



Water Improvement Initiatives in New Zealand Using Melter Slag Filter Beds

Bill Bourke, SteelServ Ltd, Auckland, New Zealand

ABSTRACT

The ability of iron and steel industry slag aggregates to remove phosphorous and certain heavy metals from degraded water has been understood and well researched for many years (e.g. Yamada *et al.* 1986). Aggregates from the unique, ironsand based steel industry at New Zealand Steel exhibit similar properties.

This paper gives a brief overview of the iron and steel making operation at New Zealand Steel and then examines some recent initiatives to further expand the use of these materials in water improvement projects: as well as reviewing the results from installations that have been in place for some time.

Key words: iron sand, slag, phosphorous, zinc, suspended solids, pH, waste water, storm water.

INTRODUCTION

Iron Making at New Zealand Steel

The iron and steel making operation at New Zealand Steel's Glenbrook mill in South Auckland, New Zealand is unique compared to its international contemporaries. The Glenbrook operation is the only iron and steel manufacturing process based on the utilization of iron sand and commenced operation in the early 1970's.

The iron sand deposits were the result of a series of eruptions around 2.5 million years ago, centered on a series of volcanoes on the west coast of New Zealand's North Island, the last remaining being Mt Taranaki (Appendix 1).

The results of these eruptions deposited large quantities of titanomagnetite iron bearing material, which were ground by the action of the sea, then swept by currents up and down the west coast of New Zealand's North Island to eventually be deposited in large dunes, some of which are 90 metres high and extend up to two kilometers inland.

It is estimated that there are 1.4 billion tonnes of titanomagnetite deposits along the West Coast of the North Island and it is from one of these deposits, containing around 150 million tonnes, that New Zealand Steel draws their raw material.

Unlike conventional iron ore, there is no overburden to remove in the mining operation. Standard earthmoving equipment and custom designed bucket wheel excavators with belt wagons are all that are required. Through this method, New Zealand Steel mines about 4 million tonnes a year of burden, which produces approximately 1.3 million tonnes of iron bearing material or “Primary Concentrate”.

The iron bearing material is then separated magnetically and by gravity, by running it with water over magnetic drums and through a series of cones and spiral separators, where the heavier iron bearing material gravitates towards the center and the residual clays and silts towards the outside.

It is then pumped 18 kms as a slurry to the steel mill through an underground pipeline, where it is dewatered and stockpiled.

The steel mill itself is also rather unique. It is located in a very rural environment and it is still the smallest integrated steel mill in the world, producing around 650,000 tonnes of finished steel products a year. The company also runs an 1100 acre farm as a buffer zone around the plant.

To convert the iron sand to iron, the direct reduction process is used, by adding coal and limestone to the ironsand, before preheating in four multi-hearth furnaces, which also drive off the volatiles in the coal. The material then enters one of four rotary kilns where the direct reduction takes place – the process taking about 8 hours.

The directly reduced product is melted in one of two large electric melters. It is from this stage of the process that SteelServ Ltd.¹ obtain about 250,000 tonnes a year of the iron making or “melter” slag. The New Zealand Steel process has remained unchanged for many years, which means the slag chemistry is very stable and consistent.

The chemistry of the iron sand based slag is somewhat different than conventional blast furnace equivalents (Table 1). The New Zealand Steel product has a high percentage of titanium and higher concentrations than the industry norm of magnesium oxide and aluminum, while at the other end of the spectrum, the material is low in silicon, calcium oxide and sulphur.

From a slag marketing perspective there are plusses and minuses in the chemical and geological structure. Unlike conventional blast furnace slag, the iron sand based material cannot be granulated, which immediately precludes its use as a cement replacement in concrete manufacture. Conversely, the lower than normal sulphur and calcium oxide content, presents opportunities in the water improvement arenas which will be discussed below.

¹ SteelServ Ltd is a 50/50 joint venture company between New Zealand Steel and Multiserv, an international steel mill servicing company. Multiserv purchased the international operations of the UK based Slag Reduction Company in 1998, which included the operation at New Zealand Steel.

Table 1: Comparison of New Zealand Steel and Blast Furnace Slag Chemistry

Constituent	BFS slag %	NZ Steel Melter Slag %
CaO	41	14.5
SiO ₂	35	12
FeT	0.49	4
MgO	6.5	13.6
MnO	.45	1
TiO ₂	1	34.3
Al ₂ O ₃	14	17
V ₂ O ₃	<0.05	0.2
S	0.6	0.030

Source: Australasian Slag Association and New Zealand Steel analysis

Leachate Analysis

New Zealand Steel began to examine their melter slag in detail in the late 1980's, with a view to establishing that there were no harmful leachates if the product was used as a road making and drainage material (New Zealand Steel Report 1992).

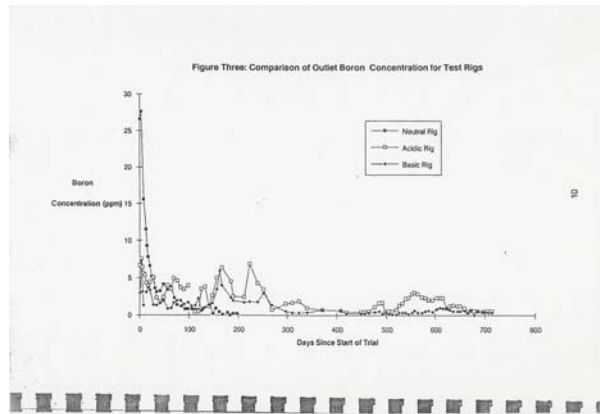
During these studies, which took place over two years, it was found in common with a number of other iron and steel making slags, that the company's melter slag could remove phosphorous and certain heavy metals from laboratory input waters. The studies used three water mixes – basic, neutral and acidic – and again in common with other slags, the study showed that there could be some leachate issues if the pH of the water dropped below 5.5, as it would begin to leach iron and manganese.

The leaching studies also identified that there could be a Boron² spike when the material was first exposed to water input. (Figure 2). Although a number of subsequent field studies have shown no boron leachate, SteelServ's policy is to wash all the aggregate that is destined for water treatment, to reduce the potential for any initial boron spike.

The New Zealand Steel laboratory findings were subsequently confirmed by small scale trials in a wetland on a dairy farm (Tanner 1991; Curtiss 1996) and in a small pilot waste water treatment plant (Bruce Wallace Partners 1991).

² The boron comes from the coal, used in the direct reduction process.

Figure 2: Melter Slag Boron Leachate



Source: New Zealand Steel melter slag leachate study 1992

WASTE WATER TREATMENT

Coincidental with the New Zealand Steel studies, Bruce Wallace Partners Ltd., an engineering consultancy, were designing a new wastewater treatment plant (WWTP) for the township of Waiuku, close to the steel mill. The design required large aggregate filter beds to remove suspended solids and algae, although phosphorous reduction was not part of the original brief.

The investigatory work carried out by New Zealand Steel, as well as some pilot plant trials, convinced the designers and the local Council that the material was safe to use as an aggregate source³.

The plant was installed in 1993 and handles up to 3000m³ a day of treated effluent from the settling ponds. The hydraulic residence time in the filter beds is two days, the slag depth in the beds being about half a metre. There are 10 filter beds in all, utilizing some 15,000 m³ of slag aggregate (Bruce Wallace Partners 2004).

Figure 1:
Waiuku WWTP



³ Because of the steel mill's location close to the project, melter slag was also the cheapest aggregate source.

Subsequent monitoring of the plant showed that it was removing a very high level of the incoming phosphorous – around 80% on average for the first five years - and most of the suspended solids and algae.

The beds are not planted, as the designers did not want to encourage swamp birds defecating on the filter beds after all the hard work cleaning up the water had already been done. Planting also adds management problems as the “crop” has to be continually harvested.

Indeed one feature of this type of design is the relatively low maintenance requirements and comparatively low capital cost – ideal for smaller provincial and rural communities – where there is also room to put in the aggregate beds.

More recent monitoring by SteelServ of this utility’s performance confirms the drop off in phosphorous removal after 13 years of operation, but a continuing satisfactory removal rate of suspended solids (Table 3).

Table 3: Waiuku wastewater treatment plant water analysis

Element		Inlet 1	Outlet 1	Inlet 2	Outlet 2
pH		7.3	7.4	7.2	7.3
s	ppm	15	21	15	22
Zn	ppm	0.018	0.011	0.018	0.014
P	ppm	5.82	2.785	5.79	2.344
Pb	ppm	<0.02	<0.02	<0.02	<0.02
Cd	ppm	<0.005	<0.005	<0.005	<0.005
Ni	ppm	<0.005	<0.005	<0.005	<0.005
Cr	ppm	<0.002	<0.002	<0.002	<0.002
Mn	ppm	0.091	0.246	0.144	0.251
Fe	ppm	0.23	0.40	0.22	0.53
Mg	ppm	8.5	8.8	8.5	8.7
aL	ppm	0.13	0.09	0.14	0.10
Ca	ppm	26.1	24.6	26.0	24.7
Cu	ppm	<0.002	<0.002	<0.002	<0.002
K	ppm	14.2	14.1	14.1	14.2
Co	ppm	<0.005	<0.005	<0.005	<0.005
B	ppm	1.0	1.0	1.0	1.0
SS	ppm	36	7	35	<5

Source: New Zealand Steel Technical laboratories, Water Laboratory report W12852 20th August 2004.

Of particular interest to SteelServ is that the level of leachates closely correspond to the original New Zealand Steel studies.

On the day the sample was taken, a small amount of sulphur, plus iron and manganese were being added, but no boron. The beds were also extracting small quantities of zinc, aluminum and calcium. A second set of grab samples in

December 2004, showed a reduction in the sulphur (15ppm >10ppm), the pH unchanged, a 52% removal of suspended solids and about a 15% reduction in phosphorous⁴.

It is to be noted that there is very little change if any to the pH of the water. Using steel making slags for this end use may increase the water's alkalinity because of the slag's higher lime content – possibly to unacceptable levels – depending on the where the filtered water is being discharged⁵. However other studies (Smyth *et al.*), indicate buffering of the pH can be achieved through geochemical interactions with aquifer materials and CO₂ in the vadose zone, which resulted in little change to the pH of shallow ground water in three monitoring wells, approximately a metre down-gradient of a BOF slag filtration bed.

The application of treated wastewater to land filtration by dripper systems is an increasingly common practice. A recent example in New Zealand (Gearing 2005, Turf Craft 2004), demonstrated the successful application of treated effluent through subsurface drip irrigation on a golf course, the system subsequently being expanded due to its initial success. A dripper system has also been used in conjunction with a recent melter aggregate filter bed and WWTP in Northland (see below).

It is therefore suggested that if pH is an issue, then there are innovative solutions that do not require chemical dosing and have the potential too add considerably to the life style of the serviced community, without harm to the environment.

There are now three more waste water treatment plants in commission using melter slag as a filtration medium (Appendix 1). Those at Ngatea and Paeroa are also from the design of Bruce Wallace Partners, following the success of the Waiuku plant. The latest to be commissioned, designed by Integrated Treatment Systems Ltd., is in the Waipoua Forest towards the top of the North Island or about 300kms from SteelServ's operation.

At the time of writing there are another eleven in design, some of which melter slag aggregate has already been specified and others which SteelServ is monitoring as they go through their resource consent, design and tendering process. Other designers - apart from Bruce Wallace Partners - are recognising the potential of melter slag as a water improvement medium and can justify to their clients, the additional cost of transporting it.

SteelServ has initiated a programme of monitoring the performance of the later installations to track the aggregate's performance in a variety of different configurations.

A WWTP at Paeroa - again from the design of Bruce Wallace Partners - is utilising around 12,680m³ of melter slag and was commissioned in 2000. The hydraulic residence time is just over two days and the water flow is around 2100m³ a day (Bruce Wallace 2004).

⁴ NZ Steel Technical Laboratories. Water Laboratory report W12892 December 2004

⁵ In the case of the Waiuku WWTP, discharge is to sea via the Waiuku river inlet. Discharge is timed to coincide with tidal movements

Inlet and outlet grab samples in January 2005, indicated the beds were removing just over 77% of the incoming suspended solids and 53% of the phosphorous. The temperature of the bed water was 28°C on that day⁶. There has been some recent study in New Zealand (Shilton *et al.* 2004), that indicates increasing temperatures result in better performance. The field evidence for this is not conclusive from our random grab samples. Samples from this plant taken in July last year, when the bed temperatures were around 7°C produced the same result for phosphorous reduction but only a 53% reduction in suspended solids⁷.

It is suggested that a more rigorous sampling régime than that initiated by SteelServ, is needed to prove this one way or the other.

The smallest of the Bruce Wallace designs is at Ngatea, utilising about 3900m³ of melter slag in two filter beds, with a water flow of 250m³ a day (Bruce Wallace Partners 2004).

Inlet and outlet grab samples from this facility on the same day as the Paeroa samples were taken, indicated an 86% reduction in suspended solids and a 75% reduction in phosphorous. The pH again was virtually unchanged and sulphur had reduced from 16ppm > 6ppm⁸.

(The predominant aggregate size that has been used in all these plants is a 20mm top size and 10mm bottom size).

The latest installation, is at the Department of Conservation Headquarters in the Waipoua Forest in the far north of the North Island (Figure 3).



Figure 3:
Waipoua Forest
Filter beds

These filter beds are taking water from the septic tank installations that service the Department's headquarters and the camping ground. The treated effluent is

⁶ New Zealand Steel Technical Laboratories. Water Laboratory Report W12936 19th January 2005

⁷ New Zealand Steel Technical Laboratories, Water Laboratory Report W12839

⁸ Ibid W12936

then pumped up to the forest where it is distributed by drippers. The filter beds are quite small, using only about 80m³ of aggregate.

Results from grab samples taken a week after commissioning showed the beds removing over 90% of the incoming phosphorous⁹, but on past experience we would expect this to drop to around the 80% mark once the plant settles down.

INDUSTRIAL STORM WATER TREATMENT

A more recent object of study has been to further examine melter slag's ability to remove heavy metals, on which neither SteelServ or New Zealand Steel had undertaken any further work since the original laboratory studies in the early 90's.

Figure 4:
Northern side
Storm water
Ponds,
NZ Steel



Figure 4 shows New Zealand Steel's main storm water settling ponds, which capture the solids from around the production units, roads, unsealed areas and SteelServ's stockpiles. Each pond size is 15,000m³.

Although New Zealand Steel meets current discharge regulations, the local Maori people had asked the company to consider further treatment of the water, before it passes into the estuary on the mill's boundary. It was also a good opportunity to really test melter aggregate's ability to remove heavy metals such as Zinc. Accordingly, it was decided in May 2004 to construct a small melter slag filter bed.

Bruce Wallace Partners were engaged to design the unit, which handles about a quarter of the projected flow from the ponds.

⁹ Verbal report to author by Integrated treatment Systems Ltd

Figure 5:

Pilot Storm
Water treatment
Filter, NZ Steel



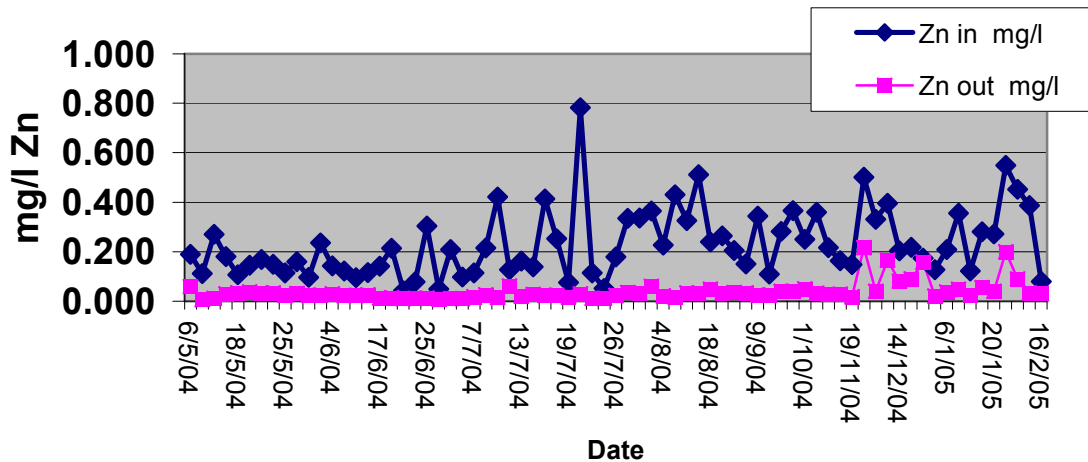
Water is sprayed across the top of the first bed, then drains through a second bed of coarser aggregate before discharge. The water volume is approximately 65m³ an hour and the hydraulic residence time is only about two hours. Slag volume is just over 260m³.

There was a deliberate decision taken to push the performance of this pilot plant, by using a reasonably high hourly water flow and a reduced volume of melter aggregate, compared to the wastewater treatment plants already discussed. Both New Zealand Steel and SteelServ wanted to see how long the filters would last under these operating parameters.

New Zealand Steel samples their water discharges daily, so this unit's performance can be monitored quite closely. Since commissioning, the plant has been removing an average of 80% of the incoming zinc¹⁰ and virtually all of the remaining suspended solids.

¹⁰ The zinc comes from the iron sand, where the concentration is around 700 ppm. Quite a bit of this is released during the iron making process.

**Figure 5: New Zealand Steel - Northside Outfall Slag Wetland #1
Zinc Removal Performance (grab samples)**



The spike in the middle of the graph, was caused by a hot spot on one of the direct reduction kilns, which required more water to cool it off. Note however that it appears to have had little impact on the outlet performance.

New Zealand Steel are very pleased with the performance of the trial unit and in September 2004, installed a second, larger unit. They are also planning a third, so that eventually the majority of the site's storm water will be filtered before discharge.

Rather than using sprays, the water for this second installation is gravity fed through the beds. It has been found on the first unit, that the very top layer of the filters were starting to blind off with solids under the sprays, after about 3 months in service. A quick rabble of the surface fixes this, but the ultimate goal is low maintenance, like the waste water treatment plants.

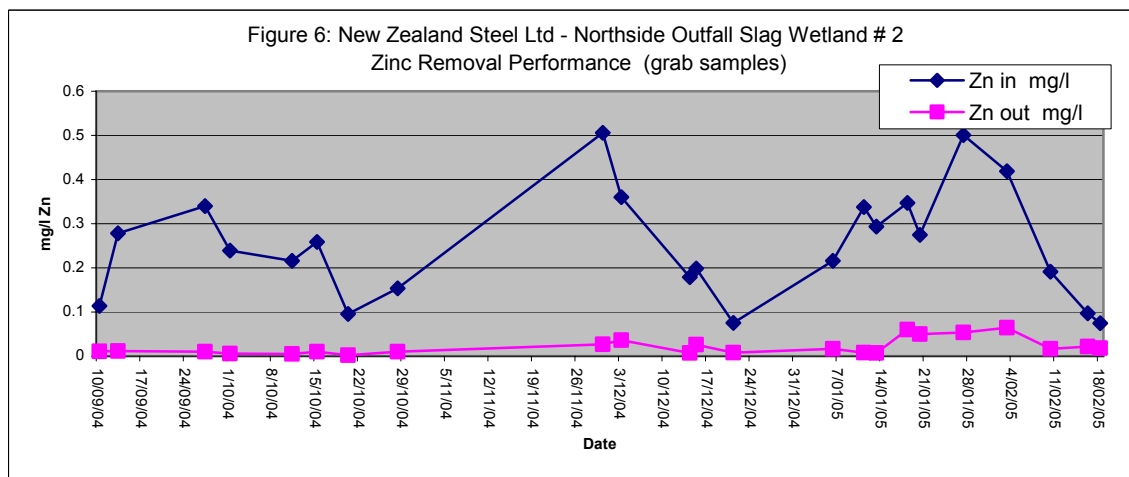


Figure 6 shows the results for Zinc extraction from the second bed. Again note that the beds seem handle incoming spikes of zinc concentrations in their stride.

A lesson that has been learnt with both these installations is the need to have a coarser aggregate – or perhaps a replaceable pre-filter system – ahead of the main beds, to quickly reduce the suspended solids. Otherwise the receiving ends of the beds are susceptible to blinding off and maintenance to ensure uninterrupted water flow, although this seems to have little impact on the bed's extractive performance to date.

URBAN STORM WATER

SteelServ's main purpose in pursuing the heavy metals aspect, is best encapsulated in a statement at a recent conference in New Zealand on water and wastes.

“Road runoff can be a major source of pollution. It can contribute as much as 50% of total suspended solids, 16 – 25% of total hydrocarbons and between 35 – 75% of total heavy metals to receiving waters”. (Taylor, et al. 2004).

In New Zealand there is rapidly growing concern about heavy metal runoff from road ways, freeways, parking lots and commercial and industrial sites. The impact of these degraded waters in the Auckland area alone have resulted in local authorities allocating \$NZ 45 million to reverse trends and practices that have been the accepted norm for a long time¹¹. Such practices have often led to disastrous results for the well being of nearby waterways, including the quality of life for those living next to them.

SteelServ's current strategy, is to use the results from the filter beds at New Zealand Steel, along with those we have obtained from the waste water treatment plants, to promulgate melter slag as an alternative or additional clean up medium.

There are already a considerable number of proprietary storm water catchment and clean up systems, most of which use a variety of different aggregates, sands or chemicals, along with litter traps.

SteelServ's objective, is to work with companies already providing proprietary mechanisms, with a view to introducing melter slag as an alternative or supplementary aggregate to their designs.

We are only in the initial stages of investigating this initiative and we plan in conjunction with the ASA, to work with one of the Universities to help us develop and test some of these concepts. But we believe there is good potential for steel industry aggregates in this market.

¹¹ New Zealand Herald 20/05/04

RESTORATION OF DEGRADED LAKES

The degradation of lakes due to eutrophication (nutrient enrichment), is a worldwide phenomenon. It is also of great concern for significant New Zealand lakes, particularly the Rotorua lakes in the central North Island – long regarded as a major attraction for tourists and fishermen. As lakes become eutrophic, bottom waters become anoxic and internal recycling of nutrients from bottom sediments increase, thus compounding the problem.

There are therefore two important aspects of lake restoration: first, preventing nutrients from the catchments from being transported to the lake and second, preventing nutrients from being released from the bottom sediments.

SteelServ's interest in this potential market was triggered by the receipt of a paper from Korea, where the authors had used steel making slags to restore polluted harbour bottoms (Kim 2003). Coincidentally, this paper arrived the week that the New Zealand Herald – New Zealand's largest newspaper – began a series of articles on the state of the North Island lakes.

Circulation of the Korean paper to those responsible for restoring the lakes, elicited some interest in the use of slag as a potential phosphorous reduction medium. However, a number of questions arose, such as how the material would perform in anoxic conditions in the bottom of some of the deeper lakes, what would be the effect on biota or aquatic life and how best the material could be used to assist with restoration.

To address these questions SteelServ, along with Environment Bay Of Plenty (EBOP) and Technology New Zealand, is sponsoring a study led by Professor David Hamilton, who holds the Chair in Lakes Management and Restoration, in the Department of Biological Sciences faculty at the University of Waikato.

The Chair is sponsored by EBOP, who are the Regional Council responsible for the lakes. Professor Hamilton is one of the Council's key scientific advisers.

The objectives of the research are:

- To carry out scientific study of the technical and economic feasibility of the use of iron and steel making slag aggregates, as media for removal of nutrients from stream flows and lake waters.
- Determine where and how slag based aggregates may play a part in assisting with lake restoration in New Zealand and overseas, with a view to providing an outlet and constructive end use for surplus steel industry co-product.
- Confirm the safety and suitability of the slag materials for these environmental end uses.

To enhance the international relevance of the study, it is planned to include BOS and EAF slags in the study where possible, for it is recognized that the New Zealand Steel material is somewhat unique, but lake degradation is not. Professor Hamilton's testing will involve three components which can be summarised as:

- Lab work to examine the nutrient removal potential using artificial, stream and lake water.
- Mesocosm enclosure experiments in a degraded lake, to examine nutrient stripping and stability under anoxic conditions.
- A stream study to examine slag's potential for stripping nutrients from stream flow. Scaled to determine if whole stream applications are practical.

The study will also investigate combining melter slag with a natural zeolite, to see if the two products can provide a synergistic effect – one going for phosphorous and other for nitrates.

The work has commenced and will take about 15 months. If these results are positive, then SteelServ believes the potential for slag in this end use could be substantial – not just in New Zealand, but internationally.

DAIRY FARM EFFLUENT

The final area of the company's investigation revolves around the improvement of water discharge from intensive dairy farming. Nutrients from this source are a key contributor to lake and river water degradation, which has prompted Dr Richard McDowell of AgResearch in NZ to examine methods of clean up – particularly dealing with farm land where dairy shed effluent is sprayed onto paddocks.

Dr Mc Dowell conducted a series of experiments a fluvarium at an American University, using a number of industrial co-products, such as coal fly ash and steel industry slags, including New Zealand Steel's melter slag (McDowell *et al.* 2004)

Encouraged by the results, AgResearch have initiated a field trial, which involves the placing of a number of tile drains using melter slag aggregates around the drain coil and greywacke aggregates as a control on two further drains.

"Socks" containing melter aggregate have then been inserted up three of the drains to determine if reduction can be



a better phosphorous achieved.

Figure 7:

AgResearch trial,
Filter sock
Installation.

Two sets of water samples have been retrieved since this trial was installed. They show promising results, with 35 – 40 % of phosphorous being removed by the drains surrounded by melter aggregate and a 90% reduction in the drains containing the socks; compared to the greywacke controls. Sampling will continue for the next six months to build up a more robust data series.

New Zealand Steel and SteelServ are also examining the installation of small melter aggregate filter beds on the company's dairy farm, which is managed in conjunction with a local Maori trust. In this case the water to be improved discharges from the standard anaerobic/aerobic two pond treatment system. Bruce Wallace Partners have been commissioned to produce design concepts which are being considered at the time of writing. The brief includes the ability to experiment with the installed system, by routing the piping so various combinations of filter beds can be trialed to determine the most economic solution.

CONCLUSION

It can be seen that SteelServ are approaching this market on a broad, but interrelated front.

The company has determined that water quality improvement is a competitive advantage which steel industry aggregates have over their quarried, naturally occurring equivalents. While it is true that rock filters constructed from natural aggregates can and will remove suspended solids and have been used for many years, they cannot, with the exception perhaps of natural zeolites, add some of things to the equation that slag can. They are also a finite material.

As the ASA's library will attest, investigations into slag's unique properties in this regard have been going on for many years. But it is SteelServ's view that that much of this work was possibly a little before its time and it is only relatively recently, that nutrient enrichment of fresh water rivers and lakes, heavy metals pollution from storm water runoff and the increasing drive to utilise recovered and recycled materials has come to the forefront of those responsible for control and remedial action. This is certainly so in New Zealand.

ACKNOWLEDGEMENTS

SteelServ wishes to acknowledge the work carried out at Montreal University by Dr Alexandra Drizo and her scientific colleagues, concerning the possibility of

rejuvenating slag's phosphorous reducing potential by drying it out (Drizo *et al.* 2003).

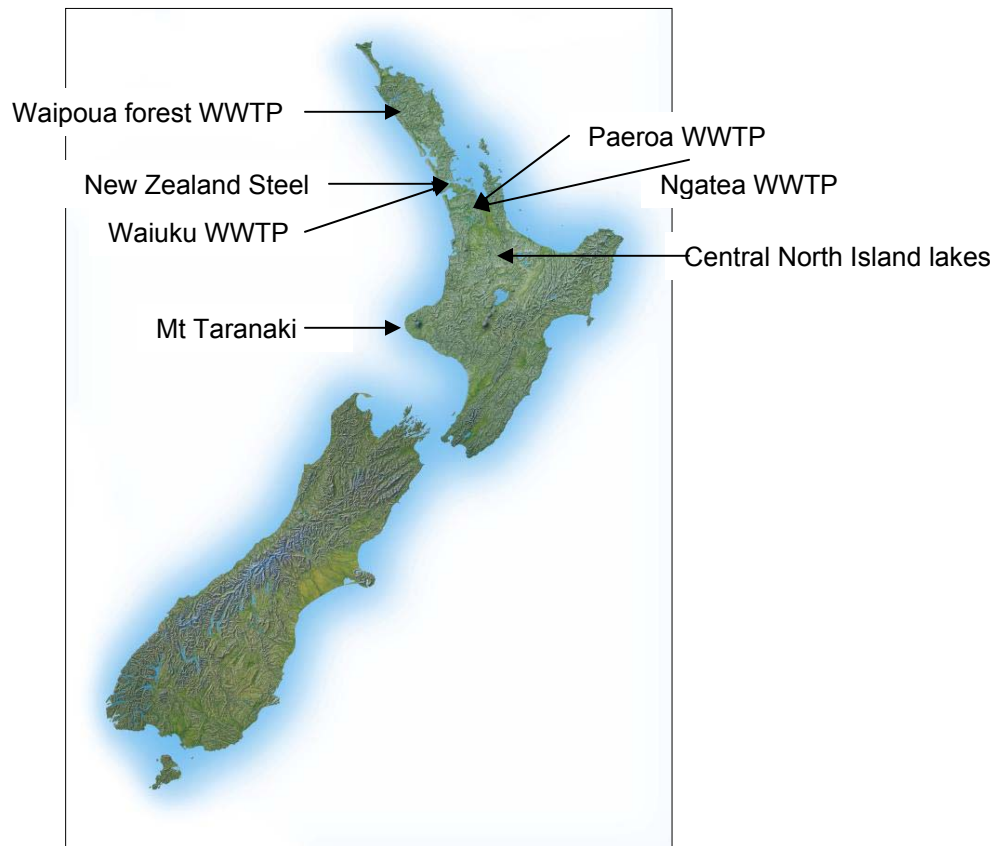
It was this paper that re-wakened the company's interest in the potential use of slag in this and associated end uses, even though some 60,000 tonnes of melter aggregate were already in service in the waste water treatment plants detailed in this paper.

Massey University in New Zealand are further examining the potential for rejuvenation, as well as gaining a better understanding of why these materials work in the way they do. Dr Drizo has contributed to this work at Massey in early 2005.

The author also wishes to acknowledge the enthusiasm and assistance SteelServ have received from New Zealand Steel's environmental and laboratory staff. Without the input of their expertise and ready access to a first class water laboratory, engaging in these investigations would have been a much more challenging and considerably more expensive undertaking.

APPENDIX 1

Location map: New Zealand



REFERENCES

Bruce Wallace Partners Ltd., (May 1991). Franklin District Council, Waiuku Wastewater Treatment Plant, Effluent Upgrading. Report on Pilot Tests Using Subsurface Flow Gravel Beds.

Bruce Wallace Partners Ltd., (2004). Slag Gravel Filter Beds Treating Municipal Waste water. Summary page. Available on application to Bruce Wallace Partners Ltd.

Curtiss, A.F. (1996). Granular medium filtration of dairy shed effluent. Internal Report, BHP NZ Steel, Glenbrook, South Auckland.

Drizo, Comeau, Forget & Chapuis. (2003). Phosphorous Saturation Potential: A Parameter for Estimating the Longevity of Constructed Wetland Systems. Journal of Environmental Science and Technology, American Chemical Society.

Gearing, P. (2005). Subsurface drip irrigation of Omaha golf course fairways with treated effluent. URS New Zealand Limited. Conference Proceedings, (Technical Session 26), New Zealand Land Treatment Collective, March 2005.

Kim, Hyung-Suek. (2003) The Beneficial Reuse of Steel-Making Slag in the Restoration of Korea's Coast Ecosystem. Research Institute of Industrial Science & Technology, Korea. Paper presented at the S.E. Asian Iron and Steel Institute Conference, Bangkok, August 2003.

McDowell, R.W. (2004). The effectiveness of industrial by-products to stop phosphorous loss from a Pallic soil. Australian Journal of Soil Research, 2004, **42**, 755 – 761.

McDowell, R.W., Sharpley A., Bourke, B., Hopkins, K. (2004). Treatment of drainage water to prevent phosphorous loss from tile drained land receiving effluent. Conference Proceedings, (Technical Session 26), New Zealand Land Treatment Collective, March 2005.

New Zealand Steel (1992). Results of Leaching Trials Conducted on Melter Slag. Report prepared for Slag Reduction (NZ) Ltd by the Process & Environmental Engineering Department.

Shilton, A., Pratt, S., Drizo, A., Mahmood, B., Banker, S., Billings, L., Glenny, L., Lou, D. (2004). Active Filters For Upgrading Phosphorous Removal From Pond Systems. Available from Dr A. Shilton, Massey University, Palmerston North, New Zealand.

Smyth, D., Blowes, D., Ptacek, C., Baker, M., Ford, G., Foss, S. (2002). Removal of Phosphate and Waterborne Pathogens From Wastewater Effluent Using Permeable Reactive Materials. Proceedings of 55th Canadian Geotechnical and 3rd Joint IAH-CNC and GCS Ground Water Specialty Conferences, October 2002. Published by the Southern Ontario Section of the Canadian Geotechnical Society. 1123 -1127

Tanner, Chris C January (1991). Experimental investigation of melter slag as an alternative substrate for subsurface-flow constructed wetlands treating wastewaters. Aquatic Research, Ruakura Agricultural Centre, Ministry of Agriculture and Fisheries, Hamilton. Report prepared for New Zealand Steel Ltd and The Slag Reduction Company Ltd.

Taylor, Lee, Pandy, Buckley, (2004). Road Runoff Containment Removal by a Treatment Wall in a High Traffic Industrial Area. Proceedings from NZ Water and Wastes Association Conference, May 2004.

Turf Craft International (2004). Issue 94, 8 – 10. Article on Omaha irrigation system.

Yamada, H., Kayama, M., Saito, K., and Hara, M. (1986). A Fundamental Research on phosphate removal by using slag. *Wat. Res.*, **20** (5) 547 -577.

Abbreviations

ASA – Australasian Slag Association

BOS – Basic Oxygen Steel

EAF – Electric Arc Furnace

EBOP – Environment Bay of Plenty

WWTP – Wastewater treatment plant