduction to the smallest common element carbon can be used to balance processes and to indicate pollution. As stated in the United Nations Framework, carbon balances are one of the most significant causes of environmental problems, including environmental pollution and health and are also closely related to climate change in general. With carbon balances resource efficiency and resource protection can be transferred into practice.

Finally, all results were collected and verified in a decision support system with the aim to optimize the treatment steps and to make the results transparent and available for users in academia and practice. The work was exemplary in showing that the approach of environmental sciences and techniques to reverse anthropogenic interferences back to natural sustainability and evolution, optimized the equilibrium of nature.

Keywords: Sustainable development, Resource efficiency, Heavy metal contamination, Optimization, Evolutionary algorithms, Soil amelioration.

Opsomming

Volhoubare ontwikkeling en effektiwiteit van hulpbronne is die algemene globale strategieë van die 21^{ste} eeu. Die werklike globale verbruik van natuurlike hulpbronne deur die mensdom het die limiet vër oorskry en om hierdie wêreldwye hulpbronverbruik te kan dek is die produktiwiteit van 1.5 aardes nou nodig.

Die werk *“Reduction of anthropogenic environmental influences by advanced and optimized technologies”* bespreek die problem van gevorderde hulpbron-effektiwiteit met mynbou-aktiwiteite in Suid-Afrika as ‘n voorbeeld. Verwante strategieë om antropogeniese impakte om te keer tot so ‘n mate dat dit die natuurlike kondisies verteenwoordig wat voorheen bestaan het, word ook bespreek. Grond en water wat gekontamineer is met swaarmetale is met natuurlike tegnieke en verskillende natuurlike media behandel om die kontaminasie te verminder of te elimineer asook om ‘n markwaarde te voorsien aan voorheen onbruikbare materiaal. Grondbehandelingsprodukte en natuurlike filter media wat spesiaal ontwikkel is kan die totale kwaliteit van grond en water verhoog. Selfs plante kan in hierdie veranderde kondisies gevestig word. Wanneer dit in die natuurlike omgewing aangewend word, kan ‘n opgradering van mynbou-aktiwiteite bereik word.

Om hierdie laboratorium- en veldresultate te optimiseer, is ondersteuning gegenereer deur die gebruik van evolusionêre algoritmes as deel van die kunsmatige intelligensie. Deur toegepaste tegnologieë met die evolusionêre strategie te kombineer, kon ‘n optimiseringshulpmiddel ontwikkel word om die prosedures vir die omkeer van antropogeniese impakte te simuleer, optimiseer en voorspel. Met hierdie hulpmiddel kon ‘n oordrag van oplossings na ander soortgelyke toepassings in onderontwikkelde en ontwikkelende lande aangedui word.

Die transdissiplinêre wetenskaplike benadering wat gevolg is deur die balansering van die sneller-element koolstof, het bewys dat die vermindering van die kleinste gemeenskaplike element, koolstof, aangewend kan word om prosesse te balanseer en besoedeling aan te dui. Soos in die United Nations Framework gestel word, is koolstofbalanse een van mees beduidende oorsake van omgewingsprobleme, insluitend omgewingsbesoedeling en gesondheid en dit is ook nou verwant aan klimaatsverandering in die algemeen. Met koolstofbalanse, kan hulpbron-effektiwiteit en –beskerming oorgedra word na die praktyk.

Ten slotte, alle resultate is versamel en geverifieer in ‘n besluitnemingsondersteuningstelsel wat daarop gemik is om die behandelingstappe te optimiseer en om die resultate deursigtig en beskikbaar te maak vir die akademie en die praktyk. Die werk is ‘n uitstekende voorbeeld om te wys dat die benadering van omgewingswetenskappe en -tegnieke gebruik kan word om antropogeniese impakte om te keer na natuurlike volhoubaarheid en evolusie en daardeur die ewilibrum van die natuur te optimiseer.

Sleutelwoorde: Volhoubare ontwikkeling, Hulpbrondoeltreffendheid, Swaar metale besoedeling, Optimalisering, Ewolusionêre algoritmes, Grond herwinning.

Table of contents

Abbreviations	V
Figures	VII
Tables	IX
1 Introduction	1
1.1 Introduction	1
1.2 Aim of this study	2
1.3 Overview	4
1.4 Relevant sources	5
2 Optimizing the Rehabilitation of Polluted Mine Tailings and Water by an Organic Medium - Passive Acid Mine Drainage Treatment in South Africa ..	7
2.1 Introduction	7
2.2 Materials and methods	8
2.2.1 Organic medium	11
2.2.2 Laboratory experiment	13
2.2.3 Field experiment	16
2.3 Results and discussion	16
2.3.1 Results of deposit fresh water and moisture soil	16
2.3.2 Results of testing the deposit Acid Mine Drainage (AMD)/ Acid Rock Drainage (ARD)	18
2.3.3 Remove potential of iron (Fe_{tot}) and manganese (Mn)	19
2.3.4 Long-term sustainability of the organic medium	21
2.3.5 Cost-effectiveness	21
2.3.6 Total quality of treated AMD	21
2.4 Conclusions	22
2.5 References	23
2.6 Bibliography	24
3 Using Evolutionary Algorithms to Optimize Anthropogenic Material Streams	26
3.1 Introduction	26
3.2 Materials and methods	27
3.2.1 Indicator carbon	27
3.2.2 Indicator fiber length	27
3.2.3 Environmental factor (UWF)	28
3.2.4 Use of evolutionary algorithms for optimization	29
3.2.5 Aim of optimization: input of different fiber length	31
3.3 Results	32
3.4 Conclusion	34
3.5 Declaration of Interest	34
3.6 References	35

4	Mine Tailings: Waste or Valuable Resource?	37
4.1	Introduction	37
4.2	Materials and methods	38
4.2.1	Selected substrate	38
4.2.2	Selected tree species	39
4.2.3	Laboratory investigations	39
4.2.4	Characterization of substrata	39
4.2.5	Control methods of microbiological activity - dehydrogenase activity	40
4.2.6	Investigation approach	40
4.3	Results and Discussion	41
4.3.1	Results and discussion of laboratory experiments	41
4.3.2	Results and discussion of field experiments	42
4.4	Optimization	44
4.4.1	Methodological approach	44
4.4.2	Application of evolutionary algorithms for a decision support system	47
4.5	Conclusions and recommendations	47
4.6	References	48
5	Improvement of Contaminated Mining Soil Quality through Reforestation ..	51
5.1	Introduction	51
5.2	Materials and methods	51
5.2.1	Laboratory and field trial	51
5.2.2	Quality of polluted mining soil	52
5.2.3	Ameliorants	53
5.2.4	Selected tree species – <i>Searsia lancea</i> (Linneaus F.) F.A. Barkley syn. <i>Rhus lancea</i> Linneaus F.	54
5.2.5	Control methods of microbiological activity - dehydrogenase activity	54
5.3	Results and Discussion	55
5.3.1	Visual differences in plant growth	55
5.3.2	Differences in soil quality	55
5.3.3	Differences in microbiological activity	59
5.3.4	Total quality	61
5.4	Conclusions	62
5.5	References	62
6	Carbon-Balance – A Case Study for Paper Production and Recycling in Germany	64
6.1	Introduction	64
6.2	Materials and methods	66
6.2.1	Indicator Carbon	66
6.2.2	Composition of determined solid and liquid materials	66
6.2.3	Wood preparation	66
6.2.4	Sulphite Pulp Mill / Sulphate Pulp Mill / Mechanical Wood Pulp ...	67

6.2.5	Cleaning of recycled paper	67
6.2.6	Deinking	68
6.2.7	Fiber preparation	68
6.2.8	Paper machine	68
6.2.9	Bleaching	68
6.2.10	Refining	69
6.2.11	Paper consumption	69
6.2.12	Rags, linter and other fibers	69
6.2.13	Waste water treatment	70
6.2.14	Waste incineration / energy use	71
6.2.15	Recycling / disposal	71
6.2.16	Paper classes and ingredients	71
6.2.17	Additional and exhausting air	71
6.3	Results	72
6.4	Conclusion	74
6.5	References	75
7	Summary and Vision	77

Abbreviations

$\text{Al}_4\text{Si}_4\text{O}_{10}(\text{OH})_8$	Kaolinite
AOX	Absorbable organic halides
AMD	Acid Mine Drainage
ARD	Acid Rock Drainage
ATP	Adenosine-triphosphate
ATV-DVWK	Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall e.V. (German Association for Water, Wastewater and Waste)
BMU	Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (Federal Environment Ministry)
C	Carbon
$(\text{C}_6\text{H}_{10}\text{O}_5)_n$	Polysaccharide
Ca	Calcium
CaCO_3	Calcium carbonate
CKW	Chlorinated hydrocarbon
Cu	Copper
DM	Dried matter
DSS	Decision support systems
DWAF	Department of Water Affairs and Forestry
EC	Electrical Conductivity
ECF	Elemental chlorine free
EPER	European register for toxic substances
Fe_{tot}	Total iron
GPS	Global Positioning System
ICP-MS	Inductively Coupled Plasma Mass Spectrometry
INT	Iodonitrotetrazolium chloride
K	Potassium
LUA	Environmental authority of the State North Rhine-Westphalia
Mg	Magnesium
$\text{Mg}_3(\text{OH})_2\text{Si}_4\text{O}_{10}$	Magnesium-Silica-Hydrate
Mn	Manganese

NO₃	Nitrate
NH₄	Ammonium
O₂	Oxygen
pH	Value for acidity or alkalinity (lat. potential “power” and hydrogenium “hydrogen”)
PO₄	Phosphate
ppm	Parts per million
PTS	Paper Technology Specialists
PVC	Polyvinylchloride
SO₄	Sulphate
SS	Sewage sludge
TVF	Totally chlorine free
TiO₂	Titan-dioxide
UBA	German Federal Environmental Agency
UT	Platinum substratum
UTM	Universal Transversal Mercator Coordinate System
UWF	Environmental factor
VC	Vermi-compost
VDP	Association German Paper Factories
WC	Woodchips

Figures

Numbering	Title	Page
Figure 1-1	Overview and combination of problems and solutions	3
Figure 2-1	Graphic representation of treatment	10
Figure 2-2	Organic medium	11
Figure 2-3	Organic medium packed in bags	11
Figure 2-4	Immobilization of heavy metals by ion exchange	12
Figure 2-5	Electron microscope view of the porous structure of the organic medium	12
Figure 2-6	Electron microscope view of vascular tissues of the organic medium	13
Figure 2-7	Leaching tubes (cylinders) prepared for AMD experimental design	13
Figure 2-8	Filter material 1: organic medium mixed with Sand	14
Figure 2-9	Filter material 2: Eliote-bark mixed with Sand	14
Figure 2-10	Filter material 3: Casuarina mixed with Sand	14
Figure 2-11	Model for recycling the AMD	14
Figure 2-12	Cylinders prepared for AMD test	15
Figure 2-13	Comparison of pH, Fe [mg/l] in the tap water after passing through the cylinders	15
Figure 2-14	Cascades on the mine	16
Figure 2-15	Comparison of pH and Fe [mg/l] in the AMD and after passing through each cylinder	17
Figure 2-16	Comparison of pH, Fe [mg/l] in the AMD and after each circulation	19
Figure 2-17	Amount of iron (Fe_{tot}) and manganese	20
Figure 2-18	Remove [%] of iron (Fe) and manganese (Mn) after every step of treatment in the cascades	20
Figure 3-1	Production processes for paper production	27
Figure 3-2	Allocation of fiber length and percentage of secondary material for different paper classes	28
Figure 3-3	Sequence diagram of evolutionary algorithms	30
Figure 3-4	Stray field of potential results	30
Figure 3-5	Results of the material mix from paper and board for technical and special usage (fiber length 1.5 – 2.7 [mm])	32

Figure 3-6	Results of the material mix from sanitary papers (fiber length 1.5 – 6.0 [mm])	33
Figure 3-7	Calculation of the banana-function from Rosenbrock by using the simplex-method by Nelder-Mead (done with MatLab/Optimization)	34
Figure 4-1	Sequence diagram of evolutionary algorithms	45
Figure 4-2	Stray field of potential results	45
Figure 4-3	Example of poltyoptimization by evolutionary algorithms	46
Figure 5-1	Lab test: multivariate analysis of performing principle components by Canoco	56
Figure 5-2	Field test: multivariate analysis of performing principle components by Canoco	58
Figure 5-3	Lab test: Quality change of microbiological activity in the different soil types	60
Figure 5-4	Field test: Quality change of microbiological activity in platinum soil with different fertilizers	61
Figure 6-1	Production processes in the paper production	65
Figure 6-2	Fiber-disintegration methods	67
Figure 6-3	Calculated consumption of paper and cardboard from 1990 to 200	69
Figure 6-4	Carbon flux for the system “paper production”	72
Figure 6-5	Carbon flux for each process steps	73
Figure 6-6	Comparison of balance sum for each process step	74

Tables

Numbering	Title	Page
Table 2-1	Cost-effectiveness of the organic medium compared with chemical treatment	8
Table 2-2	Optimum results of the analysis of the organic material after saturation with fresh water	9
Table 2-3	Summary of optimum results before and after treatment with the organic medium	18
Table 2-4	Quality limitations for irrigation (DWAF) and of treated AMD by the organic medium	22
Table 3-1	Costs of waste paper and influence of the environmental factors (UWF)	29
Table 3-2	Distribution of fiber length of different materials	31
Table 3-3	Distribution of fiber length and waste paper application quote of different paper types	31
Table 3-4	Deviation of results from evolutionary algorithms compared with results from the banana-function	34
Table 4-1	Analysis of untreated substrata	40
Table 4-2	Chemical analysis of laboratory measures	42
Table 4-3	Chemical analysis of field trials	43
Table 4-4	Analysis of biometric measures (platinum tailings)	43
Table 5-1	Analysis of the compost, control soil and polluted mine tailings material (Macro-elements)	53
Table 5-2	Analysis of the used compost, control soil and polluted mine tailings material (Micro-elements)	53
Table 5-3	Lab test: Quality change in soil and tailings chemistry (Macro-elements)	56
Table 5-4	Lab test: Quality change in soil and tailings chemistry (Micro-elements)	57
Table 5-5	Field test: Quality change in soil and tailings chemistry (Macro-elements)	59
Table 5-6	Field test: Quality change in soil and tailings chemistry (Micro-elements)	59

1 Introduction

1.1 Introduction

The impact of human activities on water, soil and climate is an old and essential problem for future generations. These anthropogenic activities influence the cycle of minerals, resources and the environment in total. Consequently, the natural environmental equilibrium is out of balance.

Since the 1970's, the shortage of available and usable resources has been seen as the 'limit to growth' (D. L. Meadows, 1972). Since then, the regenerative ability of the environment – its ability to absorb harmful substances and waste products – has achieved a similar standing. Critical ecological examination must take the beginning, but also the end, of production chains into consideration. Only then can equal weight be given to the exhaustion of important production materials (energy, raw materials) and to the over-stretching of the ecological reproduction capacity of the Earth.

In order to cover the current global natural resource consumption of humankind, the productivity of approximately 1.5 earths is necessary. Projections show that by 2030, we will need 2 earths to cover our steadily raising resource consumption (World Wide Fund For Nature, 2010; World Health Organization, 2010). This implies that the total economy of the world as we know it today has to work more efficiently and take into account the importance of climate and resource protection. This further implies that a total change in attitude towards the environment is necessary.

Especially under-developed and developing countries are influenced by these activities because of the illusion that these countries have an abundance of natural resources, such as minerals. Because of this mining activities worldwide and particularly in South Africa, are causing huge and generally irreversible environmental damage in all related sectors. History has shown that South Africa is one of the most important mining countries in the world and that the economic benefits from mining are tangible even today. However, these economic benefits come with a price and unfortunately it is always the environment that has to pay the price for the economic boom. The environment has to cope with the damage and can not recover soil quality, water quality and quantity or rehabilitate by itself anymore.

Anthropogenic activities influence the cycle of minerals, resources and the environment in total. This results in the imbalance of the natural environmental equilibrium.

The responsibility of the imbalance equilibrium is a global responsibility. International research shows the importance of finding and adapting solutions to these environmental concerns so that it is applicable to under-developed and developing countries. The negative environmental effects and altered conditions, especially in natural areas like soil, water and air must be reversed to obtain a state as close as possible to the previous natural state. Long-term and linked solutions must be in place to avoid further irreversible interferences between human beings and nature.

In Africa and especially in South Africa water is becoming an increasingly rare resource. Contamination of water by mining activities causes the quality of water to deteriorate far beyond the limits of governmental regulations. The water is polluted by heavy metals and pH is low – often between 2.0 and 3.0 – rendering the water useless.

Because of underground activities groundwater has to be pumped to the surface to guarantee safe working conditions underground. The average daily amount of polluted water per mining shaft is approximately 20,000 m³ per day.

Additionally, huge amounts of storage facilities for polluted sludge, soil and rock influence the aesthetics of the natural environment and pollute the groundwater and the environment by air transport kilometers away. These tailings facilities are characterized by low carbon, low pH, low water and plant nutrients but enhanced with different pollutants. This results in contamination of settlements around these tailings.

All environmental influences mentioned above need to be addressed by implementing long-term legislative procedures and a confirmed rehabilitation program. This document discusses a selection of proved rehabilitation methods to negate the mentioned anthropogenic damages.

The problems with feedback, relevant to this study, were as follows:

- Are anthropogenic activities and anthropogenic environmental damages reversible human-nature interactions?
- Water quantity and water quality as a human rights are relevant topics for all developing countries.
- A soil quality upgrade for food and health security is a worldwide necessity.
- The natural carbon balance must be equalized.
- To support and solve these problems the support of information technology is essential.

(Relevant actual literature: Cohen, 2005; Recknagel, 2003; Wolkersdorfer, 2005; World Health Organization (WHO), 2010)

The topics have been internationally peer reviewed and published in different international, peer-reviewed journals. The following chapters summarize partial sustainable aims as a scientific contribution to reverse anthropogenic interferences into nature's optimized equilibrium.

1.2 Aim of the Study

The aims of the study were to:

- Originate and establish important calculation tools for decision support systems (DSS) to reduce and reverse the anthropogenic impact back to the natural state of the environment.

- Proof that natural processes are able to clean high amounts of acidic polluted water in running production processes.
- Demonstrate that reforestation is an alternative for soil amelioration and prevention of aeolian transport of pollutants.
- Evaluate the effectiveness of soil amelioration and valorization of polluted mine tailings.
- Proof that closing of material circles is resource efficient.

This research aimed to demonstrate that it is possible to integrate and practically implement natural methods to reduce anthropogenically caused environmental pollution. The results benefit economy and science and especially solved the problems associated with mine activities. The results of each separate topic were included in decision support systems to simulate and optimize possible solutions.

With the smallest common natural element - carbon - it was possible to break down processes, compare strategies of life cycles and try to balance material cycles. With this procedure, it was possible to calculate and evaluate optimization steps in mine rehabilitation for outlined requirements and purposes.

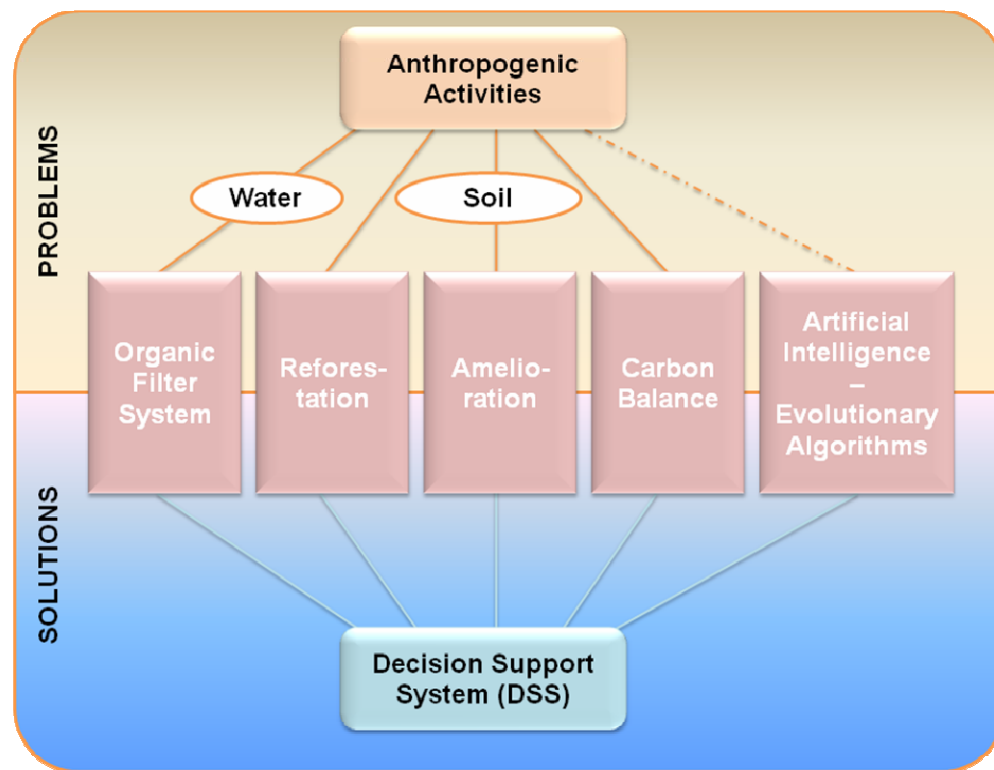


Figure 1-1: Overview and combination of problems and solutions

1.3 Overview

In chapter two the occurrence of Acid Mine Drainage (AMD) also known as Acid Rock Drainage (ARD) from South Africa's gold mines was discussed as treatment by the precipitation of heavy metals with lime and costly caustic soda caused the residues to accumulate in the treated water. This water was then dispersed into wetlands for natural remediation. The environmental damage to the soil was irreversible and could sterilize soil in a very short period of time while acting as a plant toxin. This study about AMD as one of the major environmental problems was carried out using organic and mechanical treatment with an organic medium.

Chapter three selected the problem of the polluted environment and transfers it to optimization algorithms. In order to optimize anthropogenic material streams, the production process, as well as the quality of the products, had to be known. With knowledge of these requirements, it was possible to use extra applied algorithms - in this case evolutionary algorithms as part of artificial intelligence - for the optimization of these secondary material streams. The benefit of this application was the fast and precise calculation of the local and global optima of the optimization problem. This calculation method used the benefits of the biological reproduction by applications of mutation, selection, and recombination to find one of the best results in a huge amount of possible and potential results. For the use of secondary materials in the paper production as an example, it could be proven that in spite of high quotas of secondary materials in different paper classes, there were some paper classes in which the amount of secondary material could be raised without losing any quality.

Chapter four dealt with different trials to revalue polluted mine tailing and soil as one of South Africa's key economic supports. For many years the economy was focused on all mining activities with little thought for the future after the economic boom. Nowadays, profit from such operations is moderate and some of the former leading mining companies have closed or are planning to stop mining. The long-term impact on the environment caused by mining in South Africa was, in general, increased concentrations of heavy metals and changes in pH, both in impacted soils and surface water. During closure the mining company had to make sure that the mine property and surrounding environment was free of any serious pollution and as close as possible to the former natural environment. The present research examined the potential of the addition of a variety of organic products acting as a nutrient source and soil ameliorant in contaminated platinum and gold tailings. In turn allowing the indigenous tree species – *Searsia lancea* (L.f.) F.A. Barkley – to grow, despite high levels of contamination. A laboratory trial was conducted using two types of tailings material with a combination of different ameliorants and cultivation techniques. The trial showed a reduction in contamination and an increase of microbiological activity after treatment. Evolutionary algorithms were used to optimize the combination of ameliorants and thus improved the effectiveness of the treatments. With the use of ameliorants for waste valorization, it could be shown that waste mine tailings material could be changed into a resource with a market value.

In chapter five the problem of unfertile and sterile soil was discussed internationally with defined solutions of reforestation. Most sub-Saharan countries are influenced by drought or heavy rainfall, poor soil quality and anthropogenic and industrial impacts. South Africa is one of the countries in the region in which the greatest impact of mining on the environment was seen and this needed to be addressed, especially in rural development and agriculture sectors. The addition of different organic fertilizers, as a nutrient source and soil ameliorant in contaminated platinum and gold tailings, allowed the indigenous tree species – *Searsia lancea* (L.F.) F.A. Barkley – to grow despite the high levels of contamination. In a laboratory trial, with both types of tailings material, the combination of different fertilizer and cultivation techniques allowed for a reduction of 50% in heavy metal contamination and an increase of ~ 140% in microbiological activity after treatment. The results of this soil amelioration indicated that a sustainable use of trees combined with fertilizer minimized the contamination of mine soil while producing a resource (wood).

Chapter six utilized the solutions of soil amelioration and combined it with a different aim by using the smallest common element to balance processes and indicate pollution. In order to recognize the carbon influence of production processes it was necessary to balance anthropogenic material streams. The smallest common and not further reducible indicator for the process of paper production and recycling, for example, was carbon. With knowledge of the requirements it was possible to reduce carbon consumption as a scarce natural resource and fossil fuel which was used in the paper production process. Therefore, the material fluxes as the product of density (mass by volume) and flow velocity (distance by time), had to be known for every place and time of the production process. This investigation showed that the annual input and output of carbon in the process was almost balanced. With this carbon-balance it was possible to identify resources and depressions of carbon and to point out approaches for optimization.

Chapter seven summarizes all chapters and points out the development of solutions and their success.

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2 Optimizing the rehabilitation of polluted mine tailings and water by an organic medium passive acid mine drainage treatment in South Africa

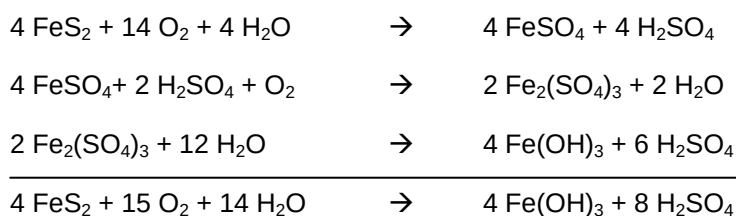
Published in: International Journal of Environment and Pollution (IJEP), Inderscience Publisher, Volume 41, No 3/4, pp 336-354, ISSN 1741-5101 (Online), ISSN 0957-4352 (Print), DOI: 10.1504/IJEP.2010.033240 (04/2010)

2.1 Introduction

Over a period of 150 years of mining in South Africa, natural ecosystems have been exposed to high amounts of polluted substances. The breaking of rock by explosives exposes more new surface areas with an abundance of water-soluble elements. The earth's crust naturally contains sulphide minerals that can oxidize and generate acidic water when broken by explosives or during naturally occurring rock breakage by tectonic movements and seismic events. This phenomenon is called AMD or ARD and is generated by a combination of chemical reactions and biological processes, whereby pyrite is converted into sulphates and iron oxy-hydroxides (Barnes and Romberger, 1968; Neculita et al., 2007). When pyrites and pyrrhotite are exposed to water and oxygen this reaction is further amplified when reactions are catalyzed by aerobic bacteria (*Thiobacillus*) ferrooxidans (Zagury et al., 1997; Brown et al., 2002).

Ferric iron is not soluble in water if the pH is in the range 2.3–3.5 depending on the total ion concentration (Brown et al., 2002). This in turn highlights the importance of introducing oxygen to the passive treatment of AMD. The availability of oxygen in a passive treatment system increases microbial growth and promotes a decrease of pH to optimize iron oxidation. The greatest advantage of this technique is that it minimizes the volumes of AMD waste collected within the process.

Iron disulphide is especially reactive with oxygen and water and is responsible for the acidity in AMD (Barnes and Romberger, 1968):



National law (National Water Act No. 36 of 1998, National Environmental Management Act/Waste Management Bill, DEAT, 2007; The South African National Water Resources Infrastructure Agency Bill, DWAF, 2007) hold mining companies responsible for the rehabilitation of mines and the surrounding areas to an ecologically and environmentally acceptable condition. The common remediation technique for AMD is the treatment with lime (calcium carbonate) or with caustic soda (sodium hydrox-

ide) (Maree et al., 2004). Both techniques are chemical treatments of mine water and are prohibitively expensive (van der Walt, 2007). To neutralize a fluid with an acidity of 3 g/l (as CaCO₃) with lime (CaO, R360 per ton in 2004) to a purity of 93% cost up to R57 million/annum (Maree et al., 2004). In 2007, the price for lime rose to about R922 per ton (Table 2-1). It is therefore essential to find solutions for neutralizing AMD, which are suitable, sustainable and cost-effective. For sustainable treatment of acid mine water, chemical treatment alone is not effective enough to keep the environment free from residues (Hattingh, 2003). The long-term environmental result of the past treatment with caustic soda is the saline soil with potential for irreversible sterile soil conditions downstream. This treatment actually magnifies the problem over the long term. The high-density sludge produced during AMD neutralization with lime must be treated separately because of its hazardous content and has special disposal requirements (Maree et al., 2004).

Table 2-1: Cost-effectiveness of the organic medium compared with chemical treatment

Feed Flow Rate:	13.32	ML/day	555.00	m ³ /h
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<i>Cost - Stoichiometric</i>	<i>Value</i>	
Cost of Lime	922.05	R/t
Present use	15785.20	kg/d
SZ Process use	3055.94	kg/d
Present	14554.74	R/d
SZ Process	2817.73	R/d
Present - 40 days	582189.71	R
SZ Process - 40 days	112709.22	R
Savings per 40 days	469480.49	R

<i>Cost - Actual</i>	<i>Value</i>	
Cost of Lime	922.05	R/t
Present use	10065.92	kg/d
SZ Process use	2637.36	kg/d
Present	9281.29	R/d
SZ Process	2431.78	R/d
Present - 40 days	371251.41	R
SZ Process - 40 days	97271.11	R
Savings per 40 days	273980.30	R

To avoid these side effects it is necessary to focus on organic material, in addition, to filter the acid water, bind and immobilize the heavy metals. The organic medium in question is a natural, organic hydrocarbon and chemical absorbent, used in a 50% mixture by volume of bark of the pine *Eliote* and leaves of the beech species *Casuarina equisetifolia* with additional populations of bacteria (e.g., *Bacillus licheniformis*, *Bacillus cereus*, *Serratia marcescens*, *Bacillus pumilus*), fungi (e.g., *Acremonium*, *Aspergillus*, *Geotrichum*, *Phoma*, *Penicillium*), yeast and micro-organisms from the semi-decomposed leaves and bark. This material is able to raise the pH of the acid mine water, and because of the high content of lignin and tannin in the bark, binds to metals. Organic compounds like tannin immobilize the heavy metals by subsequent chemical precipitation. These metals, phosphate and sulphate precipitate as salts on the surface of the material where they can be removed afterwards.

2.2 Materials and Methods

The methodology for cleaning AMD comprises different steps. First the organic material for treating AMD has to be moistened with about 20% water to prepare the or-

ganic cells for better reaction, lift the vitality and saturate the material with fresh water (Table 2-2) (Yamane, 1993). With this prepared material, two sets of experiments were done, a simulation with leaching tubes (cylinders) in a laboratory and a field trial with a cascade system under natural conditions.

In the laboratory, the material was left for an hour saturated with fresh and clean water (Table 2-2) before the AMD was filtered through different cylinders. The first leaching tube was filled with the organic medium, a 50% mixture by volume of Eliote (bark) and Casuarina (needles) with populations of, fungi, yeast and microorganisms from the semi-decomposed needles and bark and then mixed with 50% (by weight) sand. The second leaching tube was filled only with Eliote-bark and sand – mixed 50% by weight, the third with Casuarina and sand – mixed 50% by weight. With this test arrangement it was possible to see which material is the most suitable for cleaning AMD (Figure 2-1).

Table 2-2: Optimum results of the analysis of the organic material after saturation with fresh water

Description	Ca [mg/l]	Mg [mg/l]	K [mg/l]	Na [mg/l]	PO ₄ [mg/l]	SO ₄ [mg/l]	NO ₃ [mg/l]	NH ₄ [mg/l]	Cl [mg/l]	HCO ₃ [mg/l]
Fresh water	14.43	6.56	5.86	11.95	< 0,01	11.88	0.70	1.12	10.28	88.47
Organic Medium	8.02	2.43	8.21	10.58	1.23	11.01	0.41	0.11	13.12	36.61
Eliote bark	4.01	1.70	6.26	6.21	0.00	7.74	0.00	0.09	8.51	21.36
Casuarina equisetifolia	20.44	6.56	5.86	11.04	2.36	40.42	0.48	1.64	7.22	70.17

Description	Fe [mg/l]	Mn [mg/l]	Cu [mg/l]	Zn [mg/l]	B [mg/l]	pH [--]	EC [mS/cm]
Fresh water	0.02	0.010	0.07	0.020	0.05	7.79	0.20
Organic Medium	0.44	0.15	0.003	0.011	0.21	6.36	0.13
Eliote bark	0.35	0.25	0.006	0.007	0.18	6.02	0.08
Casuarina equisetifolia	0.25	0.04	0.003	0.005	0.19	6.56	0.23

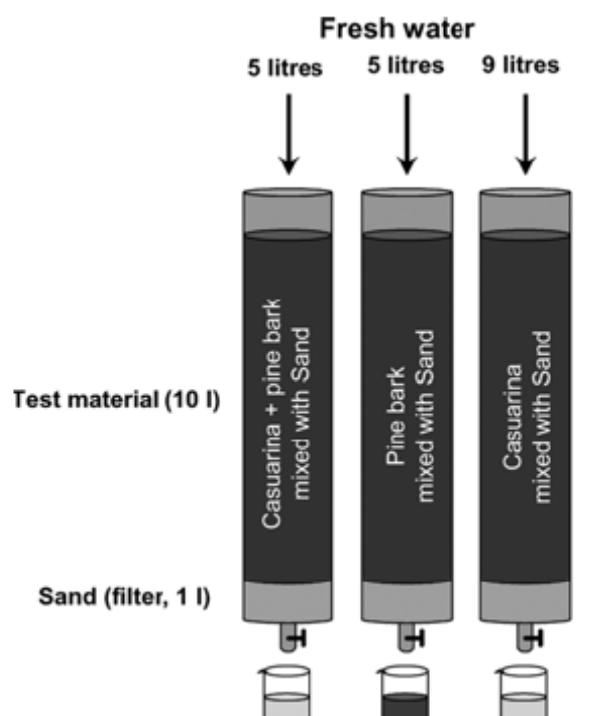


Figure 2-1: Graphic representation of treatment

A passive field bioreactor containing a mixture of organic material must be given a long enough lag time to allow the key microbial populations to increase in numbers and activity in the absence of AMD throughput (Johnson and Hallberg, 2005). Availability of nutrient sources for cellulytic and fermenter microbes is vital to the long-term sustainability of passive treatment systems (Lynd et al., 2002).

To note differences in the reaction process the AMD was recycled ten times through the system to allow a contact time of about 20 min, similar to the contact time of the cascade system discussed here. After every cycle, samples were collected and analysed from each leaching tube to measure the pH and the total Fe. After all cycles the organic treated AMD was tested.

Under natural conditions, the AMD was filtered by a test-bed of cascades filled with different materials. The first cascade consisted of only organic medium. The second cascade contained only Eliote-bark and the third only Casuarina – both the Eliote and Casuarina were mixed with 50% sand by weight. Finally, the AMD had to pass over a cascade of dolomitic rocks to get the pH stabilized. With this procedure, it was possible to see which material is the most suitable for treating AMD under natural conditions.

Mostly lab conditions differed from field conditions because not all natural climatic changes and other factors like wind and rain can be duplicated, but under field conditions these natural phenomena influence the results significantly.

During the initial test period – about one month – daily samples were collected after every cascade to test the pH, total iron and manganese in a mobile lab on site. Samples of the treated AMD were collected once a week from every cascade and tested

for macro-, microelements by straight water analysis and Inductively Coupled Plasma Mass Spectrometry (ICP-MS) at the Eco-Analytica Laboratory (North-West University).

2.2.1 Organic Medium

The organic material with its ingredients of Eliote-bark and Casuarina needles was mixed in the same percentage amounts in the laboratory as well as in the field trial. This mixed material is packed in plastic bags made from coarsely woven fibers to let the water easily pass through (Figures 2-2 and 2-3). It is important to use specific PVC plastic bags designed for this application, because the microorganisms present will decompose all other materials within a few days or weeks. The Eliote-bark with its ingredients of lignin and tannin increases the pH to make the heavy metals available and usable for reaction with the needles.



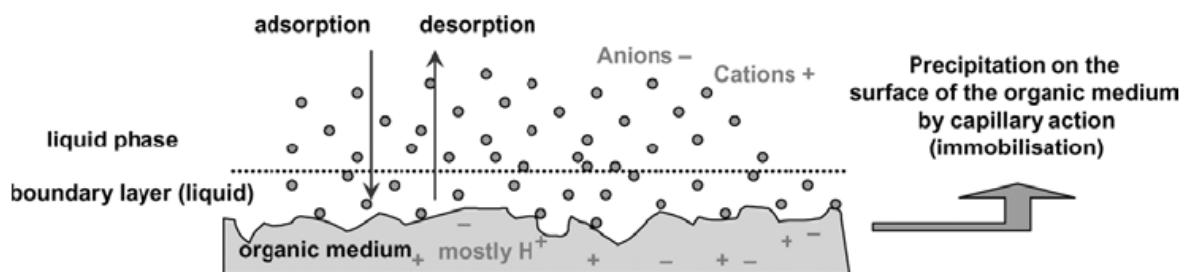
Figure 2-2: Organic medium



Figure 2-3: Organic medium packed in bags

Casuarina equisetifolia is also known as iron wood, she wood and beef wood. This wood has a high amount of iron in the cells and can withstand these high amounts better than other plants. If the concentration exceeds the solubility of the compound, it will be precipitated. Solubility varies greatly with the chemistry and crystallization of a mineral (Le Bissonnais and Singer, 1992). This reaction is to protect the organic medium from overdosing the cells with toxic elements.

The organic medium has the ability to exchange both, positive and negative ions between the organic material and a fluid (Figure 2-4) at active surfaces as cations. The different strength of charges is because of the different semi-decomposed organic material such as pine leaves and bark. When the process of decomposition starts, the charge of the organic medium changes to low and high negative because of the higher amount of H^+ ions from the decomposing processes of the different organic materials and the humic acid.



Source: Pollmann et al. (2008)

Figure 2-4: Immobilization of heavy metals by ion exchange

Thus cation and anion exchange can occur in the organic medium at the same time. The wide-open pores allow the needles to build up a high capillary pressure to carry the heavy metals to the surface (Figures 2-5 and 2-6). The semi-decomposed organic medium with the bound heavy metals from the contaminated soil is a good growth medium and serves as a fertilizer for different nitrogen fixing or heavy metal adapted plants.

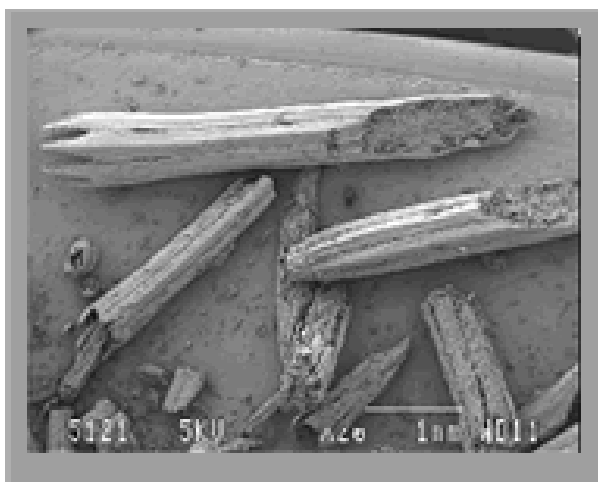


Figure 2-5: Electron microscope view of the porous structure of the organic medium



Figure 2-6: Electron microscope view of vascular tissues of the organic medium

2.2.2 Laboratory experiment

The field laboratory with the necessary equipment is on a mine site on the West-Rand (Gauteng Province) in South Africa, the samples of polluted AMD also originated from shaft '18 Winze' on this same mine. The simulation treatments in the laboratory are similar to the environment of the test-bed of cascades, especially in terms of the simulated contact time, the material used and the AMD. Temperature conditions could not be replicated because of the high fluctuation between night and day temperatures. The implemented experiment ran for three days with a flow rate of $Q = 1.0 \text{ l/min}$ with one cycle through all cylinders every hour. The water temperature was stable with $\sim 12^\circ\text{C}$. All three tubes (cylinders) had a sand filter of about 1 l, covered with a filter paper on top and bottom. The cylinder was then filled with 10 l of the organic test material (Figures 2-1 and 2-8).



Figure 2-7: Leaching tubes (cylinders) prepared for AMD experimental design

The design of the leach tubes of 1 m height and 0.01 m diameter was chosen to retard the flow of the AMD water through the material and hence to create a contact time of about 20 min. Because of its finer consistency, the Casuarina absorbed a volume of 9 l of fresh water while the organic medium and the pine-bark only absorbed a volume of 5 l each for saturation of the material and acclimatization for the microorganisms (Figures 2-8 – 2-10). After an hour the material was saturated from top to bottom and the effluent fresh water (analysis see Table 2-2) was sampled to test for pH and total iron as well the moisture soil for macro- and microelements (Table 2-2).



Figure 2-8:
Filter material 1: *organic medium*
mixed with Sand

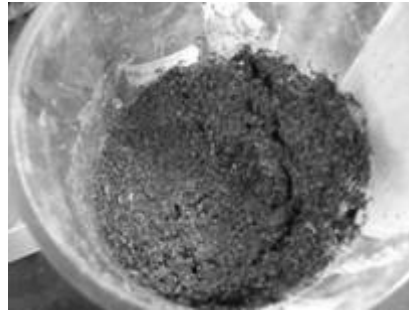


Figure 2-9:
Filter material 2: *Eliote-bark* mixed
with Sand

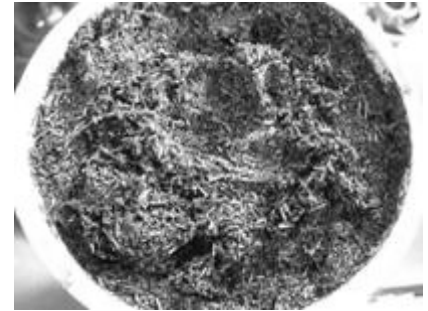


Figure 2-10:
Filter material 3: *Casuarina* mixed
with Sand

The procedure used for treating the AMD entailed to leach 10 l of AMD through consecutive leaching tubes one by one. After passing through all the leaching tubes, the treated AMD was pumped back to the first cylinder to again pass through the system for a total of ten times (Figures 2-11 and 2-12). After leaching through each cylinder, the pH and total Fe of the AMD were measured (Figure 2-13). Finally, after all circulations the AMD and the soil were analyzed for macro- and microelements (Table 2-2). The process of filtering the AMD though each cylinder equates to a total contact time of 20 min. This exactly replicates the treatment of AMD in the test-bed cascades (Figure 2-14).

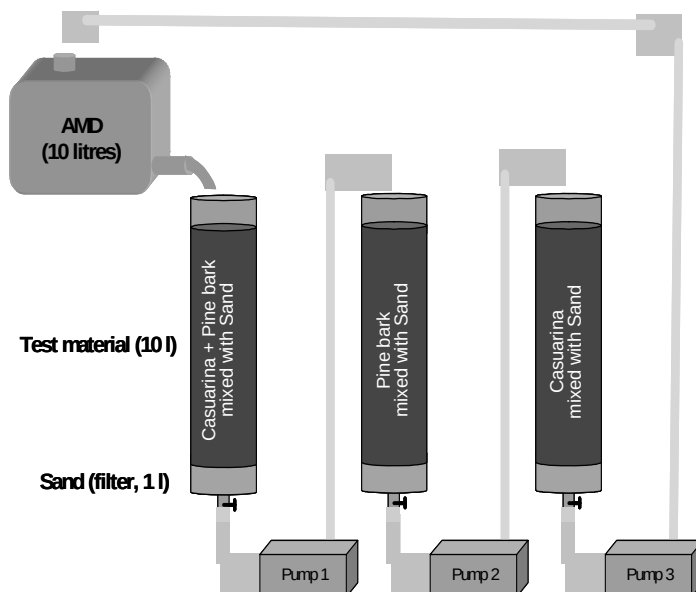


Figure 2-11: Model for recycling the AMD



Figure 2-12: Cylinders prepared for AMD test

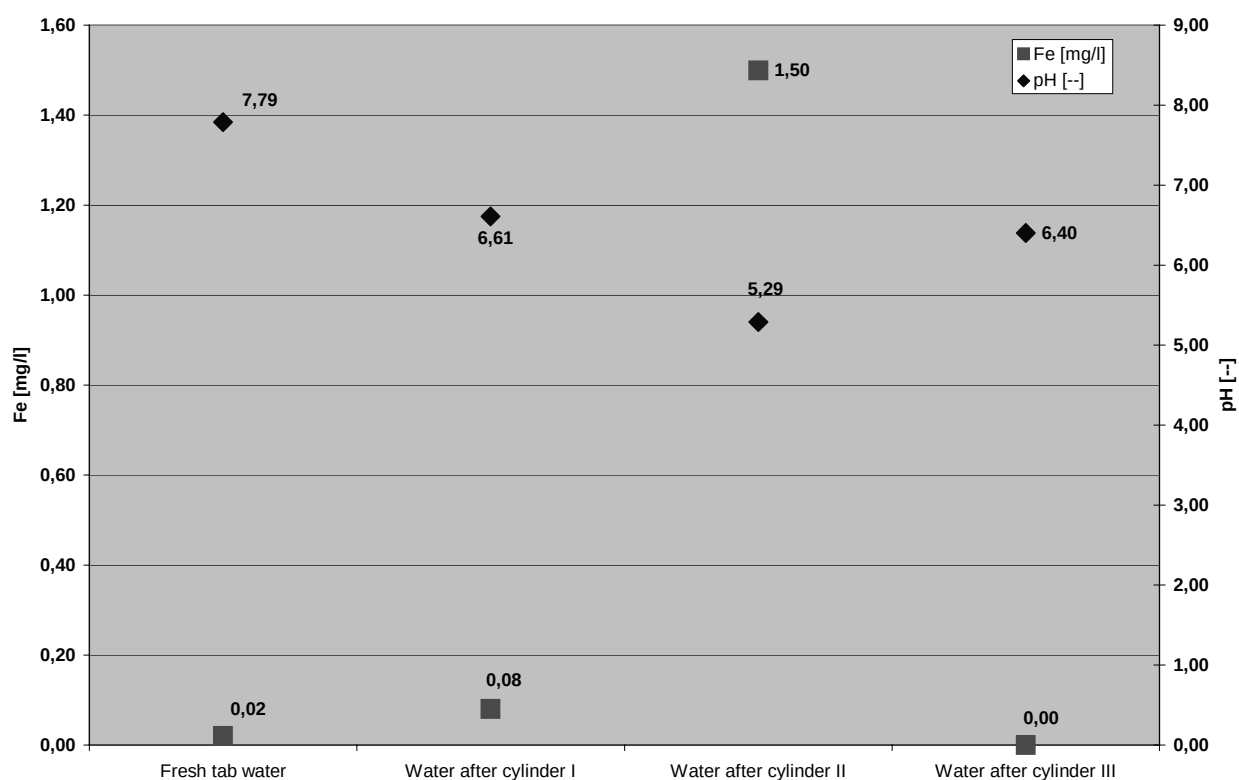


Figure 2-13: Comparison of pH, Fe [mg/l] in the tap water after passing through the cylinders



Figure 2-14: Cascades on the mine

2.2.3 Field experiment

A system of cascades as test-beds was designed with four steps (Figure 2-14). Each cascade was 25 m long, 8 m wide and 0.3 m deep. Plastic liner was used as a basic seal and on side to prevent the system from overflowing. The first three cascades were filled with 250 bags of about 6 kg each packed upright against the flow of the stream to force the water to run through them.

After each cascade, oxygen was introduced into the water as it flowed over small waterfalls and then onto a shade net filled with loose organic material. In detail, the first cascade was filled with a mixture of 50% Casuarina and 50% Eliote, the second only with Eliote and the third only with Casuarina analogously to the laboratory experiment. The last cascade was only filled with dolomitic rocks, a sedimentary rock, which raised the pH from pH 3.5 to pH 3.8 and also acted as a medium for the sedimentation of highly contaminated sludge. The slow flow over the stones allowed for the dissipation of additional oxygen. The total process from the inflow of the first cascade to the outflow after the last cascade took only 20 min. This was the contact time allowed for the material to remove most of the heavy metals and precipitate them to the surface of the bags. After the treatment, the AMD was channeled to a dam to be mixed with other sources of AMD to reduce costs of the treatment with caustic soda and lime as a post or final treatment.

2.3 Results and discussion

2.3.1 Results of deposit fresh water and moisture soil

The analysis of the filtered water and the moist organic material indicate that the pH drops from pH 7.79 in the fresh water to pH 5.29–6.61 in the filtrate, after passing

through the organic medium in the cylinders (Figure 2-13). In this pH range, conditions for the precipitation of metals in the organic medium are favorable, so that most part of total iron (Fe_{tot}) is removed from the water (Figure 2-15).

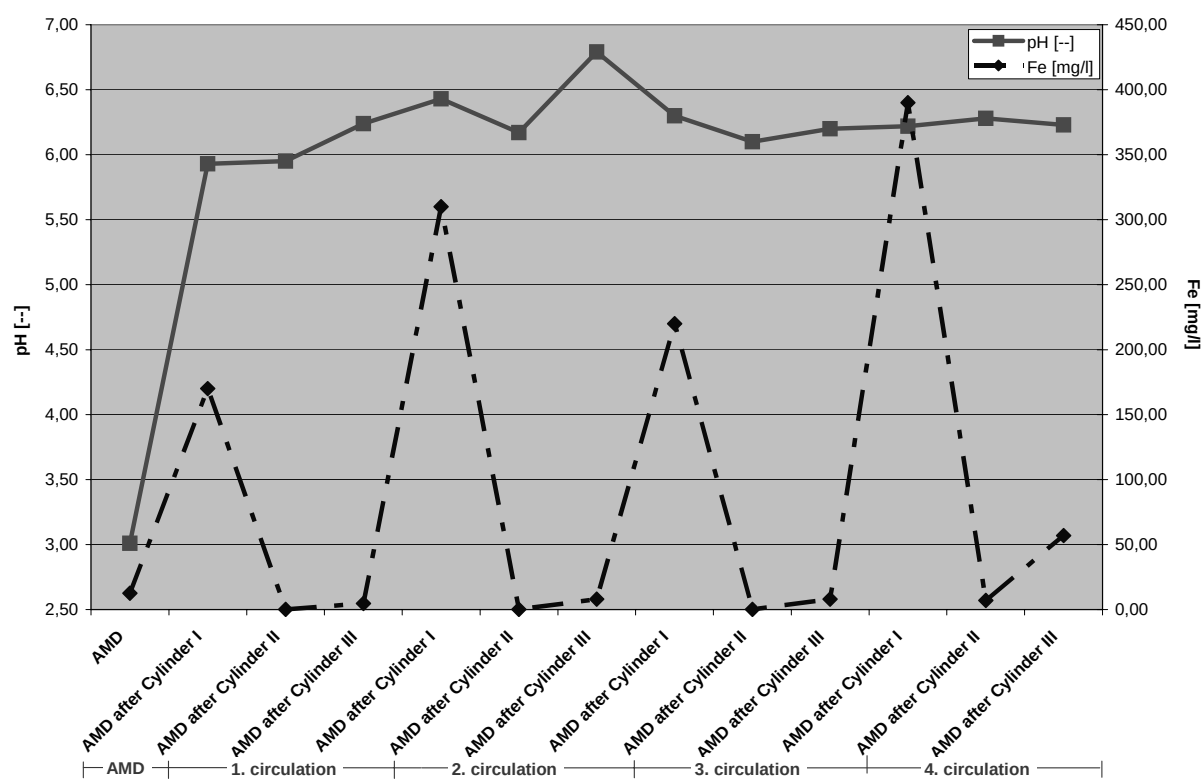


Figure 2-15: Comparison of pH and Fe [mg/l] in the AMD and after passing through each cylinder

The elements remaining in suspension inside the moist organic medium, are bound, immobilized and precipitated at the surface of the medium. Fe_{tot} was reduced to almost half the amount – from 0.44 mg/l to 0.25 mg/l, manganese was reduced to less than half – from 0.15 mg/l to 0.04 mg/l (Table 2-2) and the low Electrical Conductivity (EC) of 0.13 mS/cm also showed that most of the heavy metals and major ions are removed (Table 2-2).

The pH in the moist organic material stabilized between pH 6.02 and 6.56. The organic material saturated with water should have a lower pH because of the humic and fulvic acid produced naturally within the material, but the high amount of tannin and lignin in the bark conversely keep the pH constantly high. Humic acid is that portion of organic material that is soluble in alkaline solution but insoluble in acid solution. Humic acid does not have a single unique structure, but it is a mixture of intermediate chemical products resulting from the decomposition and conversion of lignin and other plant materials (Srivastava and Walia, 1998).

2.3.2 Results of testing the deposit Acid Mine Drainage (AMD)/Acid Rock Drainage (ARD)

The contact of AMD with pine-bark during the filter process showed the best results by reducing 50.1% of magnesium, 29.2% of sodium, 71.8% of sulphate, 78.5% of nitrate, 84.6% of ammonium, 97.3% of iron, 60.0% of copper and 94.0% of zinc. The tannin and the lignin in the bark raised the pH from 3.01 in AMD to pH 8.04 after treatment (Table 2-3).

After circulating ten times through the leaching tubes, the pH of the treated AMD stabilized and total iron was reduced from 12.57 mg/l to 0.34 mg/l. The organic medium binds and removes most of the metals of the water but also releases some of the metals after each cycle (Figure 2-15).

Table 2-3: Summary of optimum results before and after treatment with the organic medium

Description	Ca [mg/l]	Mg [mg/l]	K [mg/l]	Na [mg/l]	PO ₄ [mg/l]	SO ₄ [mg/l]	NO ₃ [mg/l]	NH ₄ [mg/l]	Cl [mg/l]	HCO ₃ [mg/l]
AMD before treatment	297.78	178.88	14.86	116.10	< 0.01	2,897.23	11.14	5.72	45.81	0.00
AMD after treatment	317.82	89.20	64.90	82.30	< 0.01	815.57	2.39	0.88	49.13	613.21

Description	Fe [mg/l]	Mn [mg/l]	Cu [mg/l]	Zn [mg/l]	B [mg/l]	pH [--]	EC [mS/cm]
AMD before treatment	12.57	7.07	0.05	1.08	0.15	3.01	6.18
AMD after treatment	0.34	7.03	0.02	0.06	0.63	8.04	2.87

From the results of Figure 15, it may be seen that the organic medium has a high potential to bind and immobilize heavy metals, despite the laboratory conditions, with less surface for precipitation. The comparatively lower surface area causes the organic medium to allow the leaching out of the metals. The treated water after passing through cylinder 2 and 3 had less total iron showing that the removal of metals is more efficient when treating AMD with a larger amount of bark (Figure 2-15).

The circulations of up to ten times with treated AMD water prove that the system is not failing with multiple circulations. The pH is stabilized at a pH > 7 – after the last circulation the pH rose to over pH 8 (Figure 2-16). Under these conditions, the organic medium can easily immobilize the metals.

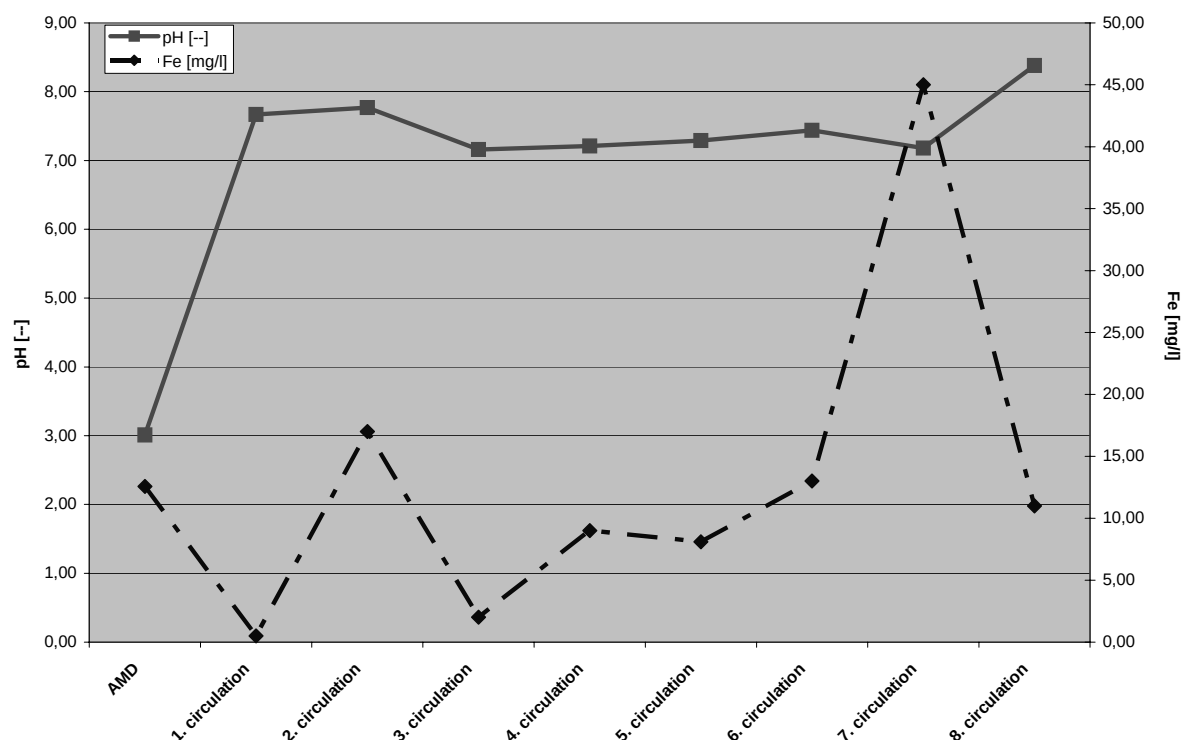


Figure 2-16: Comparison of pH, Fe [mg/l] in the AMD and after each circulation

2.3.3 Remove potential of iron (Fe_{tot}) and manganese (Mn)

The main aim was to prove that a non-chemical system for treating AMD can reduce more pollutants than other chemical treatment methods – in terms of amount of removal, cost-effectiveness and environmental acceptability and sustainability over a long period. The chemical treatment of AMD with caustic soda and lime to achieve the same final quality is more than double in the cost per megalitre than with the organic medium (van der Walt, 2007).

By monitoring the concentration of iron (Fe_{tot}) and manganese (Mn), the most common elements predominating in AMD, it may be seen that the organic medium removes about 67.86% of the total iron concentration – from 560 [mg/l] to 180 [mg/l] – and 61.19% of manganese concentration – from 335 [mg/l] to 130 [mg/l] – (Figure 2-17). The remove potential for each step of treatment detected the conditions under which the metals are available and ready for reaction with the organic medium (Figure 2-18). There is enough retention time between the AMD pipe and the end of cascade 1 to release portion of required oxygen. Oxygen is necessary to transform iron sulphide to ferrous iron and sulphate and ferrous iron to ferric iron and therefore free acid with a low pH. Most of the oxygen is used for the reaction of iron sulphide to ferrous iron and sulphate up to the beginning of cascade 2, after which more oxygen is added with the aid of a small waterfall. The amount of dissolved oxygen before the waterfall was 0.98 mg O_2/l . The same situation occurred in cascade 2 – a high enough retention time while running through the cascade raised the removal potential of the organic medium. After adding oxygen of about 0.5 mg O_2/l the removal potential seemingly dropped again.

To bind and immobilize a higher range of elements the organic medium has to bind all metals that are available in a lower pH range in the first cascade before the pH is raised in the following cascades.

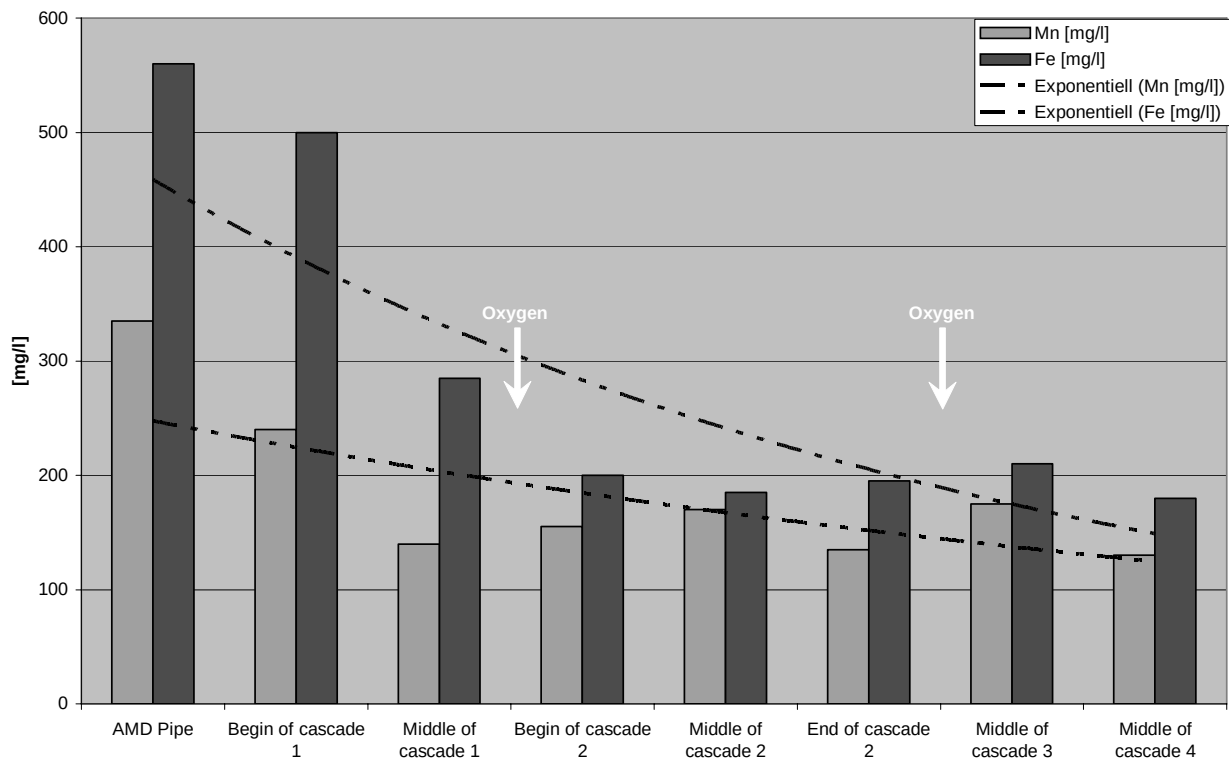


Figure 2-17: Amount of iron (Fe_{tot}) and manganese

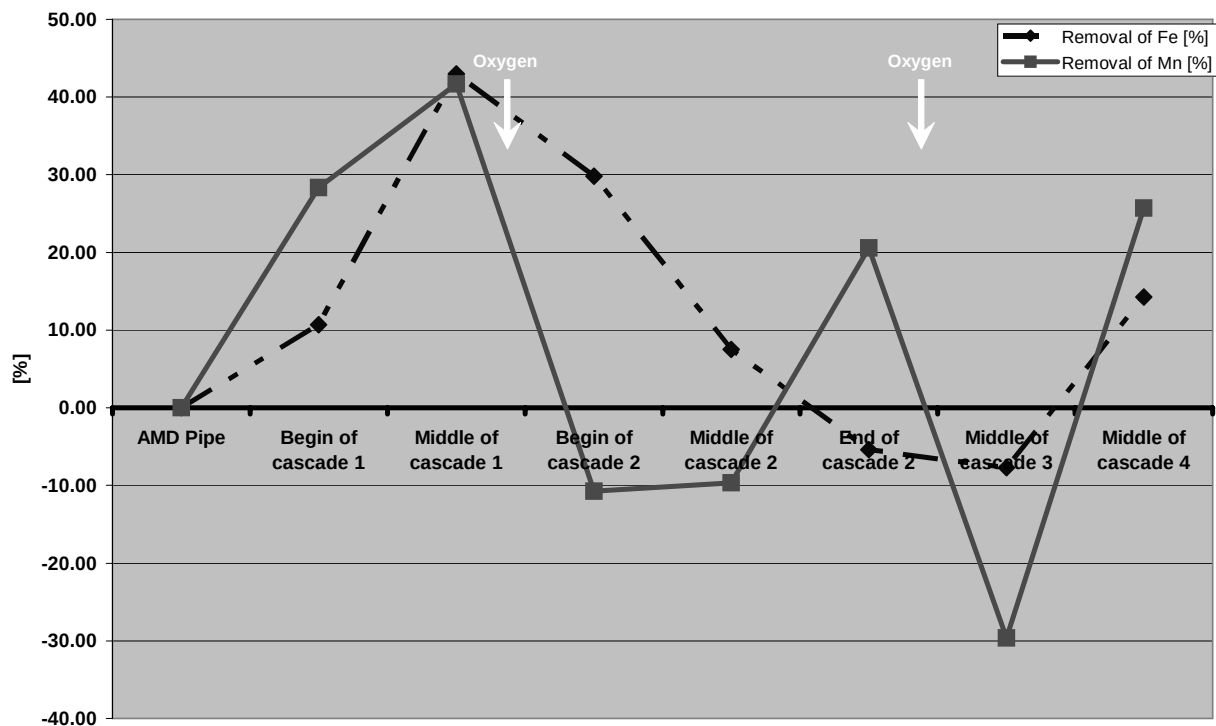


Figure 2-18: Remove [%] of iron (Fe) and manganese (Mn) after every step of treatment in the cascades

The effectiveness of the organic material was shown by the removal of iron and manganese concentration in different percentages from cascade to cascade (Figure 2-17). After the treatment with the organic medium general water quality was greatly improved, measured as the concentration of iron, manganese, pH and EC. Some algae (*Nitzschia palea*, *Micospora stagnorum*) and zooplankton could be detected by microscope indicating that there was enough free oxygen and enough available nutrients. This reflects the first step towards the restoration of good water quality after treatment.

2.3.4 Long-term sustainability of the organic medium

According to the effectiveness of the organic medium the long-term use and sustainability were also investigated – in this case for treatment of AMD for up to 24 months. The loose organic medium was tested by X-ray examination at the Department of Geosciences (South Africa) under conditions simulating long periods of exposure to elevated concentrations of heavy metals and AMD. This long-term treatment was simulated by treating 1 kg of loose organic material with 6000 m³ of polluted AMD per day. After treatment, the loose organic medium was saturated by the bound metals and turned into a hard material. The detected amount of iron (in [ppm]) in the AMD is about 230 times higher than the amount in the organic medium itself. For a medium treatment period of about 10 month, the estimated amount in the used organic medium will be about 10 times higher for iron, 2 times higher for manganese and 23 times for arsenic (measured in [ppm], Dep. of Geosciences).

2.3.5 Cost-effectiveness

When the organic material is used as a pre-treatment system a large number of heavy metals, macro- and microelements are bonded and immobilized. This demonstrates that costs usually incurred for lime and caustic soda used in the past for AMD treatment could be reduced by up to 65% for caustic soda and up to 68% for lime in a 20 megalitre plant. When cost-effectiveness is calculated for a 13 megalitre plant a 73.8% saving in running costs is found (Table 2-2). Stoichiometric calculations show that the savings could be even higher. Treatment of 5500–6000 m³ of AMD daily with about 26,600 kg of the organic medium could save more than a million Rand of annual costs by reducing expenditure on chemical treatment. The benefit of using the organic medium over a long term and coupled with the higher amount of treated AMD (~20,000 m³) the organic medium works much more effective and saves even more chemicals (van der Walt, 2007).

2.3.6 Total quality of treated AMD

The quality of AMD after treatment with the organic medium is within the requirements for agricultural use – in this case for irrigation (Table 2-4) – specified in the guideline Water Quality Guidelines, Volume 4: 'Agricultural Use: Irrigation' by the Department of Water Affairs and Forestry (DWAf, 1996a, 1996b). Samples of treated AMD were taken after the above-mentioned treatment with leaching tubes and analyzed at the Eco-Analytica Laboratory (North-West University). This demonstrates that sterilization of soil after irrigation with treated AMD – as occurs after treatment

with caustic soda and lime – cannot occur. With an increased organic treatment, chemicals can probably be replaced totally by the organic material.

Table 2-4: Quality limitations for irrigation (DWAF) and of treated AMD by the organic medium

Parameter	Units	Irrigation (by DWAF) max. limit	Treated AMD by organic medium
pH	-log ₁₀ [H ⁺]	6.50 - 8.40	8.04
Sulphate	[mg/l]	200.00	118.00
Aluminium	[mg/l]	5.00	1.90
Arsenic	[mg/l]	0.10	0.066
Cadmium	[mg/l]	0.01	0.0033
Chromium	[mg/l]	0.10	0.026
Copper	[mg/l]	0.20	0.061
Iron	[mg/l]	20.00	8.00
Lead	[mg/l]	0.20	0.0046
Nickel	[mg/l]	0.20	0.15
Zinc	[mg/l]	1.00	0.053
Uranium	[mg/l]	0.01	0.00023

2.4 Conclusions

The results of these experiments show the successes with which the organic medium reduces the concentration of total iron in AMD from 12.57 [mg/l] to 0.34 [mg/l] and increases the pH from 3.1 to 8.4. Under these optimized laboratory conditions about 97.3% of the total iron concentration could be removed. Turbulent flow combined with passive treatment as in the cascade system was found effective to remove up to 68% of all metals and sulphates in pH of between pH 3.0 and pH 4.5. The disadvantage of such a reactor was the large area required (500 m²) to successfully treat 6 megalitres AMD per day with a total retention time of 20 min. Even at a low pH the organic medium removes the metals and precipitates them onto the surface of the bags. With this precipitation the metals are immobilized and can be safely and economically removed.

The results of this study proved, that the 50 : 50% mixture of Casuarina and Eliote-bark in the organic medium can be optimized by using 70 : 30% mixture because of the higher binding and precipitation of elements. The lower amounts of tannin and lignin in the bark provide enough potential to raise the pH so that the needles of Casuarina can bind and immobilize more of the heavy metals. After treatment the used material can be deposited on hazardous waste certified waste dumps, or could be recovered and recycled as a source of minerals. A possible application for the used organic medium can be natural fertilizer or detoxifier on waste dumps. Mixed with the hazardous mine soil, the organic medium absorbs leaching water and detoxifies the soil by immobilization of metals, so that Casuarina pines – which is an ingredient of

the organic medium – can be planted in the soil and on top of mine tailings. This added benefit prevents dust storms on the dumps and fertilizes these tailings. Future research projects will show the effectiveness of soil treatment and optimized rehabilitation using these methods.

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3 Using Evolutionary Algorithms to Optimize Anthropogenic Material Streams

Published in: International Journal of Applied Artificial Intelligence, Taylor & Francis, Volume 23, Issue 9, pp. 883-893, ISSN 1087-6545 (Online), ISSN 0883-9514 (Print), DOI: 10.1080/08839510903283339 (10/2009)

3.1 Introduction

The aim of zero waste is a good goal for the future, but we have to accept that an affluent society will always produce natural and anthropogenically created waste.

There are “three Rs” - Reduce, Re-use and Recycle that are always mentioned and important and with these the hierarchy of waste minimization is explained. But what should be done with waste without the use of recycling?

In this case the recycling itself has to be optimized to process the largest possible amount of waste products in the production process of new materials. This optimization allows a minimization of primary raw material and additionally a minimization of waste. Because of the use of more short-life products the affluent society always requires more resources to fulfill the need of the required materials. Because of such consumption, nature has too little time for recovery and regeneration. The use of secondary materials as a substitute resource can for the most part cover the bulk of the resource requirement whilst preventing overexploitation of the natural primary resources at the same time. The sixth German Environmental Program from the Federal Ministry of Environment and Conservation clearly pointed towards improved resource utilization efficiency and minimization of the negative impact on the environment by the usage of available resources (BMU, 2006).

Fundamental to the argument for the effective use of secondary materials is an understanding of the product circle and the numerical calculation of the resource input. The boundaries of the production process and the qualities and quantities of the materials are also related.

All these factors have to be considered in the calculation and have different impacts on the production process and the final product itself. Because of the great variability of mutually dependent parameters in the calculation, most of the common numerical calculation methods reach their limits (Pollmann, 2007). As the main calculation module for the problem of optimization evolutionary algorithms were used as a component of artificial intelligence. With these algorithms, acting like the model of evolution, the input of secondary materials for the production of products with similar quality was optimized.

Using paper production as an example, it could be proved by utilizing evolutionary algorithms that by raising the input of secondary materials (waste papers) the quality of the final product need not be compromised. This result makes it possible to im-

plement the substitution of primary materials in the paper production process by means of more efficient use of existing resources.

3.2 Materials and Methods

3.2.1 Indicator Carbon

In order to optimize the use of secondary materials in the paper production, the process itself was investigated (figure 3-1) and reduced to the lowest common indicator – in this case carbon.

This indicator is an element which cannot be reduced any further (Baccini, 1996). Related to different products all proportions of carbon are calculated relative to the mass and balanced for each production step. This balance makes it possible to finally compare all carbon fluxes to prove that the results from the optimization by fiber quality are comparable to the results from the carbon fluxes. Additionally, other allowances for optimizations of the resource input can be visualized.

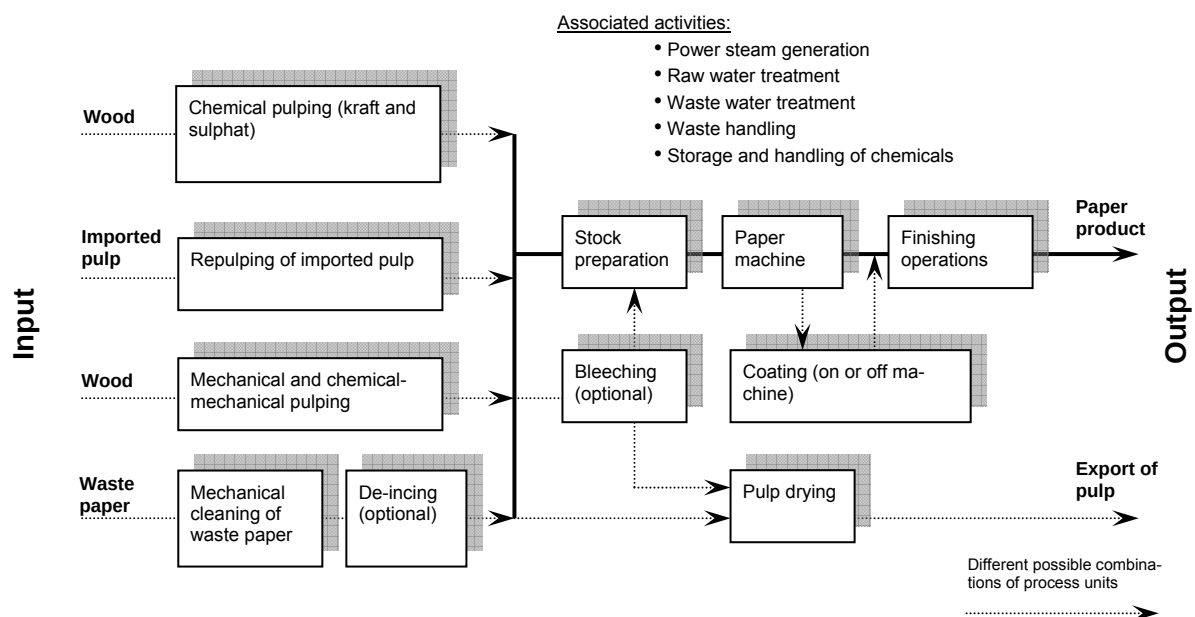


Figure 3-1: Production processes for paper production (Pollmann, 2007)

3.2.2 Indicator fiber length

Quality, availability and re-usability are always related to the length of the fibers of the material. This indicator is also used for the calculation and optimization with the evolutionary algorithms. The quality of the paper produced is understandably linked to the fraction of included secondary material. The higher the percentage of secondary material included the shorter the average length of the fibers in the paper and consequently a less desirable resultant quality (figure 3-2). To produce a paper of high quality the carbon fluxes are related to the classes of waste paper and fresh pa-

per to display the material fluxes. With these input values, the evolutionary algorithms can optimize and demonstrate the material flux related to the product quality. With this data it is possible to raise the percentage of secondary materials in almost all paper classes without loss of quality.

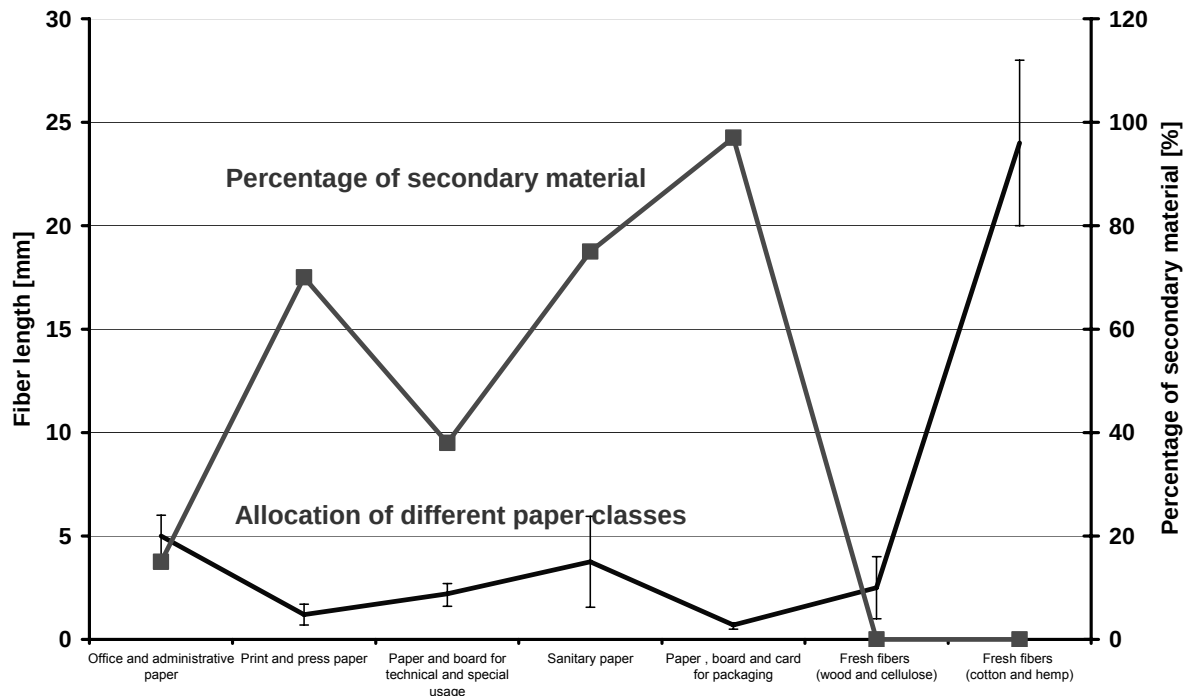


Figure 3-2: Allocation of fiber length and percentage of secondary material for different paper classes (Erhard, 2006)

3.2.3 Environmental factor (UWF)

To inspect the influence of the chosen material mix on the ecology and economy, a cost related factor (UWF) was implemented. This environmental factor (UWF) is a cost-related coefficient which explains the influence and the impact of secondary material on economic and ecological aspects (table 3-1). Therefore this factor has an influence on the use of secondary material of lower quality. Beside the use in paper production, most of the secondary materials have no other use in production (ATV-DVWK, 2001). Because of that the waste paper has to be deposited on dumping sides which results in relatively high costs (Bos et al., 1999). In this case the environmental factor influences the calculation positively because of the reuse of the waste paper. Consequently, the use of high quality fibers the factor will influence the process negatively because fibers with a high market value were used where fibers of lower quality were banned.

Table 3-1: Costs of waste paper and influence of the environmental factors (UWF) (Pollmann, 2007)

Classes	Costs (1999) [€/t]	Environmental factor (UWF) [-]	Chosed UWF [-]
Group 1: lowest class	- 5,- € to + 62,- €	0,00 - 1,00	0.50
Group 2: middle class	+ 46,- € to + 92,- €	0,50 - 1,30	0.90
Group 3: better class	+ 169,- € to + 221,- €	0,60 - 1,50	1.00
Group 4: energy containing class	+ 65,- € to + 145,- €	0,80 - 2,00	1.40
Group 5: special class	+ 140,- € to + 330,- €	1,00 - 3,50	2.20
Sulphate pulp	+ 359,- € to + 544,- €	0,00 - 1,00	0.30

If the factor increases the net result will be ecologically worse. Decreasing factors will improve the total result ecologically and by changing the boundaries the results of the optimization will be improved as well.

This factor has no influence on the optimization process of the evolutionary algorithms itself. It only demonstrates the influence of the results on environmental and monetary issues.

3.2.4 Use of evolutionary algorithms for optimization

The composition of different paper classes requires an algorithm which is able to solve equations with ten or more unknown factors which are additionally interdependent. With common numerical methods these calculations are solvable only with long calculation time if at all. Because of this fact evolutionary algorithms were used as a solver functioning as the biological model of evolution (Gerdes et al., 2004).

The benefit of evolutionary algorithms is the objectives-orientated, fast and precise calculation of local and global optima by consideration of different evolutionary influences (figure 3-3). To calculate the application of optimizing secondary materials the following parameters have to be determined: computational accuracy, size of search area, objective function, amount of individuals, amount of generations, impact of mutations, crossover, fitness, selection and definition of an abort criterion. With these specifications it is possible to optimize different input materials for the production of paper relative to different quality requirements (Pollmann, 2006).

As input materials, all the different secondary and recycled papers and additionally the primary fibers are available. From these the optimized composition related to the fiber length can be calculated. The start vector of the initial population (individuals from the start generation) will be chosen randomly from the mix of input materials.

The principle flowchart (figure 3-3) was used and implemented for the application of evolutionary algorithms in the paper production. In this regard the following steps were followed:

1. Defining of input and output variables, constants and functions.
2. Random generation of lists with start populations.
3. Suitability for each list of the population. This implies defining how good the items in the lists comply with the requested task.
4. Executing the selection by fitness function.
5. Executing the gene exchange (crossover, mutation, reproduction), so that correct lists are always generated.
6. Repetition of steps 3 to 5 till the defined abort criterion is achieved.

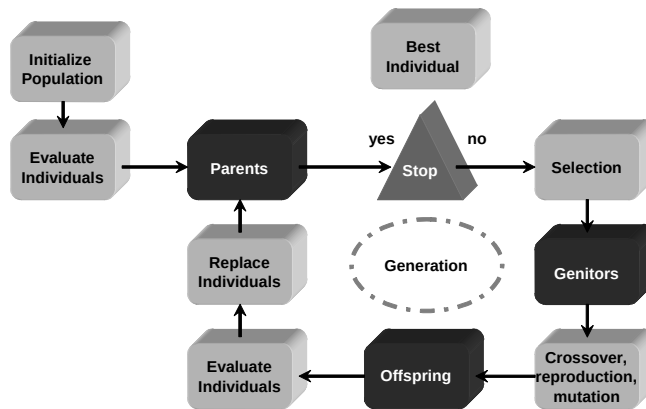


Figure 3-3: Sequence diagram of evolutionary algorithms (Pollmann, 2007)

Important for the flow is that mutation and crossover should be used at same time to eliminate the premature convergence, a disadvantage of evolutionary algorithms. Otherwise an occurrence of local optima or of the same individual as a result of the optimization is possible but undesirable.

The result of the material flux optimization in paper production is a calculated material mix which achieves the desired quality. The evolutionary algorithms calculate randomly, by generating a batch of acceptable results within the restricted boundaries, the best result for the solution of the problem is (figure 3-4). The benefit of calculating a system like this with evolutionary algorithms is the very fast detection of possible restricted global optimum (Y_t) out of the total sum of possible results (ΣX_t).

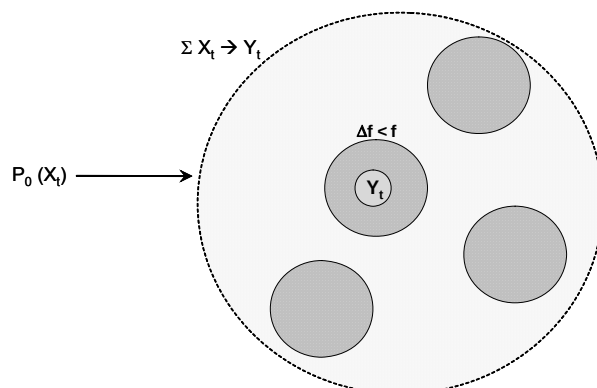


Figure 3-4: Stray field of potential results (Pollmann, 2007)

3.2.5 Aim of optimization: input of different fiber length

To optimize the input of secondary fibers the problem was defined and valued by the fiber length of different paper types. The shorter the paper fibers are the poorer the quality of the paper will be. Recycled fiber lengths are shorter because of the processing process. To get a certain average fiber length for a specific paper type by optimization, the quality of the required product must be known. The basis for this optimization is the divided classes of waste papers (table 3-3) and new papers (table 3-2) in different quality classes.

Because of these quality indicators an array of different mixtures of secondary materials combined with primary materials for the production of defined paper types can be calculated and optimized by utilizing evolutionary algorithms. Some new fibers will still have to be used because of the fact that these fibers ensure the crucial required quality of the end product.

Table 3-2 Distribution of fiber length of different materials (see table: from literature)

Classes	Fiber length [mm]	From literature
Cotton and hemp fibers (a)	$18.00 \leq L_a \leq 22.00$	Meister, 1999
Wood and cellulose (b)	$1.00 \leq L_b \leq 4.00$	Erhard, 2006 und Gruber 2000
Waste paper category 1 (c)	$0.70 \leq L_c \leq 0.85$	PTS, 2007
Waste paper category 2 (d)	$0.55 \leq L_d \leq 0.70$	PTS, 2007
Waste paper category 3 (e)	$0.40 \leq L_e \leq 0.55$	self disposition
Waste paper category 4 (f)	$0.25 \leq L_f \leq 0.40$	Leonhardt, 2000
Waste paper category 5 (g)	$0.10 \leq L_g \leq 0.25$	self disposition

Table 3-3: Distribution of fiber length and waste paper application quote of different paper types (see table: from literature)

Paper classes	Fiber length [mm]	from literature	Input quote of waste paper [VDP, 2004] [%]
Office and administraton paper	4,0 - 6,0	self disposition	15
Print and press paper	0,7 - 1,7	Meinl, 2007	70
Paper and board for technical and special usage	1,5 - 2,7	self disposition	38
Sanitary paper	1,5 - 6,0	Mondi, 2007	75
Paper, board and card for packaging	0,5 - 0,8	Meinl, 2007	97
Fresh fibers (wood and cellulose)	1,0 - 4,0	Erhard, 2006 u Gruber 2000	0
Fresh fibers (cotton and hemp)	20,0 - 28,0	Meister, 1999	0

3.3 Results

The optimized material input was calculated (equation 1) with three different algorithms: GASTeadyStateGA, GACrowdingGA and GADemeGA as part of artificial intelligence. All calculated values were all in the same range with small insignificant deviations. These deviations in different types of algorithms probably reflect the influence of variable boundary conditions.

$$f(x) = \sum_{i=1}^7 x_i * V_i * U_i \quad (1)$$

with: x_i = concentration (as relative fraction), V_i = volume, U_i = environmental factor (UWF)

As a summed up result this optimization demonstrates an improvement for the paper types *paper and board for technical and special usage* of about 2% (figure 3-5) and *sanitary papers* of about 6% (figure 3-6) with the same end product quality.

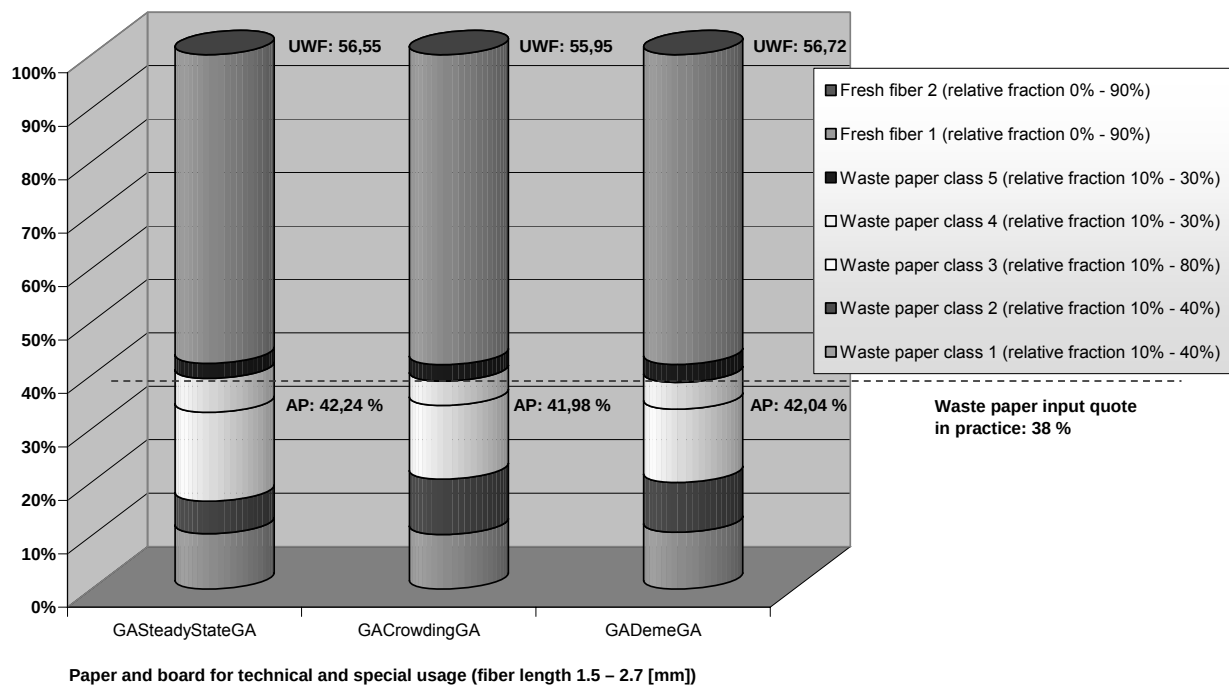


Figure 3-5: Results of the material mix from paper and board for technical and special usage (fiber length 1.5 – 2.7 [mm]) (Pollmann, 2007)

The result of this investigation was an increase of secondary material input for the paper classes *sanitary papers* and *paper and board for technical and special usage* without any loss of quality in the paper itself.

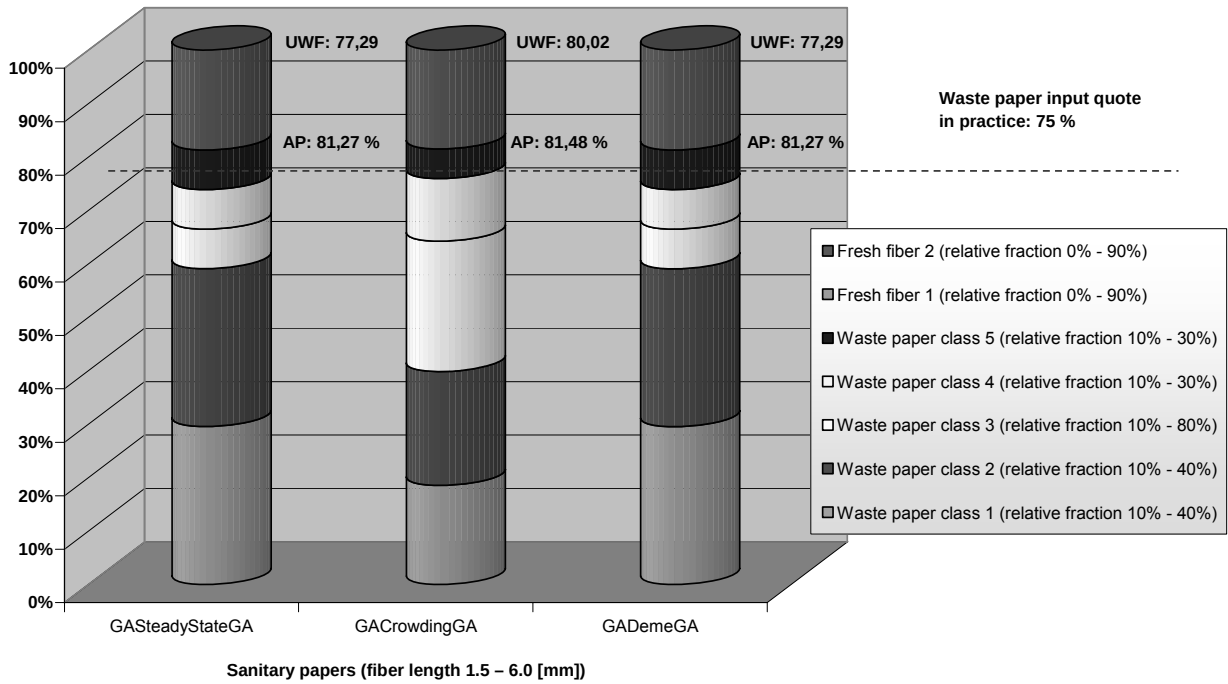


Figure 3-6: Results of the material mix from sanitary papers (fiber length 1.5 – 6.0 [mm]) (Pollmann, 2007)

To validate the results from the optimization with the evolutionary algorithms two types of similar calculations were done as an inductive verification. First the results were recalculated (equation 2) with the simplex-method invented by Nelder and Mead (1965). This method does not use any derivation it constructs 3-D polyhedrons, which approximate the optimum (center) as a simplex.

$$x = \frac{1}{n} \sum_{i=1, i \neq s}^{n+1} (x^i) \quad (2)$$

with: x = amount of vertexes, n = amount of points, s = worst point.

In this case the equation is solved as a minimum search by the command `fminsearch`. The optimal minimum is at the point $f(x) = 0$, whereas x_i always has to be unequal to zero. The calculation was done with the tool Optimization as part of the mathematic software MathLab (The MathWorks Inc. Natick, Massachusetts). To calculate the 7-dimentional problem it was necessary to solve 200 equations within 123 iteration steps. All results were in the same range as the evolutionary algorithms.

As the second method the “banana-function” (equation 3) from Rosenbrock (1960) as a common problem of minima was calculated with evolutionary algorithms to check their accuracy (Rosenbrock, 1960).

$$f(x) = 100 * (x_2 - x_1^2)^2 + (1 - x_1)^2 \quad (3)$$

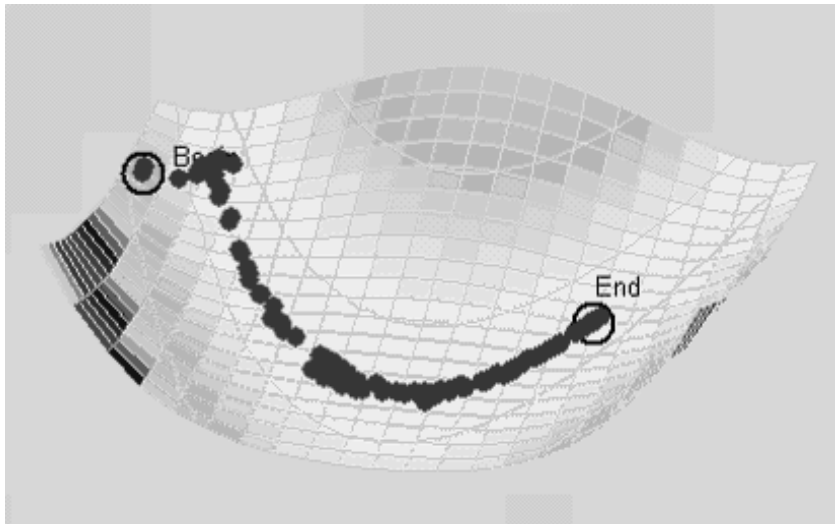


Figure 3-7: Calculation of the banana-function from Rosenbrock by using the simplex-method by Nelder-Mead (done with MatLab/Optimization)

The known result of the equation (3) is the minimum (1,1) with possible solutions between 0 and 100. All methods of the evolutionary algorithms showed an average deviation of 0.027% from the result of Nelder/Mead (table 3-4). Therefore 100 individuals and 1,000 generation steps were used.

Table 3-4: Deviation of results from evolutionary algorithms compared with results from the banana-function (Pollmann, 2007)

Type of evolution	X1	X2	average deviation
GASteadyStateGA	0.999969	0.999940	0.00045%
GACrowdingGA	1.000240	1.001340	0.07900%
GADemeGA	0.999993	0.999987	0.00010%
Nelder-Mead	1.000000	1.000000	0.0%

3.4 Conclusion

This research proved with different methods and inductive verification that it is possible to enhance the input of secondary materials for some paper types without any loss in quality. This enhanced input of secondary materials has economic as well as ecological impacts on the total paper production process. On the other hand the research also showed that the use of evolutionary algorithms as part of artificial intelligence might have a role to play in waste management.

By posing a problem in a specific manner the evolutionary algorithms can be applied to an array of other problems with an anthropogenic origin.

3.5 Declaration of Interest

The described implementation of evolutionary algorithms and the application for the paper industry should show a possibility to reduce waste without any negative influ-

ence of quality. With this contribution paper producing companies have to rethink the production process itself to keep the paper production environmental friendly. I hereby also certify that there is no actual or potential conflict of interest in relation to this article.

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4 Mine Tailings: Waste or Valuable Resource?

Published in: International Journal of Waste and Biomass Valorization, Springer Publisher, Volume 1, No 4, ISSN 1877-2641 (print), 1877-265X (online), DOI: 10.1007/s12649-010-9042-6 (12/2010)

4.1 Introduction

Land degradation has become a global concern. Soil has been recognized for its value as a natural resource and accordingly, serious concerns exist regarding anthropogenic activities, including civil engineering programs and intensive agriculture that cause environmental degradation (Harris, 2003). The past fifty years have seen considerable losses in terms of healthy soil ecosystems worldwide. Of the 8.7 billion hectares of agricultural land, permanent pastures, forests, and woodlands, around 2 billion hectares have been degraded (Arshad, 2002). In 1999, the National State of the Environment Report for South Africa indicated the average soil loss as 2.5 tons per hectare per annum (DEAT, 1999).

Mining in South Africa provides a vast contribution to the economy, both in terms of the actual materials that are mined and in the creation of hundreds of thousands of jobs, with benefits to many aspects of society (Mining Review Africa, 2003). However, mining activities inherently hold extensive adverse effects for the biophysical, social, and economic environment and result in severe disturbance of large areas of land (Milton, 2001, Mummey, 1992). The natural grassland biome, traditionally the grazing areas of South Africa, is poorly conserved and its fragmentation by an abundance of mine tailings and discard sites leads to degradation of environmental quality and eventually affects human living standards (Van Wyk, 1997, 2002). Tailings material is processed at a rate of millions of tons per year (Rösner, 2001) and massive tailings dam facilities originating from coal and ore mining litter the South African landscape. In 1996, the mining industry was responsible for the production of 377 million tones of tailings, accounting for 81% of the solid waste stream in South Africa (Van Wyk, 2002). Currently, mining waste is still the principal contributor to the solid waste stream, followed by pulverized fuel ash (6.7%), agricultural waste (6.1%), urban waste (4.5%) and sewage sludge (3.6%) (Arendse, 2002). Cyanide compounds, heavy metals, radionuclides, and asbestos are all possible toxic components of mine waste. If mine waste is not managed properly, it represents a potential hazard for surrounding ecosystems and public health in nearby communities (Hoskin, 2003). Other impacts of mining include destruction of land and vegetation, pollution, and changes in surface drainage. As a result, environments are prone to increased soil erosion, compaction, subsidence, changes in topsoil characteristics, and a reduced capacity to support vegetation growth (Arendse, 2002).

Although mines are expected to provide for and apply rehabilitation measures before closure is granted (Milton, 2001), it is much more complicated than simply restoring the disturbed area. The consequence of mining activities is a soil environment typi-

fied by poor physical characteristics (table 4-1, table 4-2), such as poor textural material properties, combined with the effect of the slopes of the discard sites (Van Wyk, 2002); low levels of plant nutrients and organic matter; pH-value extremes; and the presence of harmful substances such as heavy metals (Mining Review Africa, 2003). The processing of mine tailings and discard materials usually results in an elevated topography which means that these discard sites are particularly exposed to the adverse effects of wind and water erosion (Van Wyk, 2002). Arid to semi-arid climatic conditions intensify the problems of establishing a permanent self-sustaining vegetation cover (Milton, 2001, Mining Review Africa, 2003). In open cast mining, topsoil has to be stripped from sites and stored, with subsequent adverse changes in the structure, physical, chemical and biological characteristics of soils (Harris, 1989). Past rehabilitative management strategies that relied extensively on the restoration of disturbed areas by application of agronomic approaches proved unsuccessful in the semi-arid and arid areas of southern Africa (Milton, 2001). Furthermore, the rehabilitation process is complicated due to the lack of suitable assessment criteria for restoration success. It seems that vegetative stabilization is the most successful answer to achieve a sustainable rehabilitation of mine discard sites (Frouz, 2001, 2005). Since soil is the growth medium for all vegetation, it is important to find suitable methods to assess and improve the quality of this substratum. Soil quality and the associated success of rehabilitation efforts as shown in the results of our investigation are difficult to measure because soil and its functions are an ecologically complex phenomenon that cannot be readily assessed by any single soil parameter. The aim of this study was to provide methods for the improvement the quality of mine tailings, to establish growth of the experimental plants on such material and to investigate whether mine tailings are waste or a valuable resource. To make this investigation more effective evolutionary algorithms were used to optimize the application rates for ameliorants and therefore to reduce the cost of rehabilitating mine tailings.

4.2 *Materials and Methods*

4.2.1 *Selected substrate*

Tailings from platinum and gold mining were chosen for this study. The platinum tailings originated from the western Bushveld Igneous Complex northeast of Rustenburg, North-West Province in South Africa (GPS Coordinates: UTM WGS84 Zone 35S: 7178500 / 522500). The gold tailings substrate comes from an operational gold mine near Orkney, North-West Province, in South Africa (Coordinates: UTM WGS84 Zone 35S: 702600 / 477550).

Rustenburg falls within the summer rainfall climatic zone. The area is characteristically warm to hot with a mean annual precipitation of about 600 mm and a mean annual evaporation of about 1800 mm (Midgley, 1994a). Temperatures vary between extremes of -6.0°C and 40.0°C with an average of 19°C (Rustenburg Local Municipality, 2009). The soil geology is basic, mafic and ultramafic intrusive (Midgley, 1994).

The chosen representative sample is a mixture of each separate sample from one trial. Each of these samples was analyzed in the laboratory. The ameliorants chosen for this study were produced from natural materials and optimized for the specific needs of plants growing in highly polluted substrates such as mine tailings. Three different ameliorants were used for the cultivation of experimental plants. The first, sewage sludge, was aged for an average of six months (Pollmann, 2009). The second, woodchips, are a by-product of the destruction of underground supporting struts after blasting. These woodchips contain, in addition to high concentrations of plastic and explosive residues, high concentrations of nutrients necessary for the growth of plants (Maboeta, 2003a, 2003b). The third ameliorant was vermi-compost, an often used growth medium and nutrient repository (Pollmann, 2009). All three products were used to optimize the affinity for natural soil and to obtain the best bonds, related to the lyotrophic series (conversion preference, $\text{Al}^{3+} \approx \text{H}^+ \gg \text{Ca}^{2+} > \text{Mg}^{2+} \gg \text{K}^+ \approx \text{NH}_4^+ > \text{Na}^+$ (Scheffer, 2002)) and to store the required nutrients. All substances have different influences on soil quality and vegetation vitality because of the content and variety of available and essential nutrients.

4.2.2 Selected tree species

In order to monitor the improvement of tailings quality by application of soil amelioration products visually, a tree species was chosen. Such a tree species should be tolerant and adaptable to extreme environmental conditions as well as indigenous in South Africa. Therefore *Searsia lancea* (L.f.) F.A. Barkley was selected. *S. lancea* is a small to medium sized evergreen tree that usually grows to a height of 7 m. At the initiation of the field experiment the trees were 1.2 to 1.5 meters high and about two years old.

4.2.3 Laboratory investigations

The substrata were analyzed for chemical, biological and physical properties (The Non-Affiliated Soil Analysis Work Committee, 1990, USDA, 1972, Peech, 1965). The following analyses were performed:

- Water analysis (1:2 water extraction) and inductively-coupled-plasma mass-spectrometry (ICP-MS, Agilent 7500c, Agilent Technologies, Santa Clara, California, USA),
- pH-value and EC (measured with handheld Combo pH & EC, HI 98130 by HANNA),
- Microbiological activity by Dehydrogenase (method: nach Von Mersi, 1991),
- Root neck diameter and height of trees.

4.2.4 Characterization of substrata

The experimental mine tailings were analyzed and the material can overall be characterized as having poor soil qualities (table 4-1, table 4-2). In general, gold tailings have a pH-value of 3.8, platinum tailings of 7.3. Untreated tailings have high EC val-

ues of up to 3.1 mS cm^{-1} . The quality of the substratum used for plant growth is dependant on the elements calcium, magnesium and potassium. In min tailings material plants struggle to survive because of low concentrations of essential nutrients and high concentrations of phytotoxic substances. In general ions are washed out by precipitation or irrigation. This differs from the tailings storage facility, as the high content of pollutants in the material coupled with high compaction block ions from leaching (Pollmann, 2009). Analyses of gold tailings by aqua regia dissolution showed that heavy metals like chromium, copper, nickel and mercury are below the detection limit of 5 mg/kg (unpublished data). Similar analyses of platinum tailings showed high contents of chromium (947 mg/kg) and nickel (318 mg/kg) (Meyer, 2006). A sequential extraction according to Zeien and Brümmer (Zeien, 1989) showed that only up to 12% of the total nickel content is available within the first four steps. Therefore only a small part is plant available. Chromium is bound only in fractions 5 to 7 and therefore not plant available.

Table 4-1: Analysis of untreated substrata

Sample	K ⁺	Na ⁺	B ⁺	NH ₄ ⁺	Ca ²⁺	Mg ²⁺	Fe ²⁺	Mn ²⁺	Cu ²⁺	Zn ²⁺
	<i>ppm</i>									
Gold Soil	0.39	17.70	0.00	2.20	464.10	70.73	0.36	12.93	0.54	2.89
Platinum Soil	22.68	74.95	0.05	0.60	81.76	54.44	0.06	0.02	0.00	0.00

Sample	NO ₃ ⁻	Cl ⁻	HCO ₃ ⁻	SO ₄ ²⁻	PO ₄ ³⁻	pH	EC
	<i>ppm</i>					--	<i>(mS/cm)</i>
Gold Soil	18.02	16.57	0.00	1,429.40	0.00	3.75	3.05
Platinum Soil	78.36	115.15	36.61	350.63	0.00	7.34	1.24

4.2.5 Control methods of microbiological activity - dehydrogenase activity

Microbiological activity was determined by testing dehydrogenase activity using the INT-method (INT = idonitrotetrazolium chloride) after (Von Mersi, 1991). The method is based on the incubation of soil with the substrate idonitrotetrazolium chloride (INT) at 40°C for 2 hours followed by colorimetric estimation of the reaction product idonitrotetrazolium chloride-formazan (INF) spectrophotometrically at 464 nm against a blank. The amount of metabolised substrate per time and amount of protein was measured. Dehydrogenase activity is expressed as $\mu\text{g INF g}^{-1} \text{ dwt } 2 \text{ h}^{-1}$ and calculated according to the following equation:

$$INF(\mu\text{gg}^{-1} \text{dwt} 2\text{h}^{-1}) = \frac{S_1 - S_0}{\text{dwt}} \quad (1)$$

with: S1 = INF (in μg) of the test
 S0 = INF (in μg) of the control
 dwt = dry weight of 1 g moist soil

4.2.6 Investigation approach

Both, platinum and gold tailings material were mixed with the amelioration products sewage sludge (SS, 10%), woodchips (WC, 10%) and vermi-compost (VC, 10%) be-

fore adding into the prepared pot (12 test plants per type,) in the greenhouse. These 72 plants plus additional 12 plants in untreated gold and platinum substratum (UT) (in total 96 plants) were initially kept under greenhouse conditions with an average temperature of 25 degree Celsius and regular irrigation twice a week over the first three months before they were transferred to natural conditions with precipitation only for the next three months. The monitoring of the elements calcium, magnesium and potassium took place every 8 weeks (Maboeta, 2003, Pollmann, 2009].

A field trial was conducted on platinum tailings in Rustenburg (North-West Province) starting in spring of 2009. Four variants were carried out with different admixture of ameliorants:

1. 5% matured sewage sludge,
2. 15% matured sewage sludge,
3. 10% woodchips,
4. untreated platinum tailings.

All plants were irrigated every 14 days over 1.5 months.

The change of parameters of substratum as well as biometric parameters was conducted after 8 weeks. A comparative trial on gold tailing could not be conducted as permission to access the TSF was denied. After the application of different fertilizers soil/substrate quality was analyzed for macro-, micro-elements by water analysis (1:2 water extraction) and inductively-coupled-plasma mass-spectrometry (ICP-MS, Agilent 7500c, Agilent Technologies, Santa Clara, California, USA). Microbiological activity was analyzed for by testing enzyme activity and dehydrogenase activity (Von Mersi, 1991).

4.3. Results and Discussion

In this case results from only one aspect e.g. soil chemistry, soil biology or biometry will not give representative overview of the results of the research.

4.3.1 Results and discussion of laboratory experiments

The laboratory trials with three different ameliorants showed a reduction in the concentrations of certain heavy metals and an increase in the total soil quality in both different soil substrata with only a slight improvement with the addition of woodchips. Complete samples of the tailings / ameliorant mixtures (section 4.2.3 and 4.2.5). A reduction of ionic compounds was reflected by a decrease in electrical conductivity (EC) of 97% in the platinum tailings treated with woodchips and 38% in gold tailings treated with matured sewage sludge (table 4-2). This confirms the results of van Rensburg (Van Rensburg, 2004] who could show a significant decrease of salinity in similar conditions. The Similarity to the initial tailings materials in EC is related to the exchange of elements regarding the lyotropic series (section 4.2.1).

Table 4-2: Chemical analysis of laboratory measures

Sample	Time frame	K ⁺	Ca ²⁺	Mg ²⁺	pH	EC
		ppm			—	(mS/cm)
Gold Soil + woodchips 10% (GWC)	start	3.52	446.07	84.10	3.86	3.14
Gold Soil + woodchips 10% (GWC)	after 2 month	10.95	352.29	47.39	6.70	2.26
Gold Soil + woodchips 10% (GWC)	after 6 month	8.99	422.02	11.18	4.29	2.26
Gold Soil + compost 10% (GVC)	start	7.43	434.85	99.41	3.88	3.30
Gold Soil + compost 10% (GVC)	after 2 month	5.47	411.60	50.07	5.07	2.59
Gold Soil + compost 10% (GVC)	after 6 month	4.30	422.82	12.15	4.37	2.26
Gold Soil + sewage sludge 10% (GSS)	start	8.21	401.58	70.73	4.54	3.20
Gold Soil + sewage sludge 10% (GSS)	after 2 month	3.52	321.43	69.03	6.47	2.27
Gold Soil + sewage sludge 10% (GSS)	after 6 month	2.35	367.11	13.61	4.42	1.98
Gold Soil (GUT)	start	0.39	464.10	70.73	3.75	3.05
Gold Soil (GUT)	after 2 month	4.30	424.43	38.16	5.25	2.56
Gold Soil (GUT)	after 6 month	4.69	435.65	9.72	4.32	2.31
Platinum Soil + woodchips 10% (PWC)	start	104.39	340.66	149.23	6.86	4.28
Platinum Soil + woodchips 10% (PWC)	after 2 month	25.02	58.51	59.06	7.66	1.13
Platinum Soil + woodchips 10% (PWC)	after 6 month	7.82	10.42	3.65	7.70	0.13
Platinum Soil + compost 10% (PVC)	start	67.25	228.44	93.82	7.07	2.67
Platinum Soil + compost 10% (PVC)	after 2 month	8.60	23.65	21.63	7.45	0.41
Platinum Soil + compost 10% (PVC)	after 6 month	5.86	10.02	5.10	7.48	0.13
Platinum Soil + sewage sludge 10% (PSS)	start	38.32	72.14	86.28	7.53	1.65
Platinum Soil + sewage sludge 10% (PSS)	after 2 month	13.68	34.47	33.05	7.74	0.63
Platinum Soil + sewage sludge 10% (PSS)	after 6 month	3.91	5.61	3.40	7.12	0.08
Platinum Soil (PUT)	start	22.68	81.76	54.44	7.34	1.24
Platinum Soil (PUT)	after 2 month	15.64	32.86	37.92	7.34	0.75
Platinum Soil (PUT)	after 6 month	5.08	8.82	2.19	7.38	0.09

In the platinum tailings the amount of potassium decreased with the addition of all types of ameliorant, whereas in gold substratum combined with woodchips (10%) a small increase could be noted. The calcium level in gold tailings is continuously high and could not be decreased. In platinum tailings the high level could be decreased and stabilized to a lower level. Levels of magnesium could be reduced in both substrata. In gold tailings the level of magnesium after treatment is in the optimum range of about 12 ppm. In the platinum tailings the lower level of magnesium is constant but a little bit to low. Of benefit is that the ratio of magnesium to calcium always is far beyond the quotient 2 (Schulte, 1993). That indicates that plant uptake of potassium will be more than optimal.

The total microbiological activity in both unaltered tailings and ameliorated soil types was only about one third, on average about 50.0 INF $\mu\text{g}/(\text{g}\cdot 2\text{h})$, that of natural soil (110.0 INF $\mu\text{g}/(\text{g}\cdot 2\text{h})$). This is the result of the free available inhibitors of microbial growth in the tailings. The highest improvement of soil quality can clearly be seen in gold tailings ameliorated with matured sewage sludge. After the addition of the ameliorant the microbiological activity increased by 70% from 78.3 to 132.8 INF $\mu\text{g}/(\text{g}\cdot 2\text{h})$ after 2 months and stabilised at 108.2 INF $\mu\text{g}/(\text{g}\cdot 2\text{h})$ after 6 months. In the platinum tailings the most improvement in microbiological activity was achieved, after an initial decrease of 51%, after two months using woodchips. There was a 46% increase in activity from 48.7 to 71.1 INF $\mu\text{g}/(\text{g}\cdot 2\text{h})$ after the total six months test period.

4.3.2 Results and discussion of field experiments

After amelioration the pH of the soil was neutral to alkaline and the total EC was reduced by 47% on average (table 4-3). This is again similar to results by van Rensburg (Van Rensburg, 2004). A neutral to alkaline pH can inhibit the mobilization of heavy metals (Scheffer, 2002), so that higher than normal concentrations are not of

concern. An increase in potassium from 2.7 to 12.1 ppm was achieved by using woodchips (10%) as an ameliorant. Similar results were obtained with the addition of sewage sludge (15%). The concentration of calcium was reduced to a lower level on addition of all ameliorants. Magnesium could only be stabilized by the addition of woodchips (15%). All other trials showed a decrease in magnesium. The uptake of potassium by plants will be inhibited because the ratio of magnesium to calcium is lower than the quotient 2.

Table 4-3: Chemical analysis of field trials

Sample	Time frame	K ⁺	Ca ²⁺	Mg ²⁺	pH	EC
		ppm			--	(mS/cm)
Platinum Soil + woodchips 10% (PWC)	start	2.74	14.43	6.81	7.46	0.30
Platinum Soil + woodchips 10% (PWC)	after 2 month	8.21	9.62	3.65	7.15	0.17
Platinum Soil + woodchips 10% (PWC)	after 4 month	12.12	16.83	4.13	6.84	0.26
Platinum Soil + sewage sludge 5% (PSS ₅)	start	21.11	14.83	11.42	7.18	0.47
Platinum Soil + sewage sludge 5% (PSS ₅)	after 2 month	12.51	14.83	8.75	7.00	0.29
Platinum Soil + sewage sludge 5% (PSS ₅)	after 4 month	6.65	14.43	4.13	6.82	0.15
Platinum Soil + sewage sludge 15% (PSS ₁₅)	start	15.64	22.04	10.94	7.19	0.41
Platinum Soil + sewage sludge 15% (PSS ₁₅)	after 2 month	24.63	28.05	15.80	6.92	0.51
Platinum Soil + sewage sludge 15% (PSS ₁₅)	after 4 month	12.51	25.65	6.81	6.74	0.26
Platinum soil (PUT)	start	0.39	16.03	5.10	7.48	0.21
Platinum soil (PUT)	after 2 month	5.86	12.02	5.83	7.33	0.19
Platinum soil (PUT)	after 4 month	17.59	26.85	6.56	6.89	0.28

Unlike the laboratory trial, the field trial on platinum tailings showed an improvement in microbiological activity after a short time with the application of all types of ameliorant. After only two months microbiological activity increased by 57% from 68.5 to 107.6 INF µg/(g·2h) with the addition of 5% matured sewage sludge. After four months the initial growth spurt dropped off in almost all test groups.

The field trial was conducted over a period of 6 months on a platinum tailings storage facility. Growth success of the test plants was monitored regularly. The different treatments lead to a different growth success of *Searsia lancea*. The final biometric measures are summarized in table 4-4.

Table 4-4: Analysis of biometric measures (platinum tailings)

Treatment	Growth increase [cm]	Root neck diameter [cm]	Loss rate [%]	n
Platinum soil + woodchips 15% (PWC)	12.1	3.7	5	20
Platinum soil + sewage sludge 15% (PSS)	9.5	3.8	0	20
Platinum soil + sewage sludge 25% (PSS)	9.7	5.5	5	20
Platinum soil (PUT)	9.6	1.0	5	20
Platinum soil + arkadolith 3% (PA)	2.4	3.1	35	20
Platinum soil + arkadolith 12.5% (PA)	4.2	2.4	20	20
Platinum soil + compost 12.5% (PVC)	11.3	1.8	20	5

The results show clearly that the treatments performed differently when examining the biometric parameters. Growth increased within ranges from 2.4 cm for a treatment with Arkadolith to 12.1 cm for a treatment with woodchips. The treatment with sewage sludge improved the root neck diameter by 5.5 cm. Furthermore, the loss rate differs between 0% and 35%.

The results indicate that no treatment performs best in terms of all biometric parameters. Nevertheless an evaluation of only the biometric parameters is not sufficient.

Experiments by (Meyer, 2009) using vermi-compost as a soil amelioration product on platinum tailings proved that a self-sustainable grass vegetation can be established. Long-term experiments showed that the vegetation persists over several vegetation periods. Even small amelioration ratios (3 %) could improve the growth success above ground and subsurface biomass significantly.

4.4 Optimization

4.4.1 Methodological approach

The results of laboratory and field trials show that the quality of tailings can be improved as a resource for further applications. In order to use tailings material economically it is self-evident that the valorization must be cost-efficient with an optimized input of material and financial efforts.

This optimized input of material is a composition of different anthropogenic factors. These factors represent a material stream which requires an algorithm which is able to solve equations with ten or more unknown factors. These factors are mostly inter-dependent and time related.

Using common numerical methods these calculations are solvable only with a long calculation time, if at all. Because of this fact evolutionary algorithms were used as a solver functioning according to biological models of evolution (Gerdes, 2004). The benefit of evolutionary algorithms is the objective-orientated, fast and precise calculation of local and global optima by consideration of different evolutionary internal and external influences (figure 4-1). To calculate the optimized application of tailings material the following parameters have to be determined: computational accuracy, size of search area, objective function, amount of individuals, amount of generations, impact of mutations, crossover, fitness, selection, time relevance and definition of an abort criterion. With these specifications it is possible to optimize and evaluate different input values relative to different output quality requirements (Pollmann, 2009). As input, all the different impact factors for the tailings material needs to be available for material stream optimization. From these the optimized composition related to the specific aim can be calculated.

The start vector of the initial population (individuals from the start generation) will be chosen randomly from the mix of input values. The principle flowchart (figure 4-1)

was used and implemented for the application of evolutionary algorithms. In this regard the following steps were followed:

1. Defining of input and output variables, constants and functions.
2. Random generation of lists with start populations.
3. Suitability for each list of the population. This implies defining how well the items in the lists comply with the requested task.
4. Executing the selection by fitness function.
5. Executing the gene exchange (crossover, mutation, reproduction), so that correct lists are always generated.
6. Repetition of steps 3 to 5 till the defined abort criterion is achieved.

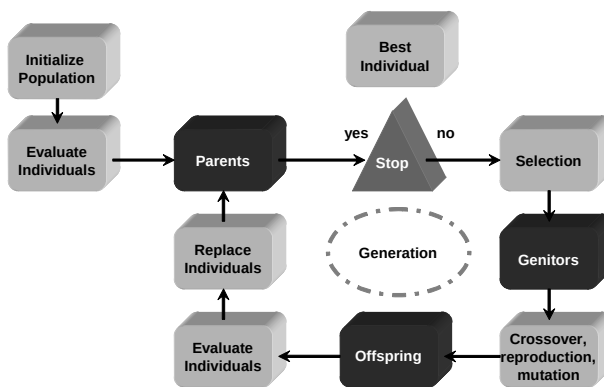


Figure 4-1: Sequence diagram of evolutionary algorithms

It is important for the flow that mutation and crossover should be used at same time to eliminate premature convergence, a disadvantage of evolutionary algorithms. Otherwise an occurrence of local optima or of the same individual as a result of the optimization is possible but undesirable.

The result of the material mix is a calculated matrix which achieves the desired quality of result. The evolutionary algorithms calculate randomly, by generating a batch of acceptable results within the restricted boundaries, which the best result for the solution of the problem is (figure 4-2). The benefit of calculating a system like this with evolutionary algorithms is the very fast detection of possible restricted global optimum (Y_t) out of the total sum of possible results (ΣX_t) (Pollmann, 2009).

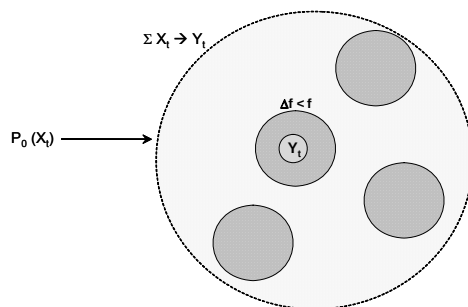


Figure 4-2: Stray field of potential results

The optimized material input was calculated by the following equation:

$$f(x) = \sum_{i=1}^n x_i \cdot V_i \cdot U_i \quad (2)$$

with: x_i = content of ameliorants and soil,
 V_i = total volume in the mixture,
 U_i = environmental impact factor

Initial investigations made use of generic algorithms as an optimization problem solver for the amendment of amelioration products under real conditions. Results are in a comparative range in soil quality. Using the algorithms (equation 2) with x_i as the content of ameliorants and soil, V_i as the total volume in the mixture and U_i as an environmental impact factor to express the positive or negative influence included the economic value. Therefore x_i can be varied between the three ameliorants in order to achieve the desired quality. V_i varies between 5 and 85% amended ameliorants and U_i varies between 1 (low impact) and 10 (high impact). Additionally U_i is related to the volume of added ameliorants. If no ameliorant or a low percentage (5%) was added, the corresponding value of U_i is 1 and indicates that the economic impact is low. The result of the optimization in this case indicates a poor quality of the total mixture. If we use a high content of ameliorant (85%) U_i will be 10 in order to indicate high economical impacts. This correlates with a good quality of the total mixture. The optimization procedure can also include different conditions for other tree types. Then this will be the requirement for the calculation of the global optimum. The results will converge asymptotically to the global optimum of the amelioration problem (figure 4-3).

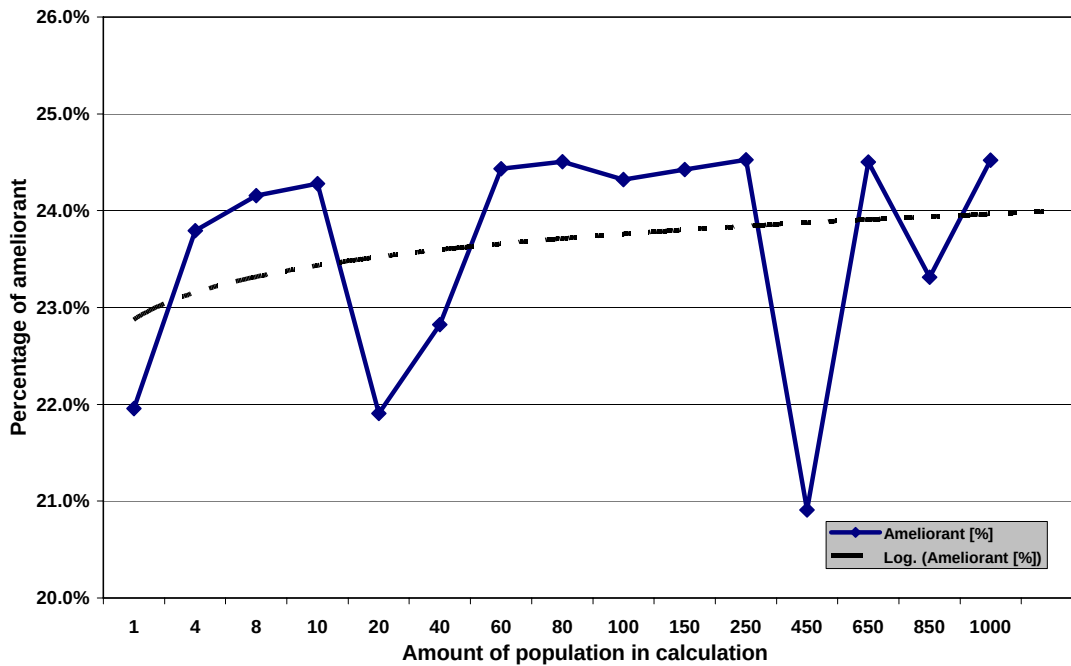


Figure 4-3: Example of polyoptimization by evolutionary algorithms

After all applications – field / laboratory investigation and computer optimization – an improvement of tailings quality could be shown. The result of this investigation was an increase of tailings quality shown by the optimized percentage of ameliorant related to the initial and favored soil quality. In our case pertaining to gold tailings material, an addition of ameliorant in the range of 21 – 25% proved to be most effective.

4.4.2 Application of evolutionary algorithms for a decision support system

South Africa has a lack of qualified experts in the fields of environmental sciences and environmental engineering. In addition, governmental ministries and research units have only limited access to a fundamental environmental data-base. This lack of expertise and knowledge mirrors the decision making problem of employees in key positions. A decision and evaluation tool for environmental based future planning will give them support in finding the best adapted solution for the future planning of mining permission, mine closure and environmental impact assessments. With this tool universities, official departments and environmentalists will be more able and effective in finding scientific based solutions for further discussions and applications.

All results from former analyses of treated and untreated mine tailings must be included in the optimization algorithms and transferred into the decision support system in order to determine different scenarios for returning the environment to a close to natural condition. The output of the decision support system will then be a matrix of different variants to be implemented related to the specific circumstances of the area.

The algorithms discussed in this paper can be included in a decision support system with a user interface to add all necessary information for each type of soil quality improvement. The user of the decision support system should be able to describe the environmental problem and to gather the required information, but it is not necessary to be able to understand the optimization procedure. After receiving the results of the optimization the user should evaluate all possible results recording their feasibilities and applicability. However, the final decision will still be made by the user but with the support of computer technology.

4.5 Conclusions and recommendations

This study has shown that that correctly treated tailings are no longer expensive waste material but a valuable resource for rehabilitation of former disturbed environments. The laboratory and field investigations showed that the chemical and biological parameters of the tailings were changed by the application of different amelioration products. The improved quality of the substrate enabled the successful growth of *Searsia lancea*, even on gold tailings treated with ameliorants.

The investigated facts from ongoing mine activities can support authorities in making the right decision for approving new mine activities and their impacts on the environment. Probably there can be even a bigger market for rehabilitated and upgraded

mine soil beside the mine sector itself. Reforestation and landscaping on low quality mine tailings improves the soil quality, controls dust emissions, upgrades the aesthetics of the mining area and creates a renewable resource. These results represent a valuable contribution to environmental protection by mining companies.

The use of evolutionary algorithms combined with a decision support system is a step forward for the enhancement of standard procedures with new technologies in order to make decisions more detailed and reliable and therefore more effective. With the support of tools like these algorithms it is possible to reveal the anthropogenic impact on the environment and to improve waste management, rehabilitation strategies and waste valorization.

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5 Improvement of Contaminated Mining Soil Quality through Reforestation

Published in: Book Chapter in: Sustainable Agricultural Development, DOI 10.1007/978-94-007-0519-7_5, Springer Netherlands, ISBN-10: 9400705182, ISBN-13: 9789400705180 (03/2011)

5.1 Introduction

South Africa is one of the sub-Saharan countries in which the highest impacts of mining activities on the environment are most evident and large areas of mining properties are highly polluted with heavy metals and sulphates and are typified by soils and water with unnaturally high or low pH and high electrical conductivity (EC) values. The ground water in these areas is highly polluted with Ca, Mg, K, Na, SO₄, NO₃, NH₄, Cl, Fe, Mn and Zn. This contamination is related to the blasting of rock with explosives, which in turn exposes new surface areas with an abundance of water soluble elements (Hatting, 2003). A large amount of sludge is produced during the acid mine water (AMD) neutralization with calcium carbonate (CaCO₃), therefore this must be pre-treated separately due of its hazardous content and special disposal requirements (Maree, et al. 2004). The sludge and the unusable soils are deposited on mine tailings storage facilities. The low soil quality, high soil bulk density due to compaction of the sediment column in a water-saturated environment and the lack drainage facility in the soil (the ratio of horizontal permeability and vertical permeability is significant different) (Bezuidenhout, 2005) prohibit the establishment of planted trees, grasses or bushes under these conditions (Van Wyk, 1997 and Carroll, 2000). In dry South African winter time permanent strong winds suspend the dust causing dust storm covering settlements, houses and the dust is inhaled by local inhabitants causing serious health hazards. The visibility may be drastically reduced by kilometre wide dust clouds (Pollmann et al. 2008). To rehabilitate these disturbed sites mining companies and government institutes are looking for sustainable methods for plant establishment on the slopes and on top of mine tailing dams. As a follow up to such efforts, gold and platinum tailings were tested both in the field and laboratory trials by treating them with different fertilizers and through cultivation of indigenous plant species *Searsia lancea*. The aim of these experiments was to establish growth of the experimental plants and to improve the quality of the polluted soil.

5.2 Materials and Methods

5.2.1 Laboratory and field trial

For both, laboratory and field trials gold and platinum tailings as well as natural soil (as a control sample) were collected from mining concessions in the northern part of South Africa – Rustenburg and Orkney (North-West Province). For the laboratory

trials (12 test plants per type): ameliorants such as sewage sludge, woodchips, vermi-compost were used (Maboeta and Rensburg, 2003a & 2003b). Twelve test plants were also cultivated in the control soil. A total of 144 plants were initially kept in a greenhouse with regular irrigation twice per week over the first three months prior to their transfer to natural, uncovered conditions with only natural irrigation, in the form of rainfall, for another three months. A field trial was conducted on platinum tailings in Rustenburg (North-West Province, 25° 31' 07,92" S; 27° 13' 12,54" E). Four different ameliorant types were used (20 test plants per type): 5% sewage sludge matured, 15% sewage sludge matured, 10% woodchips, 10% compost. The selected ratios of the ameliorants are results of former research to optimize the use of fertilizers and ameliorants on different polluted soil types (Maboeta and Rensburg, 2003a & 2003b). These soil ameliorants are functioning as plant fertilizers as well. Unaltered platinum tailings material was used as control soil. All plants were irrigated every second week, three times only then the plants adapted to the natural regional rainfall. Rustenburg falls within the Summer Rainfall Climatic Zone. The area is characteristically warm to hot with a mean annual precipitation of about 600 mm and a mean annual evaporation of about 1800 mm (Midgley, 1994a). Temperatures vary between extremes of -6.0°C and 40°C with an average of 19°C (Rustenburg Local Municipality 2009). The soil geology is basic, mafic and ultramafic intrusive (Midgley, 1994b).

5.2.2 Quality of polluted mining soil

Mine tailings material is typified by altered pH and high EC (measured with handheld Combo pH & EC, HI 98130 by HANNA). The gold tailings material had EC 3.05 mS/cm and pH of 3.75 at the beginning of the trial. Concentrations of Ca (464 ppm), Mg (71 ppm), SO₄ (1,430 ppm), Mn (13 ppm), Cu (0,5 ppm) and Zn (3 ppm) were also high (table 5.-1, table 5-2) in gold tailings were high. Platinum tailings are similar in composition to the gold tailings but had a pH of 7.34 and an EC of 1.24 [mS/cm] at the beginning of the trial tables 2.2.1 & 2.3.1). Specifically the concentrations of the elements Ca (82 ppm), Mg (54 ppm), Na (75 ppm), SO₄ (351 ppm), Cl (115 ppm), and Mn (0,02 ppm) were also of concern (table 5-1, table 5-2). Each plant has favourable soil and nutrient parameters but in this type of substrate plants struggle to survive because low concentrations of essential nutrients and high concentrations of phytotoxic substances. In the laboratory trial some of the water soluble salts were washed out by irrigation. This differs from the field trial where the high content of pollutants and dense soil inhibited such losses through leaching. Additionally the high evaporation rate in these areas shows precipitation of salt on the surface of both tailing types. The soil samples for each different substrate type (pot/tailings) were taken in different soil layers (top, 10 cm, 20cm) and mixed afterwards to get one representative sample for the different type of analyses.

Table 5-1: Analysis of the compost, control soil and polluted mine tailings material (Macro-elements)

Macro-elements											
Sample	Time frame	Ca	Mg	K	Na	PO ₄	SO ₄	NO ₃	NH ₄	Cl	HCO ₃
		ppm									
General limitations	--	72,14	14,58	31,28	22,99	0,95	86,46	130,21	7,22	35,45	48,81
Control Soil	start	144,68	43,02	47,31	13,10	0,00	88,38	642,98	8,46	27,30	6,10
Control Soil	after 2 month	24,45	12,64	8,21	28,74	0,53	106,63	14,88	0,04	34,66	21,36
Control Soil	after 6 month	2,81	1,22	2,74	1,84	2,37	12,49	1,25	0,43	0,98	6,10
Gold Soil	start	464,10	70,73	0,39	17,70	0,00	1.429,40	18,02	2,20	16,57	0,00
Gold Soil	after 2 month	424,43	38,16	4,30	27,36	0,00	1.176,76	11,65	0,76	27,30	6,10
Gold Soil	after 6 month	435,65	9,72	4,69	7,82	1,64	1.094,15	5,95	1,10	2,53	0,00
Platinum Soil	start	81,76	54,44	22,68	74,95	0,00	350,63	78,36	0,60	115,15	36,61
Platinum Soil	after 2 month	32,86	37,92	15,64	52,88	0,00	185,40	8,55	0,67	98,20	42,71
Platinum Soil	after 6 month	8,82	2,19	5,08	1,61	0,07	2,88	1,24	0,25	0,59	48,81
Compost	start	9,62	6,56	5,08	26,67	6,04	49,23	4,00	0,43	35,02	6,71
Compost	after 2 month	37,27	33,30	4,69	51,27	0,00	205,57	0,49	0,27	86,86	15,25
Compost	after 6 month	10,02	10,21	1,56	15,86	1,79	61,48	4,34	1,01	20,56	12,20

Table 5-2: Analysis of the used compost, control soil and polluted mine tailings material (Micro-elements)

Micro-elements and other data									P-BRAY 1 ppm
Sample	Time frame	Fe	Mn	Cu	Zn	B	pH	EC	
		ppm						(mS/cm)	
General limitations	--	0,56	0,05	0,05	0,06	0,11	6.5 - 6.7	0.8 - 2.1	--
Control Soil	start	0,24	0,49	0,02	0,01	0,00	4,90	1,31	41,61
Control Soil	after 2 month	2,10	0,04	0,04	0,01	0,09	6,23	0,38	34,52
Control Soil	after 6 month	1,74	0,39	0,11	0,15	0,19	5,68	0,05	36,38
Gold Soil	start	0,36	12,93	0,54	2,89	0,00	3,75	3,05	3,79
Gold Soil	after 2 month	0,05	1,55	0,05	0,06	0,00	5,25	2,56	3,47
Gold Soil	after 6 month	0,00	1,87	0,05	0,17	0,04	4,32	2,31	4,13
Platinum Soil	start	0,06	0,02	0,00	0,00	0,05	7,34	1,24	3,96
Platinum Soil	after 2 month	0,00	0,02	0,01	0,00	0,00	7,34	0,75	3,99
Platinum Soil	after 6 month	1,80	0,10	0,07	0,01	0,10	7,38	0,09	5,48
Compost	start	1,81	0,10	0,02	0,01	0,14	5,52	0,24	40,21
Compost	after 2 month	0,63	0,14	0,04	0,04	0,06	6,06	0,70	20,62
Compost	after 6 month	1,93	0,14	0,02	0,03	0,11	5,46	0,22	--

5.2.3 Ameliorants

The organic materials used in the present study were produced from natural materials and optimized for the specific needs of plants. Three different materials were used for cultivation of the experimental plants. The sewage sludge used was aged for an average of six months. The woodchips were obtained from the destruction of underground supporting struts after blasting. These woodchips contain, in addition to high concentrations of plastic as residues from explosives, high concentrations of nutrients necessary for the growth of plants. The third organic fertilizer used is compost, a typical growth medium and nutrient repository. All three different organic fertilizers materials were used to maximize the affinity to obtain the best binding, related to the lyotropic series (conversion preference, $\text{Al}^{3+} \approx \text{H}^+ \gg \text{Ca}^{2+} > \text{Mg}^{2+} \gg \text{K}^+ \approx \text{NH}_4^+ > \text{Na}^+$, Scheffer and Schachtschabel, 2002) and to store the required nutrients. All organic fertilizers materials have different influences on soil quality and tree vitality because of the content and variety of available and essential nutrients. Transformation and metabolism of elements from the substrate by plants change the quality of the soil in question. After the application of different fertilisers soil/substrate quality

was analysed for macro-, micro-elements by straight water analysis (1:2 water extraction) and inductively-coupled-plasma mass-spectrometry (ICP-MS, Agilent 7500c, Agilent Technologies, Santa Clara, California, USA). Microbiological activity was analysed for by testing enzyme activity and dehydrogenase activity (von Mersi and Schinner 1991).

5.2.4 Selected tree species – *Searsia lancea* (Linneaus F.) F.A. Barkley syn. *Rhus lancea* Linneaus F.

To explore improvement in the quality of soil/tailings material it is essential to establish the vegetation on the substrate to assess the capacity of phytoremediation. An indigenous (South African) tolerant and easily adaptable tree species “*S. lancea*” was selected to establish different stages of reforestation on the polluted mine tailings. *S. lancea* is a small to medium sized evergreen tree that usually grows to a height of 7 m and a width of 7 m but can be larger depending on environmental factors. The leaves are compound, trifoliate (a compound leaf with three leaflets) possessing narrowly lanceolate (lance shaped) leaflets. The *S. lancea* can adapt well to different soils including those that are poorly drained (Van Wyk and Van Wyk 1997). At replanting time the trees were 1.2 – 1.5 meters high and an average age of about two years. The threshold EC value for *S. lancea* is between 0.8 and 1.2.

5.2.5 Control methods of microbiological activity - dehydrogenase activity

Microbiological activity was determined by testing dehydrogenase activity using the INT-method (INT = iodonitrotetrazolium chloride) after von Mersi and Schinner (1991). The method is based on the incubation of soil with the substrate iodonitrotetrazolium chloride (INT) at 40°C for 2 hours followed by colorimetric estimation of the reaction product iodonitrotetrazolium chloride-formazan (INF) spectrophotometrically at 464 nm against the blank. The amount of metabolised substrate per time and amount of protein was measured. Dehydrogenase activity is expressed as $\mu\text{g INF g}^{-1} \text{dwt } 2 \text{ h}^{-1}$ and calculated according to the following equation:

$$INF(\mu\text{gg}^{-1}\text{dwt}2\text{h}^{-1}) = \frac{S_1 - S_0}{\text{dwt}} \quad (1)$$

with: S_1 = INF (in μg) of the test
 S_0 = INF (in μg) of the control
 dwt = dry weight of 1g moist soil

5.3 Results and Discussion

5.3.1 Visual differences in plant growth

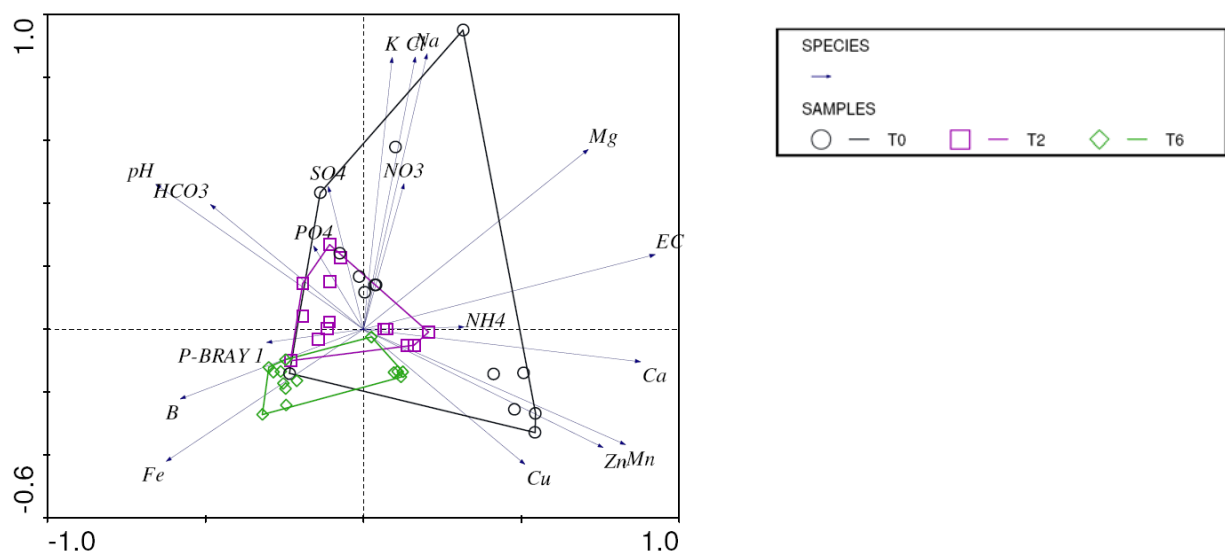
After two weeks of growth in the mine tailings, a difference between the plants could easily be visually detected. Trees growing in unaltered gold tailings material (gold soil) showed signs of die-back possibly due to the toxic content in the slimes material with a number of plant deaths in all different groups of ameliorants. Yellow-brown discolouration on the leaves indicated stress related to nutrient overdose and non-ideal growth conditions. The same symptoms, but more pronounced, were detected on the leaves of trees growing in platinum tailings (platinum soil). The trees growing in the control soil had no visual signs of any negative influence on their growth and only one of the trees died. In contrast to the laboratory trial the trees in the field trial on the tailings storage facilities had to endure near-natural conditions. However, the plants were irrigated every second week for the total trial in addition to rainfall. After the initial phase of stress from replanting, the trees recovered well and their appearance was similar with no mortalities in the first two months. After an additional two months the mortality in the control group was 1 tree out of 20, in the group with 10% additional compost 2 out of 20 trees and in the group with the woodchip ameliorant 1 out of 20 trees with one tree recovering. In total the mortality of the trees was very low.

5.3.2 Differences in soil quality

The use of pre-treated fertiliser in polluted tailings showed an improvement in soil quality after only two months of plant growth (table 5-3, table 5-4). The elements Na, Mg, PO₄, Cl, NO₃ and NH₄ in the treated gold and platinum soil in particular were significantly reduced in the laboratory trial. In addition in the platinum soil the elements Ca and SO₄ were also significantly reduced (table 5-3, table 5-4).

Table 5-3: Lab test: Quality change in soil and tailings chemistry (Macro-elements)

Sample	Time frame	Macro-elements									
		Ca	Mg	K	Na	PO ₄	SO ₄	NO ₃	NH ₄	Cl	HCO ₃
		ppm									
Control Soil + woodchips (CWC)	start	115.42	33.05	63.73	14.02	0.00	105.67	502.23	8.17	28.72	6.10
Control Soil + woodchips (CWC)	after 2 month	43.28	15.80	21.11	38.62	0.00	203.65	0.70	0.13	45.38	9.15
Control Soil + woodchips (CWC)	after 6 month	7.21	3.16	11.34	5.98	1.11	34.58	2.48	0.79	6.74	18.30
Control Soil + compost (CVC)	start	115.42	30.87	44.18	14.94	10.45	95.10	476.19	11.92	23.75	6.10
Control Soil + compost (CVC)	after 2 month	35.67	13.85	8.21	28.05	0.71	122.00	7.44	0.14	40.42	33.56
Control Soil + compost (CVC)	after 6 month	6.41	1.70	5.47	3.91	2.54	9.70	1.23	1.06	3.34	30.51
Control Soil + sewage sludge (CSH)	start	69.74	40.83	56.69	17.01	14.41	116.24	456.35	39.47	27.30	15.25
Control Soil + sewage sludge (CSH)	after 2 month	90.98	60.03	32.84	62.53	41.49	222.86	280.88	0.40	86.86	6.10
Control Soil + sewage sludge (CSH)	after 6 month	6.01	1.70	5.08	2.53	9.65	10.57	4.96	0.61	2.32	6.10
Control Soil (CCO)	start	144.68	43.02	47.31	13.10	0.00	88.38	642.98	8.46	27.30	6.10
Control Soil (CCO)	after 2 month	24.45	12.64	8.21	28.74	0.53	106.63	14.88	0.04	34.66	21.36
Control Soil (CCO)	after 6 month	2.81	1.22	2.74	1.84	2.37	12.49	1.25	0.43	0.98	6.10
Gold Soil + woodchips (GWC)	start	446.07	84.10	3.52	29.66	0.00	1,453.42	24.12	2.58	27.04	0.00
Gold Soil + woodchips (GWC)	after 2 month	352.29	47.39	10.95	18.16	0.00	1,034.59	7.56	0.72	23.06	12.20
Gold Soil + woodchips (GWC)	after 6 month	422.02	11.18	8.99	6.90	0.00	1,081.66	7.01	0.52	2.68	0.00
Gold Soil + compost (GVC)	start	434.85	99.41	7.43	31.04	0.00	1,443.81	149.12	18.36	19.23	0.00
Gold Soil + compost (GVC)	after 2 month	411.60	50.07	5.47	22.99	0.00	1,204.62	8.61	1.68	24.43	6.10
Gold Soil + compost (GVC)	after 6 month	422.82	12.15	4.30	5.29	0.41	1,072.05	9.11	0.97	1.56	0.00
Gold Soil + sewage sludge (GSH)	start	401.58	70.73	8.21	17.24	1.90	1,505.29	11.34	87.02	17.13	0.61
Gold Soil + sewage sludge (GSH)	after 2 month	321.43	69.03	3.52	20.00	0.00	1,036.51	30.21	1.23	16.31	15.25
Gold Soil + sewage sludge (GSH)	after 6 month	367.11	13.61	2.35	4.14	0.17	938.53	6.84	0.81	1.70	0.00
Gold Soil (GCO)	start	464.10	70.73	0.39	17.70	0.00	1,429.40	18.02	2.20	16.57	0.00
Gold Soil (GCO)	after 2 month	424.43	38.16	4.30	27.36	0.00	1,176.76	11.65	0.76	27.30	6.10
Gold Soil (GCO)	after 6 month	435.65	9.72	4.69	7.82	1.64	1,094.15	5.95	1.10	2.53	0.00
Platinum Soil + woodchips (PWC)	start	340.66	149.23	104.39	245.99	0.00	1,081.66	268.48	0.40	548.81	33.56
Platinum Soil + woodchips (PWC)	after 2 month	58.51	59.06	25.02	65.98	0.00	347.74	1.17	0.47	92.89	88.47
Platinum Soil + woodchips (PWC)	after 6 month	10.42	3.65	7.82	4.37	0.08	10.57	0.41	0.22	2.34	61.02
Platinum Soil + compost (PVC)	start	228.44	93.82	67.25	129.43	0.00	800.20	190.35	3.25	219.81	39.66
Platinum Soil + compost (PVC)	after 2 month	23.65	21.63	8.60	20.23	0.00	97.02	4.03	0.22	20.56	88.47
Platinum Soil + compost (PVC)	after 6 month	10.02	5.10	5.86	3.45	0.55	10.57	2.96	0.41	2.02	57.97
Platinum Soil + sewage sludge (PSH)	start	72.14	86.28	38.32	93.34	39.22	402.50	97.97	14.52	152.80	64.07
Platinum Soil + sewage sludge (PSH)	after 2 month	34.47	33.05	13.68	34.71	1.76	139.29	22.94	0.32	52.47	91.52
Platinum Soil + sewage sludge (PSH)	after 6 month	5.61	3.40	3.91	1.61	2.81	5.47	6.20	0.16	1.67	27.46
Platinum Soil (PCO)	start	81.76	54.44	22.68	74.95	0.00	350.63	78.36	0.60	115.15	36.61
Platinum Soil (PCO)	after 2 month	32.86	37.92	15.64	52.88	0.00	185.40	8.55	0.67	98.20	42.71
Platinum Soil (PCO)	after 6 month	8.82	2.19	5.08	1.61	0.07	2.88	1.24	0.25	0.59	48.81
Compost	start	9.62	6.56	5.08	26.67	6.04	49.23	4.00	0.43	35.02	6.71
Compost	after 2 month	37.27	33.30	4.69	51.27	0.00	205.57	0.49	0.27	86.86	15.25
Compost	after 6 month	10.02	10.21	1.56	15.86	1.79	61.48	4.34	1.01	20.56	12.20

**Figure 5-1:** Lab test: multivariate analysis of performing principle components by Canoco

A total reduction of ionic compounds could be shown by a decrease in the electrical conductivity (EC) of 97% in the platinum tailings treated with woodchips and 38% in gold tailings treated with matured sewage sludge. In this application the pre-treated fertiliser has the ability to exchange and bind the elements by the lyotropic series (Scheffer and Schachtschabel 2002). Because of nitrogen fixing micro-organisms (diastrophic organisms) (Van Leeuwenhoek, 1984) in the organic fertilizer the amount of nitrogen from nitrate (NO_3) and ammonium (NH_4) was lower after treatment. Micro-organisms, for example *Rhizobium* or *Frankia*, live in symbiosis with the roots of the plants, use ammonia for protein biosynthesis for amino-acids and change the ammonia against carbon to produce energy as adenosine-triphosphate (ATP). The total available phosphorous, essential for the plants, detected with the method P-Bray 1, increased in the control soil + sewage sludge (CSH) due to the residues mineralization from the matured sewage sludge (Table 5-4). In total all ameliorants used lead to an increased quality in both types of polluted tailings after the treatment period of six months (figure 5-2). Additionally the *Searsia lancea* trees aided the process by utilizing essential elements and nutrients for their growth and nutrient balance.

Table 5-4: Lab test: Quality change in soil and tailings chemistry (Micro-elements)

Sample	Time frame	Micro-elements and other data							P-BRAY 1 ppm
		Fe	Mn	Cu	Zn	B	pH	EC	
		ppm						(mS/cm)	
Control Soil + woodchips (CWC)	start	0.11	1.81	0.02	0.02	0.00	4.74	1.12	40.81
Control Soil + woodchips (CWC)	after 2 month	0.64	0.06	0.02	0.00	0.03	5.69	0.57	32.99
Control Soil + woodchips (CWC)	after 6 month	1.89	0.31	0.10	0.13	0.15	5.93	0.13	40.13
Control Soil + compost (CVC)	start	0.08	0.99	0.01	0.02	0.00	5.01	1.08	51.85
Control Soil + compost (CVC)	after 2 month	0.64	0.06	0.02	0.00	0.03	5.69	0.57	32.99
Control Soil + compost (CVC)	after 6 month	1.72	0.32	0.11	0.15	0.10	6.63	0.09	53.63
Control Soil + sewage sludge (CSH)	start	0.47	1.01	0.02	0.01	0.06	5.71	1.13	11.12
Control Soil + sewage sludge (CSH)	after 2 month	0.19	0.09	0.05	0.02	0.07	5.20	1.31	146.03
Control Soil + sewage sludge (CSH)	after 6 month	1.91	0.29	0.14	0.19	0.30	5.23	0.08	136.88
Control Soil (CCO)	start	0.24	0.49	0.02	0.01	0.00	4.90	1.31	41.61
Control Soil (CCO)	after 2 month	2.10	0.04	0.04	0.01	0.09	6.23	0.38	34.52
Control Soil (CCO)	after 6 month	1.74	0.39	0.11	0.15	0.19	5.68	0.05	36.38
Gold Soil + woodchips (GWC)	start	0.32	12.99	0.47	2.87	0.00	3.86	3.14	3.94
Gold Soil + woodchips (GWC)	after 2 month	0.01	1.20	0.03	0.03	0.00	6.70	2.26	3.47
Gold Soil + woodchips (GWC)	after 6 month	0.45	0.67	0.02	0.09	0.00	4.29	2.26	3.98
Gold Soil + compost (GVC)	start	0.17	12.33	0.11	2.88	0.00	3.88	3.30	12.38
Gold Soil + compost (GVC)	after 2 month	0.06	2.79	0.03	0.09	0.00	5.07	2.59	5.29
Gold Soil + compost (GVC)	after 6 month	0.08	0.95	0.01	0.09	0.00	4.37	2.26	7.38
Gold Soil + sewage sludge (GSH)	start	0.10	12.43	0.05	1.59	0.00	4.54	3.20	103.88
Gold Soil + sewage sludge (GSH)	after 2 month	0.04	0.68	0.04	0.03	0.01	6.47	2.27	49.85
Gold Soil + sewage sludge (GSH)	after 6 month	0.10	0.42	0.01	0.10	0.03	4.42	1.98	57.38
Gold Soil (GCO)	start	0.36	12.93	0.54	2.89	0.00	3.75	3.05	3.79
Gold Soil (GCO)	after 2 month	0.05	1.55	0.05	0.06	0.00	5.25	2.56	3.47
Gold Soil (GCO)	after 6 month	0.00	1.87	0.05	0.17	0.04	4.32	2.31	4.13
Platinum Soil + woodchips (PWC)	start	0.21	0.11	0.03	0.02	0.00	6.86	4.28	3.59
Platinum Soil + woodchips (PWC)	after 2 month	0.02	0.03	0.04	0.02	0.00	7.66	1.13	3.88
Platinum Soil + woodchips (PWC)	after 6 month	1.90	0.10	0.14	0.02	0.06	7.70	0.13	74.63
Platinum Soil + compost (PVC)	start	0.15	0.38	0.05	0.03	0.00	7.07	2.67	9.41
Platinum Soil + compost (PVC)	after 2 month	0.37	0.01	0.07	0.00	0.00	7.45	0.41	8.00
Platinum Soil + compost (PVC)	after 6 month	1.55	0.06	0.09	0.02	0.02	7.48	0.13	7.93
Platinum Soil + sewage sludge (PSH)	start	0.06	0.07	0.00	0.00	0.16	7.53	1.65	65.70
Platinum Soil + sewage sludge (PSH)	after 2 month	0.00	0.00	0.00	0.00	0.00	7.74	0.63	50.73
Platinum Soil + sewage sludge (PSH)	after 6 month	1.74	0.04	0.03	0.02	0.03	7.12	0.08	58.13
Platinum Soil (PCO)	start	0.06	0.02	0.00	0.00	0.05	7.34	1.24	3.96
Platinum Soil (PCO)	after 2 month	0.00	0.02	0.01	0.00	0.00	7.34	0.75	3.99
Platinum Soil (PCO)	after 6 month	1.80	0.10	0.07	0.01	0.10	7.38	0.09	5.48
Compost	start	1.81	0.10	0.02	0.01	0.14	5.52	0.24	40.21
Compost	after 2 month	0.63	0.14	0.04	0.04	0.06	6.06	0.70	20.62
Compost	after 6 month	1.93	0.14	0.02	0.03	0.11	5.46	0.22	--

A relative comparison between the different ameliorants clearly shows the benefit of matured sewage sludge and woodchips in improving the quality of the tailings in terms of most of the chemical indicators in the lab trial. The platinum tailings treated with woodchips showed a decrease in all elements except for manganese (Mn) which was not reduced as expected. In the gold tailings the woodchips could reduce the concentrations of all macro- and micro-elements with the exception of calcium (Ca) and sulphate (SO_4). These two elements could not be reduced under the limits of acceptable agricultural soil quality by any of the ameliorants used in the laboratory trails (table 5-4). The results from using matured sewage sludge are similar. This ameliorant work was successful in both tailings types but did not reduce the concentrations of calcium (Ca) and sulphate (SO_4) to the expected levels. The laboratory trials with different ameliorants showed a clear reduction in the concentrations of pollutants and improvement in total soil quality in all different soil types with only a slight improvement with the woodchips. Similar but better results were demonstrated in the field trials in platinum tailings ameliorated with woodchips, compost and matured sewage sludge (table 5-5, table 5-6, figure 5-2). All plants showed strong growth and the ameliorants improved soil quality. This trial was focused on the ameliorants with similar compositions but at different concentrations. This fact explains the similarity in the results in soil quality improvement. All ameliorant treatments did not reduce the concentrations of phosphate (PO_4), sulphate (SO_4), iron (Fe), manganese (Mn) and copper (Cu). After amelioration the pH of the soil was stable and the total EC was reduced by 47% on average (table 5-5, table 5-6, figure 5-2).

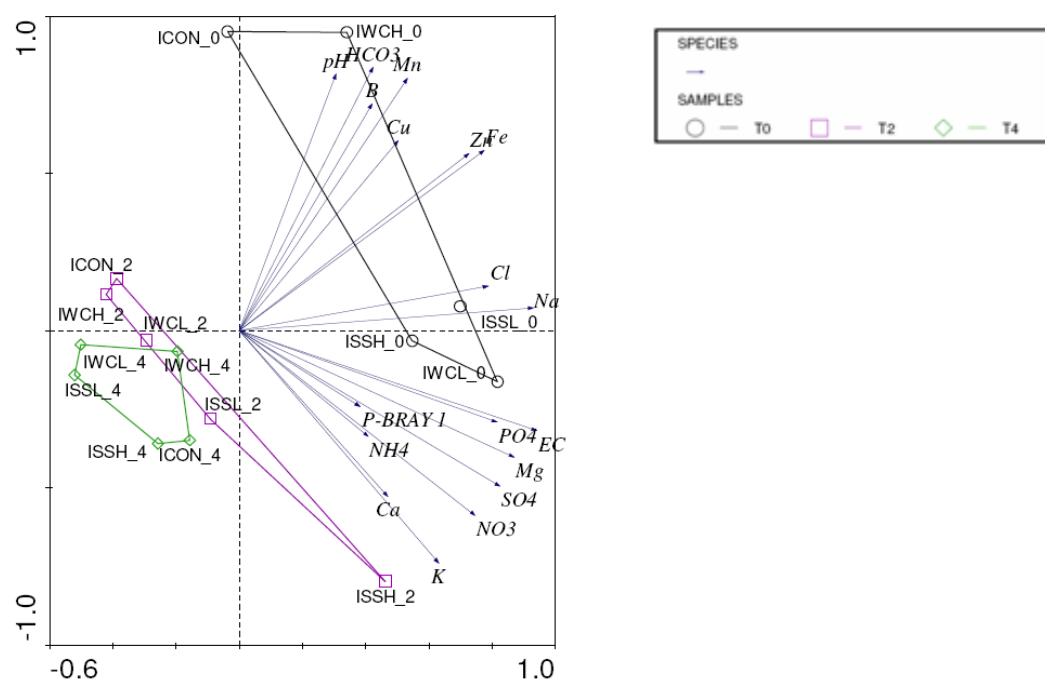


Figure 5-2: Field test: multivariate analysis of performing principle components by *Canoco*

The field trials with platinum tailings supported the results of the laboratory trials. The use of organic fertilisers changes the soil quality and supports the plant growth. However, the field trial showed small benefit in the use of compost and in the 15% addition of matured sewage sludge.

Table 5-5: Field test: Quality change in soil and tailings chemistry (Macro-elements)

Sample	Time frame	Macro-elements									
		Ca	Mg	K	Na	PO ₄	SO ₄	NO ₃	NH ₄	Cl	HCO ₃
		ppm									
Woodchips 10% (dry, IWCL)	start	28.46	14.83	22.29	46.67	29.44	77.81	86.98	0.51	13.30	57.97
Woodchips 10% (dry, IWCL)	after 2 month	10.42	5.35	8.99	18.62	18.80	24.98	6.57	0.67	4.93	45.76
Woodchips 10% (dry, IWCL)	after 4 month	18.04	3.40	7.43	2.76	7.44	17.29	10.87	0.70	2.80	45.76
Compost 10% (Woodchips + Sewage Sludge, IWCH)	start	14.43	6.81	2.74	36.09	14.25	30.74	13.38	0.32	9.68	85.42
Compost 10% (Woodchips + Sewage Sludge, IWCH)	after 2 month	9.62	3.65	8.21	14.48	9.78	17.29	2.48	0.36	4.96	51.86
Compost 10% (Woodchips + Sewage Sludge, IWCH)	after 4 month	16.83	4.13	12.12	22.99	10.49	39.39	13.02	0.36	8.51	61.02
Sewage Sludge 5% (matured, ISSL)	start	14.83	11.42	21.11	54.72	42.74	52.83	58.90	0.67	6.74	67.12
Sewage Sludge 5% (matured, ISSL)	after 2 month	14.83	8.75	12.51	23.45	17.84	33.39	50.22	0.49	4.15	42.71
Sewage Sludge 5% (matured, ISSL)	after 4 month	14.43	4.13	6.65	3.91	10.87	17.64	13.25	0.51	2.20	30.51
Sewage Sludge 15% (matured, ISSH)	start	22.04	10.94	15.64	32.42	21.84	47.07	71.30	3.88	9.24	61.02
Sewage Sludge 15% (matured, ISSH)	after 2 month	28.05	15.80	24.63	36.09	27.54	72.05	117.81	2.25	5.67	39.66
Sewage Sludge 15% (matured, ISSH)	after 4 month	25.65	6.81	12.51	7.13	11.07	30.91	52.70	0.79	3.90	39.66
Control soil (platinum, ICON)	start	16.03	5.10	0.39	17.93	6.30	14.41	9.92	0.38	4.41	79.32
Control soil (platinum, ICON)	after 2 month	12.02	5.83	5.86	13.10	10.00	19.21	4.23	0.67	3.33	61.02
Control soil (platinum, ICON)	after 4 month	26.85	6.56	17.59	8.28	13.07	45.27	34.70	0.92	4.64	45.76
Compost pure	start	197.99	446.73	486.77	237.95	717.97	1,160.43	1,146.45	35.77	173.37	73.22
Sewage sludge pure	start	46.89	25.76	186.50	84.14	1,122.55	3,169.09	270.00	2,048.10	154.49	1,049.47

Table 5-6: Field test: Quality change in soil and tailings chemistry (Micro-elements)

Sample	Time frame	Micro-elements and other data							P-BRAY 1
		Fe	Mn	Cu	Zn	B	pH	EC	
		ppm						(mS/cm)	ppm
Woodchips 10% (dry, IWCL)	start	19.63	0.57	1.15	0.36	8.13	7.09	0.53	160.00
Woodchips 10% (dry, IWCL)	after 2 month	1.67	0.09	0.18	0.03	0.00	7.12	0.21	217.85
Woodchips 10% (dry, IWCL)	after 4 month	1.70	0.18	0.16	0.06	0.00	6.88	0.16	91.35
Compost 10% (Woodchips + Sewage Sludge, IWCH)	start	21.10	1.90	1.11	0.69	12.32	7.46	0.30	158.33
Compost 10% (Woodchips + Sewage Sludge, IWCH)	after 2 month	1.53	0.14	0.19	0.05	0.00	7.15	0.17	155.35
Compost 10% (Woodchips + Sewage Sludge, IWCH)	after 4 month	2.00	0.14	0.20	0.07	0.00	6.84	0.26	115.28
Sewage Sludge 5% (matured, ISSL)	start	21.37	1.13	1.88	0.55	0.23	7.18	0.47	308.33
Sewage Sludge 5% (matured, ISSL)	after 2 month	1.66	0.09	0.19	0.05	0.01	7.00	0.29	355.35
Sewage Sludge 5% (matured, ISSL)	after 4 month	1.75	0.10	0.15	0.04	0.19	6.82	0.15	168.45
Sewage Sludge 15% (matured, ISSH)	start	19.04	0.91	1.88	0.39	0.81	7.19	0.41	260.00
Sewage Sludge 15% (matured, ISSH)	after 2 month	1.72	0.06	0.46	0.02	0.22	6.92	0.51	162.98
Sewage Sludge 15% (matured, ISSH)	after 4 month	2.00	0.10	0.17	0.03	0.20	6.74	0.26	98.10
Control soil (platinum, ICON)	start	18.70	1.49	3.69	0.23	9.18	7.48	0.21	39.17
Control soil (platinum, ICON)	after 2 month	1.43	0.12	0.17	0.01	0.20	7.33	0.19	127.57
Control soil (platinum, ICON)	after 4 month	1.53	0.10	0.29	0.04	0.20	6.89	0.28	112.20
Compost pure	start	12.51	32.38	17.64	2.14	185.95	5.42	7.16	1,970.84
Sewage sludge pure	start	20.24	2.42	232.57	1.56	67.23	7.05	12.77	3,087.50

5.3.3 Differences in microbiological activity

The total microbiological activity in both unaltered tailings and ameliorated soil types was only about one third, on average about 50 [INF µg/(g*2h)], compared to the conditions in natural soil - 110 [INF µg/(g*2h)]. This is the result of the free available inhibitors of microbial growth in the polluted tailings. These substances block the metabolism of the micro-organisms and inhibit total activity. The benefit of the adding ameliorants can be seen in initial higher microbiological activity and a deposit function of the most needed and available nutrients for the micro-organisms after two months. The microbiological activity in gold tailings ameliorated with sewage sludge and vermi-compost after two month, improved; 78.3 [INF µg/(g*2h)] with sewage sludge, 94.7 [INF µg/(g*2h)] with vermi-compost and better than the initial microbiological activity of untreated tailings of 60.3 [INF µg/(g*2h)] (figure 1). In gold tailings the initial microbiological activity in tailings ameliorated with vermi-compost was 81.9 [INF µg/(g*2h)] and is higher than the untreated gold tailings with 59.9 [INF µg/(g*2h)]. The microbiological activity of the other ameliorated soil types was lower. After two month the microbiological activity of all other ameliorated soil types (GCO, PCO) was lower than the unameliorated soil (CCO) with 207.3 [INF µg/(g*2h)] before

it dropped to 75.3 [INF $\mu\text{g}/(\text{g}\cdot 2\text{h})$] after six month (figure 5-3). The improvement of soil quality can clearly be seen in gold tailings with the ameliorant - matured sewage sludge. After the addition of the ameliorant the microbiological activity increased by about 69.6% from 78.3 to 132.8 [INF $\mu\text{g}/(\text{g}\cdot 2\text{h})$] after 2 months and stabilised at 108.2 [INF $\mu\text{g}/(\text{g}\cdot 2\text{h})$] after 6 months (figure 5-3). In the platinum tailings the most improvement in microbiological activity was achieved after an initial decrease of 51% after two months using woodchips followed by a 46% increase from 48.7 to 71.1 [INF $\mu\text{g}/(\text{g}\cdot 2\text{h})$] after the total six months test period (figure 5-3).

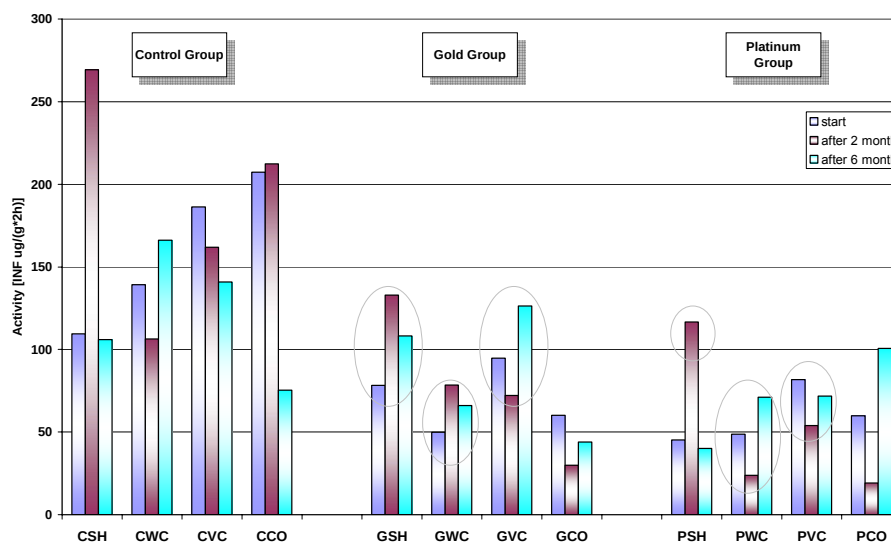


Figure 5-3: Lab test: Quality change of microbiological activity in the different soil types

An increase in microbiological activity after the first two months and a drastic drop after six months indicates that the storage capacity of the fertilizer is not effective enough to support the plants over a long period of time. The microbiological activity in the unpolluted natural soil was only improved with woodchips as an ameliorant by 19.3% from 139.2 to 166.1 [INF $\mu\text{g}/(\text{g}\cdot 2\text{h})$] after six months. All other ameliorated tailings as well as the untreated soil showed a decrease in microbiological activity over time (figure 5-3). Unlike the laboratory trial the microbiological activity in the field trial with platinum tailings was improved when using all different ameliorants after a short time. After only two months the microbiological activity increased by 57% from 68.51 to 107.55 [INF $\mu\text{g}/(\text{g}\cdot 2\text{h})$] (figure 5-4) with an addition of 5% in the matured sewage sludge. After four months the initial growth spurt dropped off in almost all test groups. Only the plants with 15% matured sewage sludge (ISSH) performed well in terms of microbiological activity. Activity decreased compared to two months earlier but increased by 34.2% compared with the initial microbiological activity. Against all expectations the control trees without any ameliorant showed an increase in the microbiological activity of 92.8% compared to the beginning of the trial.

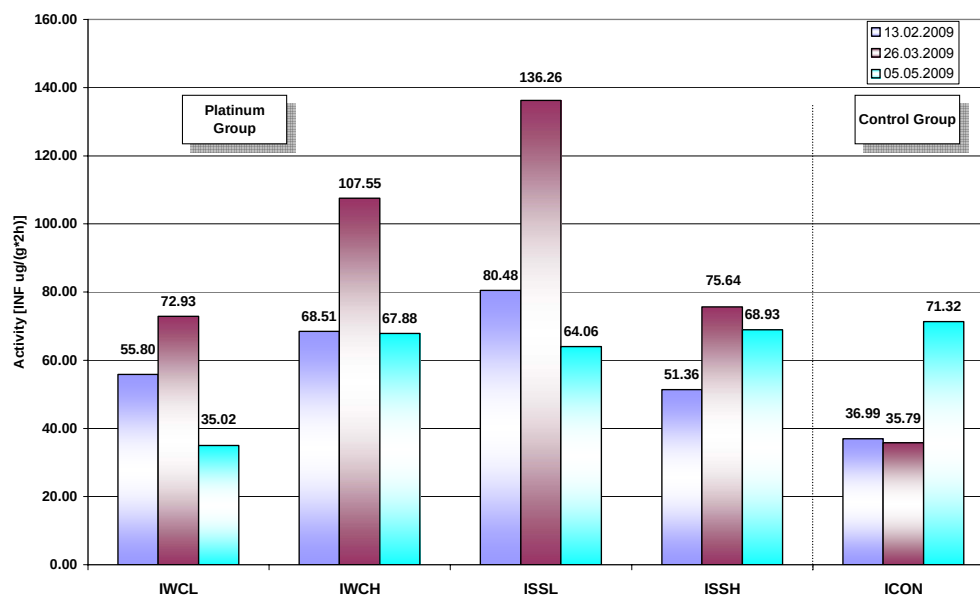


Figure 5-4: Field test: Quality change of microbiological activity in platinum soil with different fertilizers

5.3.4 Total quality

To get a better overview of change in tailings quality the visual appearance of the plants, the soil quality and the microbiological activity were monitored over a total period of six months. The same tree species as used in the laboratory trials was monitored in field trials under near-natural conditions using similar ameliorants. Only the total impact of the whole environment can give a reliable indication of change in quality of tailings. In the laboratory trial the trees grow best in gold and platinum tailings to which the matured sewage sludge ameliorant was added, while soil quality improved most in the tailings material ameliorated with the addition of woodchips. In terms of microbiological activity the matured sewage sludge worked best in gold tailings and woodchips in platinum tailings. The total quality of all different sources of impact gives a clear indication of quality change in the monitored soil. Both types of tailings, gold and platinum, showed increased plant growth, improved microbiological activity and a better chemical quality after adding the pre-treated ameliorants. The selected tree *Searsia lancea* adapted to the specific conditions of polluted tailings after replanting and controlled irrigation showed a spurt in growth and assisted in the change in soil quality. These results of the controlled laboratory and field experiments indicate a clear success and should be considered in the closure plan of both gold and platinum tailings storage facilities.

5.4 Conclusions

The growth of the trees and the microbiological activity of the soils showed a clear improvement in tailings quality after using ameliorants. The quality of both types of polluted tailings, platinum and gold, could be improved, as demonstrated by chemical analysis, so that the tree *Searsia lancea* was able to grow well. Two of the ameliorants - woodchips and matured sewage sludge - were able to bind and immobilise some of the heavy metals and sulphate and release enough nutrients to support the plant in active growth. The introduction of these tree species to the different tailings showed a utilization of pollutants and an improvement of soil quality. This is the benefit of the tree metabolism combined with immobilizing pollutants and not a result of leaching of pollutants. Finally this application was an attempt to rehabilitate and to find a basic use for polluted tailings as an area for landscaping and reforestation and possibly also for agriculture. While reforestation obviates sandstorms it also creates a new resource for energy, firewood or furniture - a reusable raw material - and influences the climate change by reducing green house gases. After a few years of detoxification treated tailings could possibly also be used as land for agriculture as well, but for this purpose soil quality and the immobility of the pollutants must be guaranteed.

5.5 References

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6 Carbon-Balance – A Case Study for Paper Production and Recycling in Germany

6.1 Introduction

The production process in paper factories use either externally produced pulp or pulp, which is produced by pulp mill process as an integrated process directly at the paper factory. As well the recycling of paper can be extern or at the same factory.

All relevant processes (figure 6-1) include input resources like water, energy, biomass, additives, chemicals and output resources. The inputs that are metabolized in the included processes are Sulphite and Sulphate Pulp Mill, Paper Production with and without integrated mechanical Pulping Process and the process of the integrated paper recycling.

Besides the main product other side products like Sulphate-/Sulphite pulp, noise, energy, solid waste, waste water, emissions as well as further residues are produced. Additional chemicals for exposure of wood like e.g. sulfur or sulfuric acid are of secondary interest only but also integrated in the balance. To describe the system the material fluxes as the product of density (mass by volume) and flow velocity (distance by time) must be known for every place [x] and time [t] of the production process. All material fluxes of the investigated processes can be collected and included in a matrix. From the collected mass fluxes and the concentrations of the used materials the material fluxes can be calculated.

For this investigation a timeframe of one year was arranged and the material fluxes refer to the annual consumptions per capita in Germany with about 82.9 Mio. inhabitants in 2004 (Federal Statistical Office, 2005).

Carbon balances are one of the most significant causes of environmental problems of environmental pollution and health and are also close related to climate change in general (United Nations Framework, 2009). With carbon balances resource efficiency and resource protection can be transferred into praxis.

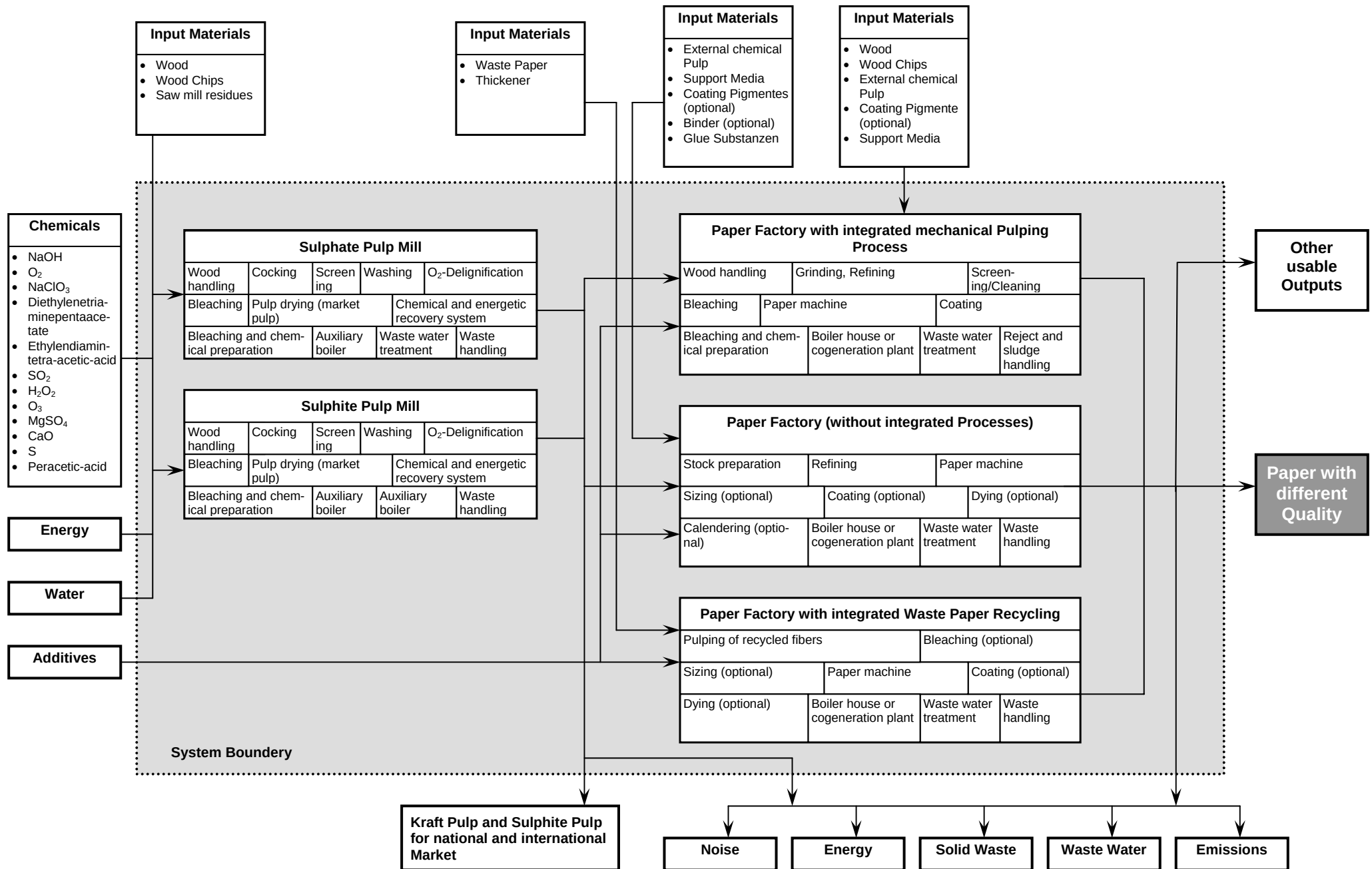


Figure 6-1: Production processes in the paper production (Pollmann, 2007)

6.2 Materials and Methods

6.2.1 Indicator Carbon

In order to balance input and output material streams and to optimize the use of secondary materials in the paper production, the process itself was investigated and reduced to the lowest common indicator which cannot be reduced any further – in this case carbon (Baccini, 1996).

Related to different products, all proportions of carbon are calculated relative to the mass and balanced for each production step. This balance makes it possible to finally compare all carbon fluxes of sub production steps to point out resources and sinks of resources and to prove that the results from the balance of input and output material respond to each other. Main aim is to focus and display the continuity of carbon as the main compound. Therefore all focused treatment steps of paper production and paper recycling are investigated separately.

6.2.2 Composition of determined solid and liquid materials

The composition of the determined materials was primarily reduced to carbon, sulfur, phosphor and nitrogen. Because of focusing on the total production process of the product paper the source material is wood which is then transformed by sub-processes to sub-products till it leaves the process as the final product paper. An essential part of this investigation chain is the element carbon. The included side products and educts are air, water, energy, additives, waste water, exhaust air and slag. These elements are influencing the main process only little.

6.2.3 Wood preparation

From the chemical point of view wood contains the following ingredients:

- 40% - 50% Cellulose,
- 10% - 55% Polyose (Hemi-cellulose),
- 20% - 30% Lignin,
- 6% - 12% other organic elements,
- 0.3% - 0.8% inorganic elements.

For the wood preparation the tree trunks are either mechanically or chemically processed. The content of bark related to the mass of the trunk is about 5%-10% (UBA, 2003). An additional important resource is waste wood, which is harvested as thinning material. In 2003 60% of the pulpwood was added to the production process as thinning material and about 40% as sawmill waste. The effectiveness of mechanically, thermo-mechanically and chemically-thermo-mechanically methods is about 85%-96%.

To get an inference of carbon consumption for the used wood, the amount of bank meter of 7,372 [kfm] without bark will be multiplied with an average weight of 567.5

[kg/fm] (Federal Research Centre for Forestry and Forest Products, 2001) and an average carbon content of 501.5 [kgC/tDM] (UBA, 2003, Austrian Waste Water and Waste Trade Association, 2004). Hence the result gives a carbon consumption of about 2.098 [Mio.tC] in Germany in 2003.

6.2.4 Sulphite Pulp Mill / Sulphate Pulp Mill / Mechanical Wood Pulp

The Sulphite and Sulphate pulp mills as the most common techniques of chemical disintegration method to produce the usable pulp. The effectiveness of wood-free fiber pulp with chemical disintegration methods is about 43%-52% (Figure 6-2).

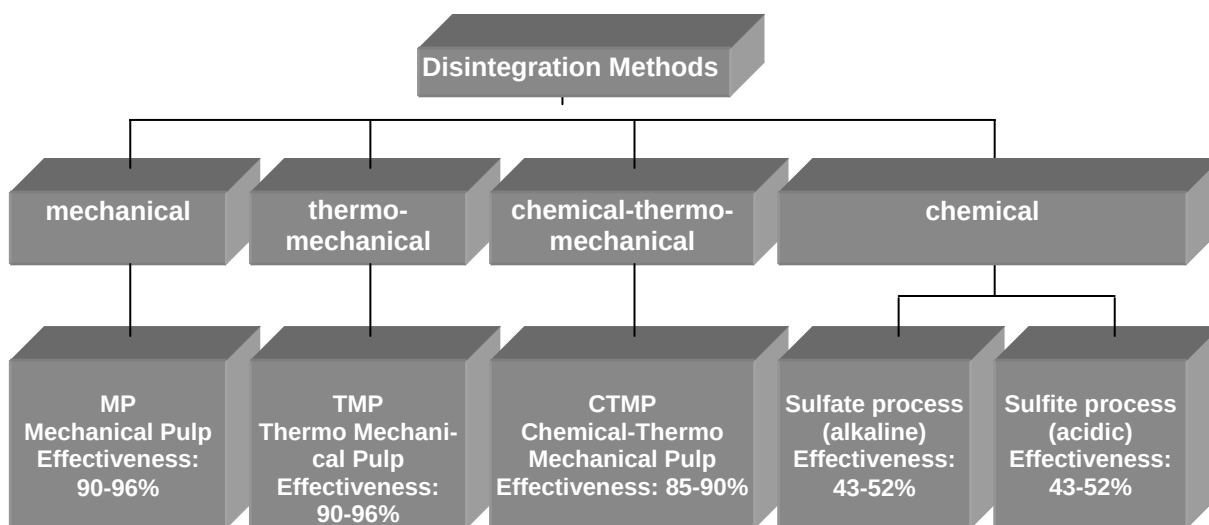


Figure 6-2: Fiber-disintegration methods (Sappi, 2004)

The included carbon in the process of wood preparation is roughly 2.098 [Mio.tC] per year. A further reduction down to 43%-52% can be achieved by the treatment technique of Sulphate and Sulphite pulp mill. After treatment the total carbon amount is about 0.9022 – 1.0910 [Mio.tC] per year.

The wood pulp - a mechanically digested fiber from wood - is produced by milling of wood chips. According to the treatment method the fibers are reduced up to 85%-96%. Hence a reduction of volume is down from 1,519 [kt] to 1,375 [kt] with a carbon content of 0.6896 [Mio.tC] per year in average.

6.2.5 Cleaning of recycled paper

All substances and ingredients which occur during the treatment of waste paper are related to different qualities. That means that all fibers from this treatment step undergo a quality downcycling. Related to the amount of recycling steps is the quality of the fibers. The material composition of the waste paper, its sorting accuracy and the degree of pollution is critical for the future use. The waste paper from the fraction of paper, board and cardboard has a carbon content of 440.0 [kgC/tDM] (Baumeler, 1998) and therefore 44% carbon in the dried matter. With an annual production of 13.703 [Mio.t] of waste paper, 6.0293 [Mio.t] carbon are bound in the waste paper.

Different is the percentage of the fraction paper, board and cardboard in wet residual waste. There the content of carbon in this fraction is reduced to 81 [Mio.C] per ton wet matter. Related to the carbon content in dried matter this step includes 357.0 [kgC]. With the annual amount of waste paper in residual waste of 2.53 [Mio.t] about 0.903 [Mio.t] carbon are bound.

6.2.6 Deinking

All fibers in the conditioning and deinking process are losing quality by bloating the fibers. The bloating of ink causes an additional loss of fibers itself. Therefore about 30% of the fibers cannot be used after deinking (UBA, 2003). These fibers are leaving the process chain as sludge.

Because of the different use only one fourth undergoes deinking in Germany (International Association of the Deinking Industry). In 2003 therefore only 3.1123 [Mio.t] of the total 12.038 [Mio.t] of waste paper was used for deinking. With a carbon content of 438.0 [kgC/tDM] about 0.9542 [Mio.t] carbon are extracted from the process.

6.2.7 Fiber preparation

Most of the fibers for the process of new paper classes are pulp and wood fibers beside recycled paper. The cleaned fibers are further processed as fiber pulp so that the carbon content stays constant. Only the screening of low quality fibers causes a loss of 17.0652 [Mio.t] fiber pulp with a content of 7.7124 [Mio.t] carbon in 2003. Additional about 35% additives and support substances like Kaolinite ($\text{Al}_4\text{Si}_4\text{O}_{10}(\text{OH})_8$), starch (Polysaccharide $(\text{C}_6\text{H}_{10}\text{O}_5)_n$), Titan-dioxide (TiO_2) and Calcium-carbonate (CaCO_3) were added to this process step. This sums up to about 4.0130 [Mio.t] paper and filler medium with a carbon content of about 381.0 [kgC/tDM]. In total about 1.529 [Mio.t] carbon were added to that step in 2003.

6.2.8 Paper machine

In the paper machine the fiber pulp is processed to paper by drying and coating. During this step 19.310 [Mio.t] paper was produced in 2003 with a carbon equivalent of 8.4964 [Mio.t].

6.2.9 Bleaching

The cellulose can be bleached by using chlorine/chlorine compounds, ozone/oxygen and hydrogen peroxide. But the most common bleaching methods are ECF (elemental chlorine free) and TCF (totally chlorine free). The applied chlorine unites with some ingredients of the wood and forms chlorinated hydrocarbon (CKW). By using chlorine bleach without any further waste water treatment, this process step produces about 8 -10 kg AOX pollution per ton fiber pulp. The use of oxygen beach reduces the pollution to 1.5 - 4 kg AOX per to fiber (Institute for applied environmental re-

search, 2003). During this process step augmented wearing substances were produced but no additional carbon.

6.2.10 Refining

The refining is the preparation of paper by crabbing, supercalendering, stamping or single or double sided coating. These processes improve the quality of the paper itself. Except the coating, all steps are mechanical, so that the carbon content will not be changed. The coat on the top layer of the paper makes the paper more shiny and clogged. The coat is composed of pigments like Calcium carbonate (CaCO_3), Kaolin ($\text{Al}_4\text{Si}_4\text{O}_{10}(\text{OH})_8$), Clay or Talcum (Magnesium-Silica-Hydrate ($\text{Mg}_3(\text{OH})_2\text{Si}_4\text{O}_{10}$) and additional natural binder like starch (Polysaccharide ($\text{C}_6\text{H}_{10}\text{O}_5$)_n) or Casein (milk product) or with synthetic binder like plastic dispersions. The resulting degree of whiteness by using Calcium carbonate is about 84-96%, by using Kaolin about 84-90% and by using Talcum about 85-87% (Pluess-Staufer AG, 2000). During this process step augmented wearing substances are produced but no additional carbon.

6.2.11 Paper consumption

The amount of produced paper in Germany in 2003 was about 19.310 [Mio.t] whereas 9.949 [Mio.t] paper was imported and 10.742 [Mio.t] exported. The resultant calculated consumption (= production + import – export) was 18.517 [Mio.t] paper in Germany (figure 6-3). The fiber pulp with a carbon content of 440.0 [kgCt/tDM] was produced to 19.310 [Mio.t] paper. Therefore 8.4964 [Mio.t] carbon were bound in the flux of paper production for consume. With a calculated consumption of 18.517 [Mio.t] in 2003 and a population of 82.5 Mio. inhabitants (I) the per-capita-consumption was 224.45 kg/la.

[Mio. t]	1990	1995	2000	2001	2002	2003	2004
Production	12,773	14,827	18,182	17,879	18,526	19,310	20,392
Import	6,931	7,168	9,818	9,446	9,651	9,949	10,574
Export	4,243	6,172	8,907	8,780	9,965	10,575	11,524
Calculated consumption	15,461	15,823	19,093	18,545	18,212	18,517	19,442

Figure 6-3: Calculated consumption of paper and cardboard from 1990 to 2004 (VDP, 2004; VDP, 2005)

6.2.12 Rags, linter and other fibers

Rags, linter and other fibers were additionally used to upgrade the total fiber quality in the paper production. With this substances of about 0.0320 [Mio.t] of material were

added to the process chain with 550 [kgC/tDM]. In total 0.0176 [Mio.t] carbon entered the process of paper production every year.

6.2.13 Waste water treatment

During paper production, water is used as a suspension and transport agent for fibers and support materials, as solvent for chemicals and as a medium to connect to hydrogen bridges between fibers. After use the water exits the circle polluted or unpolluted. The production of fibers - dependent on the different production steps - consumes about 250 – 1,000 l water per kilogram paper. In 2001 the average water use was about 12 m³/t paper (Moebius, 2003). Most of it was cycled as industrial process water, so that only a small amount of water as fresh water had to be added. The amount of waste water is equal the amount of added fresh water.

In the process step of wood production while decorticating the trunk, the water has a carbon content of 1.3 [kgC/tDM]. During this treatment step of dry and wet decorticating about 5.3 – 19.9 [Mio.m³/a] were used (UBA, 2001). With a carbon content of 1.3 [kgC/tDM] the annual carbon consumption was 0.01638 [Mio. t].

In the process step of fiber conditioning as sulphate and sulfite digestion about 124 [mio.m³] water was used per year. With a carbon content of 9.0 [kgC/tDM] about 1.1 [Mio.t] carbon was produced during this production process per year. In both of this treatment techniques black liquor (used cooking liquid) as a side product was produced in a range of 2.3 [Mio.m³] per year (BMU, 2003). The carbon content was about 340 [kgC/tDM], so that this step contains about 0.782 [Mio. t] carbon per year. In the step of waste paper cleaning without deinking 7.4 [m³/t] water and with deinking 9.25 [m³/t] was produced (Spoerl, 2005). With a carbon content of 1.7 [kgC/tDM] and a waste water amount of 50.17 [Mio.m³/a] with deinking and 25.05 [Mio.m³/a] without deinking, about 0.0853 [Mio.t] carbon with deinking and 0.0426 [Mio.t] carbon without deinking were accumulated per year. In the mechanical and physical-chemical fiber conditioning an annual water consumption of 0.0102 [Mio.m³] was used with a carbon content of 1.3 [kgC/tDM]. This results to 0.00001326 [Mio.t] carbon per year. In total, fiber conditioning used 2.0099 [Mio.t] carbon per year.

In the process step of paper production itself different paper qualities have also different content of carbon and different amount of required water. Therefore the carbon content varies from 0.7 to 2.5 [kg/tDM] (Federal Law Gazette 220, act 2000) and water use varies from 0 – 300 [m³/t]. In average a summed content of carbon was about 0.2201 [Mio.t] per year.

In total all collected waste water was about 232.0 [Mio.m³] which was channeled to the water treatment plant. That water contained a total amount of 2.2464 [Mio.t] carbon per year.

6.2.14 Waste incineration / energy use

Most of the waste to incineration was sludge from the waste water treatment which had to be dried beforehand. This fraction produced also the most waste with about 1.085 Mio.t sludge – round about 31% of the total waste from paper production with 3.5 Mio.t (LUA NRW, 2004). 35% of the dried sludge was used for energy production. In average 0.4883 Mio.t carbon was produced annually by incineration and energy production (Goetz, Pfaff, 2003). Additionally 11% of the total waste - about 0.385 [Mio.t] - was disposed as slag. With this about 0.077 [Mio.t] carbon was leaving the process chain.

6.2.15 Recycling / disposal

Beside the main waste for incineration and energy use, some additional waste from sorting paper and cardboard for recycling was produced as solid waste. This waste for disposal was about 6% or 0.21 Mio.t of the total waste with about 0.0837 Mio.t carbon. This part was extracted from the mechanical-biological pretreatment of disposal sites and extracted out of the total cycle (Goetz, Pfaff, 2003).

About 59% or 2.065 Mio.t of the total waste was recycled as biological reuse or recycling material for construction. This was equal to about 0.8231 Mio.t carbon per year. 0.3348 Mio.t of the carbon was used for the annual production of cement, 0.2511 Mio.t for biological reuse and 0.1256 Mio.t for brick production (Goetz, Pfaff, 2003).

6.2.16 Paper classes and ingredients

Each different paper class has its own specific content, recipe of ingredients and characteristics. Additionally the surface was treated differently related to the paper class and use. Therefore only an average content of carbon of 440.0 [kgC/t] can be determined. With an annual production of 19,310 Mio.t paper, the average bound carbon was 8.496 Mio.t in 2003.

6.2.17 Additional and exhausting air

Additional fresh air is important for each production room and is unlimited available. For quality control, all input and output air was controlled to fulfill the regulations of pollution (UBA, 2003, European register for toxic substances (EPER)). Investigations from the Paper Technology Specialists (PTS, 1997) showed that an amount of about 0.05 – 0.5 [kg orgC_{tot}] per ton produced paper was in the air. That amounts to 0.00097 – 0.0097 [Mio.t] organic bound carbon in 2003 for a total production of 19,310 Mio.t of new paper.

6.3 Results

The input- and output fluxes of the indicator carbon were investigated and composed (figure 6-4).

Process steps		2003		
		Material Input / Output	carbon	Carbon input / output
		[t/a]	[kgC/tTS]	[tC/a]
Input into system	Wood	4,183,610	501.5	2,098,080
	Chipped wood (Thinning wood, 60%)	2,510,166	437.5	1,098,198
	Mill waste (39,9% of pulpwood)	1,669,260	501.5	837,134
	Chemicals (ca. 0,3 t for each t paper (Austropapier))	5,793,000	0.0	0.0
	Additives (ca. 0,03 t for each t paper (VDP))	579,300	0.0	0.0
	Air [Nm³/a]	ca. 10.000.000	0.0	0.0
	Water [Nm³/a]	232,000,000	0.0	0.0
	Energy [MWh/a]	15,139,000	0.0	0.0
	Paper (Import)	9,949,000	440.0	4,377,560
Paper production	Wood pulp (effectiveness: 85 - 96%)	1,375,000	501.5	689,563
	Fiber pulp (effectiveness: 43 - 52%)	1,987,214	500.0	993,607
	Waste paper	12,038,000	438.0	5,272,644
	Waste paper deinking (effectiveness: 18%)	2,178,600	438.0	954,227
	Regs a. linter, other fibers	32,000	550.0	17,600
	Waste water from pulp production (70%) [Nm³/a]	162,400,000	9.0	1,461,600
	Additives and support material	4,013,000	181.0	726,353
consumption and disposal	Paper total	19,310,000	440.0	8,496,400
	Paper (Inland use)	18,517,000	440.0	8,147,480
	Exhaust air [Nm³/a]	9,700,000	0.275	2,668
	Recycling paper	13,703,000	440.0	6,029,320
	Waste paper	2,530,000	357.0	903,210
	Waste water (30%) [Nm³/a]	69,600,000	1.3	90,480
Output from the system	Exhaust air [Nm³/a]	9,700,000	0.275	2,668
	Slag	385,000	200.0	77,000
	Waste water [Nm³/a]	232,000,000	9.7	2,250,400
	Paper (Export)	10,575,000	440.0	4,653,000

Figure 6-4: Carbon flux for the system “paper production”

All substances are divided into substances which are introduced to the system, which metabolized during the process, substances which are used for consume or recycling and finally substances which are eliminated from the system. With these allocations even substances could be detected which are recurred in sub-processes.

All determined concentration of carbon was balanced by each process steps. This gives an input carbon sum of 2,098,080 t wood included chipped wood and mill waste in the first step - from input into the system to the paper production. On the output side of the balance an amount of about 1,683,170 t of carbon in wood and pulp

was detected. Additionally about 90,480 t carbon was bound in the waste water. That means a reduction of 15.5% by detection and calculation fault (figure 6-5).

Input into system [t/a]		Raw material for paper production [t/a]	
Wood	2.098.080	Wood pulp	689.563
		Fiber pulp	993.607
		Waste water	90.480
Σ	2.098.080	Σ	1.683.170
Input of paper production [t/a]		Paper for consumption [t/a]	
Wood pulp	689.563	Paper (total)	8.496.400
Fiber pulp	993.607		
Rags and linter and other fibers	17.600		
Additives and support material	726.353		
Waste paper	4.089.497		
Waste paper deinking	954.227		
Waste water (1/3 from recycling)	487.200		
Σ	7.958.047	Σ	8.496.400
Recycling from consumption [t/a]		Output of system [t/a]	
Paper (export / import)	275.440	Waste paper (deposit site, compost, 26%)	507.663
Waste paper (fuel, 74%)	1.381.142	Slag	77.000
		Waste water treatment	974.400
		Waste water	155.440
Σ	1.656.582	Σ	1.714.503
Total Sum	11.712.709	Total Sum	11.894.073

Figure 6-5: Carbon flux for each process steps

In total about 11,713 Mio. t carbon entered the process of paper production as input and about 11.894 Mio. t carbon exit the process as output in 2003. Because of the fluctuating carbon content of the different substances, the balance has an incorrectness of about 1.5%.

The comparison of all carbon balances (figure 6-6) show differences in each process step. This results from differing carbon contents on one hand, but also from recursive processes which are not balanced separately on the other hand. Therefore double recording as sinks and sources are not be conspicuous in the total balance but falsify the total result. In the total annual balance the results are almost equal again. The calculated material chains include sinks, sources and recursions show a clearing by time shift during one year.

Focusing on the input and output flux of the total system about 2,098,080 tons of carbon enter the system but only 1,714,503 tons exit the system. This fact clearly indicates a high amount of bound carbon in the waste water, the residues and in the process of waste paper recycling. This bound carbon exits the system after multiple uses in the process loop.

Because of balancing carbon over one year, most of the sinks and sources clear themselves out of the equation. The shorter the time frame for the balance, the more influence the sinks and sources have.

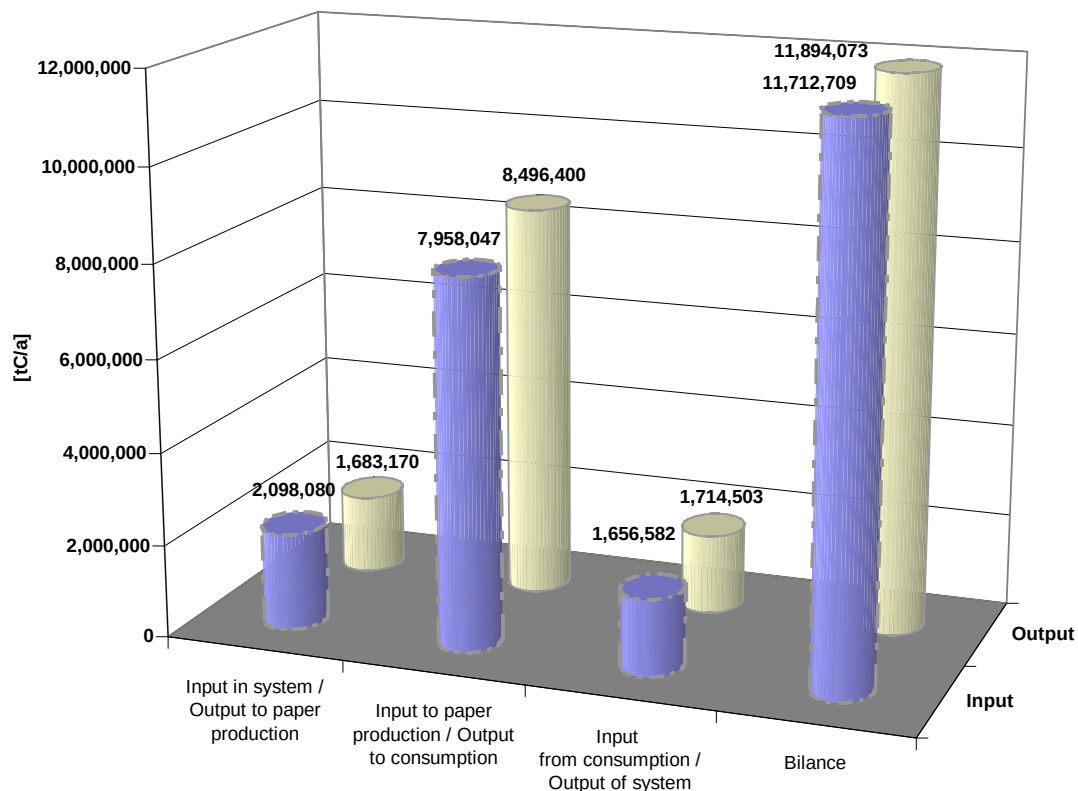


Figure 6-6: Comparison of balance sum for each process step

6.4 CONCLUSION

Carbon balances like those described in this study are essential for environmental friendly and sustainable production processes. Until the balance cannot identify sinks and sources, the carbon consumption cannot be reduced nor can substitute materials be applied. To keep the environment in an equal carbon balance, especially regarding forests and wood, sources should be conserved while additional waste should be avoided.

This study also highlighted a method for comprehensive and consistent tracking of fossil and renewable carbon sources and emissions for the process of paper produc-

tion. It also determined that such sources and emissions can vary significantly in response to changes in process practices and industry infrastructure.

The main aim is the input of recycled paper in the process of paper production can be increased without getting the carbon balance out of balance and keep the required quality. For the waste and recycling industry this will save both money and natural resources while producing less waste, lowering the impact on the environment and the carbon footprint. If the carbon balance is known beforehand, the production can be more effective and more environmentally friendlier. With this the principles of *cradle-to-cradle* - to close all material loops are then fulfilled.

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7 Summary and Vision

As early as 1987, the US Environmental Protection Agency (EPA) and in 2000, the European Environmental Bureau (EEB) recognized that “... *problems related to mining waste may be rated as second only to global warming and stratospheric ozone depletion in terms of ecological risk. The release to the environment of mining waste can result in profound, generally irreversible destruction of ecosystems.*” Additionally, the South African Council for Scientific and Industrial Research (CSIR) published the following statement in a briefing note in August 2009: “*The effect of mining on the environment includes the release of many chemical contaminants into water resources, which can cause environmental damage and threaten the health and safety of nearby communities long after mine closure. This pollution is so persistent that, in the absence of available remedies, in many instances the contaminated sites may never be completely restored.*”

These statements reflect the necessity for solutions as stated in actual reports, scientific projects and political discussions and also clearly indicate the existence of environmental influence and the damage of anthropogenic mining activities in South Africa and world-wide. This indicates the importance of immediate interaction.

As described, the main problems of mining activities deal with Acid Mine Drainage (AMD), soil sterilization, initial stages of desertification, deforestation, ground and surface water and air pollution (DEAT, 2008). Also described in the books “*Environmental Science – systems and solutions*” (McKinney, 2007) and “*Environmental Sciences*” (Chiras, 2010), it is a fact that all different environmental areas are linked together and are combined as the environment we live in. Pollution in this environment inevitably ends up in our human life and food chains.

This research proved a selection of possible application specific solutions for exactly these environmental problems. The main focus was to combine treatment steps of soil, water and air pollution with human and government policies related to legislative allowance and easier decision making processes. All solutions are based on natural materials and techniques which are proved in an evolutionary context as well. With this combined science – a combination of biology and technique called bionics – natural science could be simulated for optimized processes.

As described in chapter two, a natural harvested material mix had the ability to reduce heavy metal pollution in water by adsorption. The treated water had the economic acceptance and the quality could be used as irrigation water in agriculture. Even used natural material could be implemented afterwards as a fertilizer and ameliorant in polluted mining soil. This treatment allowed a closure in the material circle and access to millions of liters of properly treated water.

Based on this environmental water and soil problem, chapter three described the development of evolutionary algorithms as a part of the artificial intelligence to optimize material streams on different material processes. The main acceptance of this optimization was the improvement of soil quality by an optimized ameliorant mix adapted

to soil and environment conditions. By using the algorithms, calculations could be done with common personal computers in short time equation solvers. The results could be used as the basis for decision support systems (DSS) or directly to support specialists and governmental officials in the process of mine closure and provisions of pollution reduction.

With this knowledge, the discussion on the question of whether mine tailings are waste or valuable resources could be started anew. As the legislation in South Africa leaves this question open, the research clearly showed that there is a market for treated mine tailings as a product for agricultural use. Investigations on that topic are summed up in chapter four. Therefore the optimized soil ameliorant was used in optimized mixtures. The mixture was calculated by evolutionary algorithms which were integrated in a decision support system for an actual and fast solution process. With these calculated results it was also possible to illustrate a future scenario. This fact is an important tool to give forecasts of treatment methods in use. Even changes in boundary conditions like population increase or weather and climate change can be included to prove the effectiveness of these methods.

An example described in chapter five closes the circle of investigation in optimization steps in mine rehabilitation by improving soil quality and reforestation. Trees were planted under different conditions and in different polluted soil types and fertilized with a specially prepared and optimized natural material mix. This procedure resulted in a small forest growing on polluted mine dumps over a long period of time. This example is a direct result of how an optimized treatment method can improve anthropogenically caused environmental damage.

To widen up the environmental investigation, a trans-disciplinary problem was discussed in chapter six. For most environmental problems the smallest common element is carbon. That fact was used to reduce processes on that element to optimize only the carbon cycle as a reduced and simplified balance. By proving this approach, the assignment to all other different environmental problems can be treated with this method as well. By separating interconnected processes by means of their carbon cycle, an equation can be formalized to describe the total process. As an optimization, evolutionary algorithms can be used to interfere with these processes or simulate a forecast to do damage control as a worst case scenario.

In conclusion, the aim of this scientific research was to describe the problem of anthropogenic environmental influence and the steps of rehabilitation that could be developed and implemented. A decision support and optimization system was created and established to improve treatment and rehabilitation methods and to support decision makers in their work. Lined with different applications the scientific approach was demonstrated and transferred into practice; subsequently, anthropogenic interferences could successfully be reversed to nature's sustainable and optimized equilibrium.

This scientific contribution can be a support mechanism in South Africa's national fight against mining related environmental damage. As stated by the Council for Sci-

entific and Industrial Research (CSIR) (Oelofse, 2007 & 2010), especially the Witwatersrand gold mining area of South Africa is at serious risk with exactly the same problems as discussed in this work. As the economic heartland of South Africa, only few natural ecosystems remain. The impacts of mining and other problems related with mine closure and mine water management may have devastating consequences for more than just ecosystems. A possible future collaboration to include the presented results can be an effective step towards South Africa's cleaner environment.

In the international context, the scientific contribution is as important as in South Africa. Countries like Canada, Chile, Australia and also Botswana and Zambia have similar problems with environmental impacts caused by mining activities, although it is not as advanced. International mining conferences like the Australian conference *Mining 2020* held in 2008, discussed future problems of mining activities with the result of effective actions against environmental damages. The importance of urgent action was also mentioned by the World Health Organization (WHO) related to heavy metal (lead) poisoning in children in Nigeria.

These excerpts of national and international examples of anthropogenic interactions to the natural environment show the importance of the research performed in this work. Now it is the challenge of government, academics and activists to transfer these results into practice to keep the environment well preserved.

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