A DETAILED PILOT STUDY OF THE BIOLOGICAL TRICKLING FILTER PROCESS

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ABSTRACT

Napier City Council has been operating a pilot scale Biological Trickling Filter in an extended Losluj configuration for the past 15 months, in order to assess the suitability of this relatively novel configuration for the Napier community. The pilot was designed robustly so that it could be operated as a full-scale plant would be, and results could be extrapolated to the future performance of a full-scale filter.

Performance of the pilot plant at an organic loading rate of 0.4 kg $cBOD_5$ /m^3.d has been good. Operational parameters of great importance for this process configuration are the flushing cycle and dose rate. At this organic loading rate, industry standard design models can be used to predict pilot performance.

This paper details the design and construction, and assesses the performance of the pilot plant to date, in the context of the development of the Napier community's wastewater scheme.

KEYWORDS

BTF, Pilot, Organic Loading Rate, Solids Loading Rate, Losluj

1 INTRODUCTION

1.1 NAPIER CITY WASTEWATER - HISTORY TO 2004

Napier City is a mainly urban local authority with a population of 58,000; 95% of whom are connected to the reticulated sewerage system. Since 1972 Napier has discharged its wastewater to the sea via a 1.6km long marine outfall located off the coast of the southern suburb of Awatoto. In 1991 the first stage of a planned multi-stage development for sewage treatment was completed. This was the installation of a milliscreen plant consisting of four rotating 0.75mm milliscreens and a new outfall pumping station.

During the 1990s, Napier City Council (NCC) investigations and extensive public consultation resulted in a plan for further staged development of sewage treatment. It was accepted that the present method of treatment and disposal was not having an adverse effect on the natural environment but that cultural and social issues required a higher treatment standard.

In 1999 a resource consent application was lodged which proposed a separation of major industrial and domestic wastewater. The City has a number of significant wet industries drawn to the area by the abundant, low cost and high quality water available from the Heretaunga Plains aquifer and by the proximity of the ocean for effluent disposal. Until about 35 years ago some of these industries had their own ocean outfalls, but now all use the City reticulation. These industries have resulted in a wastewater system greatly impacted by industrial wastewater - approximately 25% industrial by volume and 75% by load. The consent application proposed that all wastewater be treated to a level equivalent to 'advanced primary treatment' (APT) by July 2005 and that domestic and 'non-separated' industrial wastes receive secondary biological treatment by July 2015. NCC would build a treatment plant for domestic and non-separated wastewater whilst treatment of industrial wastewater was expected to be by individual on-site systems meeting new trade waste bylaws, with a possible backup plant at the Council treatment plant.

The method chosen to achieve APT of the domestic and non-separated industry stream was milliscreening and grit removal, followed by coagulation and flocculation with alum and an organic polymer prior to settling and removal of the resultant primary sludge. After settling, the effluent would receive UV disinfection followed by disposal via the existing marine outfall. The solids would be dewatered by centrifuge and disposed to a municipal landfill, the regional Omarunui landfill. NCC put the project out to tender in late 2004 but did not award a contract due to a range of factors.

1.2 A CHANGE OF DIRECTION

While NCC was considering its options with regard to the construction process, the neighbouring local authority, Hastings District Council (HDC), began trialling passing fine-screened raw domestic effluent over a Biological Trickling Filter (BTF), with no sedimentation stage. No solids streams needing treatment or disposal would therefore be generated, which would greatly reduce the ongoing operational cost of the facility. The effluent from this process (including solids) would then be discharged to the ocean via a long ocean outfall with no further treatment. This type of process and disposal had satisfied the local community that social and cultural concerns over the discharge of human waste direct to sea were addressed, as the offensive content of domestic sewage was transformed into bacterial biomass, was therefore less offensive, and suitable for disposal to the ocean. HDC subsequently applied for and was granted Resource Consent (for a period of 7 years) to use this BTF method of treatment for the domestic portion of its wastewater flow. The HDC plant has now been constructed and is operational.

Because of the potential operational cost savings of BTF treatment plant as compared to a chemically assisted sedimentation plant, NCC decided to put construction of the APT plant on hold while it investigated the BTF concept further. An application was made to delay the implementation of an APT plant, and work began in earnest to study the BTF treatment method. It was estimated that using a BTF for Napier would result in operational cost saving of more than 50%, as compared to an APT plant primarily due to no chemicals being required, and no solid stream being generated requiring treatment and disposal. It could also easily allow for inclusion of other stages within the treatment train at a later stage if required, and could therefore meet the aims of the local community in the short and longer term.

Although the BTF process is well established and used throughout New Zealand and the world, the configuration proposed for Hastings (a variant on the 'Losluj' approach) is relatively novel due to the lack of any sedimentation stage. However, this is the aspect of the process that gives operating cost advantages in that no primary or secondary sludges needing disposal are collected. NCC therefore decided to investigate the process with a pilot plant, to gain confidence that a full-scale plant would be a sound investment for the Napier community. It would increase the limited database of knowledge available worldwide on BTFs operated in this way. Operating a pilot plant over a range of loadings, wetting rates and climatic conditions was seen as the best way to become familiar with the process. Additionally, because none of the engineering staff at NCC had much prior experience with secondary sewage treatment, a pilot plant would also play a role in upskilling staff. A robust and scaleable pilot plant was necessary, that would both have a useful lifespan and be able to trial a wide range of parameters associated with the proposed treatment method. The pilot would need to be designed, constructed and operated in as close a manner to a full-scale plant as possible, taking into account the non-standard nature of the proposed configuration.

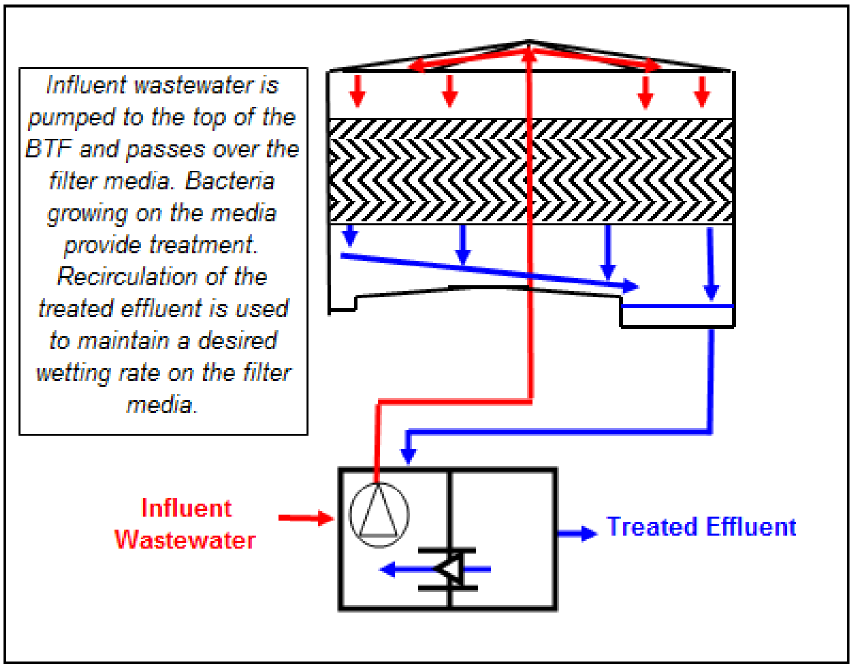
2 THE BIOLOGICAL TRICKLING FILTER PROCESS AND THE LOSLUJ APPROACH

2.1 WASTEWATER TREATMENT IN A BTF

A BTF is a fixed-film biological treatment process. Wastewater flows over plastic or rock filter media upon which an active bacterial mass grows, using the wastewater as food for growth and respiration. Heterotrophic bacteria utilise the biodegradable organic carbon and a small amount of the other contaminants in the wastewater as they grow and reproduce. In this way the organic carbon is transformed from being human waste into new bacterial mass. Heterotrophic bacterial substrate in wastewater is often characterised as the 5 day carbonaceous Biochemical Oxygen Demand ($cBOD_5$). This parameter is of key interest when considering the transformation of wastewater from being primarily of human origin to primarily new bacterial mass. Bacteria are able to quickly and easily use the soluble $cBOD_5$ fraction, and removal in a BTF is typically expected to be very high – in the order of 85 to 90%. A BTF will remove some particulate $cBOD_5$, but it will not be such a high percentage as the short hydraulic retention time (HRT) of the BTF plant restricts time for breakdown and full removal of particulate $cBOD_5$. It is not desirable to retain the particulate $cBOD_5$ within the filter media for much longer than the HRT due to the potential to cause excess biomass growth leading to anaerobic conditions and the potential for clogged areas within the filter, which can lead to offensive odour generation and reduced treatment performance.

Heterotrophic bacteria also use small amounts of other nutrients such as ammonia and phosphorus for growth and respiration. However, when the organic load to the filter is low, an autotrophic nitrifying population can establish, and BTFs are often installed in pairs, in series, to take advantage of this fact where ammonia removal is required. Wastewater compounds such as metals are not removed in a BTF. Figure 1 shows a simplified outline of the BTF process.

Figure 1: Simple schematic of the Biological Trickling Filter process



2.2 TYPICAL BTF PROCESS CONFIGURATION

Traditionally, a BTF is installed with a sedimentation stage. Typically primary sedimentation is included to remove large settleable solids from the incoming wastewater. This reduces the load onto the biological plant, resulting in less excess biomass being produced. In the BTF process, primary sedimentation has the additional function of reducing the potential of media clogging from solids accumulation within the media, which as noted above, can lead to problems with odour and reduced treatment efficiency.

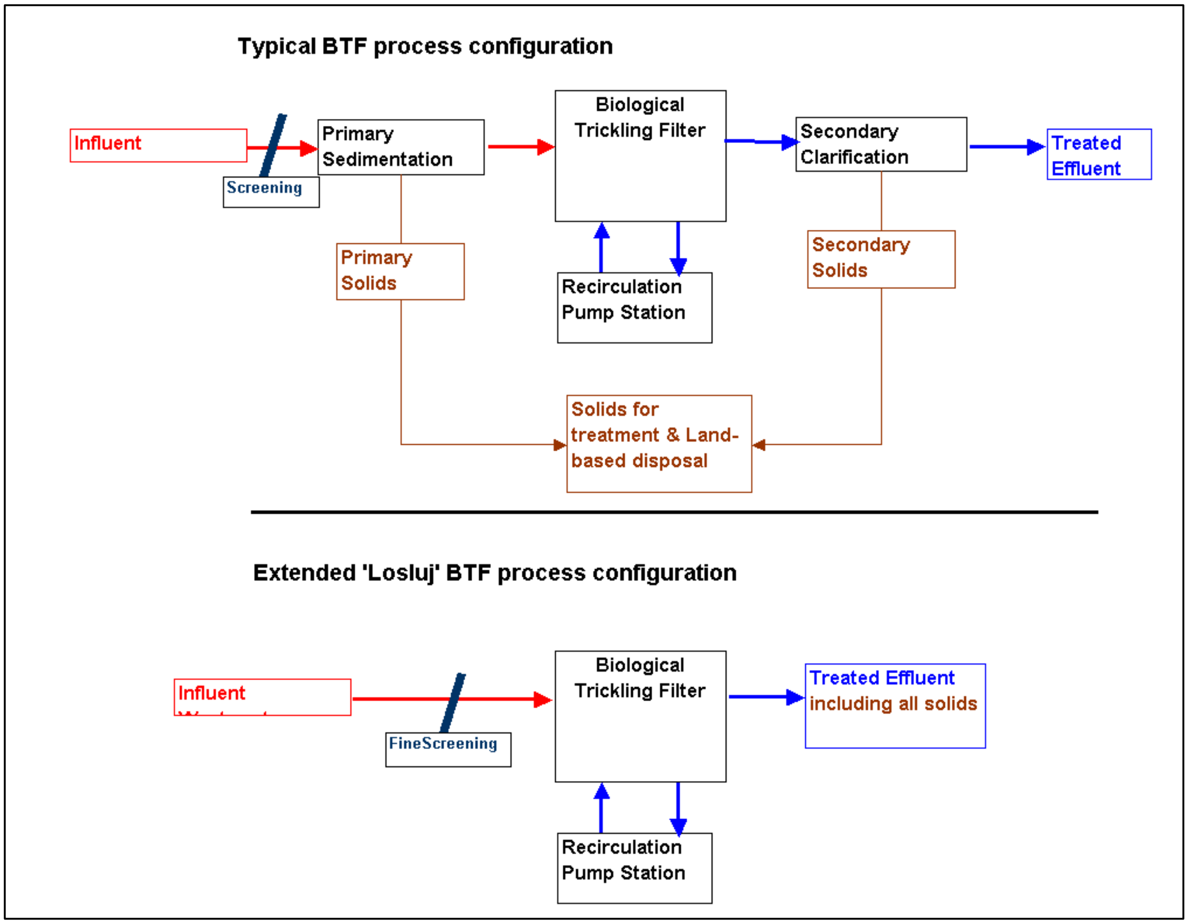
As with any biological process, bacterial growth results in surplus biomass that must be removed from the system in order to avoid process problems. Some filters operate with no primary sedimentation, but with an intermediate or secondary stage that removes the biomass and any influent solids that have passed through the filter. In these cases, fine screening is essential to avoid media clogging.

2.3 THE BTF 'LOSLUJ' CONFIGURATION

The 'Losluj' process concept arose in response to recognition of the fact that around 45% of wastewater treatment plant operational costs result from the treatment and disposal of sludge solids (Heyland and Royland, 1984). These solids handling processes can also be very resource and energy intensive, which increases the environmental footprint of a treatment facility. Omitting the primary sedimentation stage and treating settleable solids in the secondary biological treatment stage of a facility could reduce these costs. Heyland and Royland proposed that while this would increase the production of biological solids, it would reduce the net solids production by one third or more, as the yield of new bacterial mass is less than a 1:1 ratio.

The configuration proposed for the Hastings BTF was an extension of this idea. There would be no primary sedimentation, but also no secondary sedimentation. Unbiodegradable influent solids, excess biomass and particulate $cBOD_5$ unable to be degraded within the BTF retention time would be discharged direct to the existing ocean outfall. The receiving marine environment was not particularly sensitive nor used for food gathering, and environmental effects of this approach were not considered to be harmful. The Napier situation was very similar; therefore a similar treatment approach was likely to work for this community. It was decided to trial the extended Losluj configuration in a pilot plant. Figure 2 shows the difference between a standard and an extended Losluj configuration as proposed for Napier City.

Figure 2: Typical and Losluj process configurations for the BTF, showing major solids streams



3 PILOT PLANT DESIGN AND CONSTRUCTION

3.1 DESIGN CRITERIA

3.1.1 ORGANIC LOADING RATE

A BTF is primarily designed on the organic loading rate (OLR), and is defined as high, intermediate or low rate depending on the OLR that is applied. The initial basis of the BTF pilot plant design was for a loading of 0.4kg $cBOD_5/m^3$.day, an intermediate loading rate. This design came in part from Hastings District Council who received a Resource Consent for this loading in their full-scale plant; and also from Veolia, the suppliers of the Hastings BTF media. Veolia considered 0.4kg $cBOD_5/m^3$ .day loading to be at the upper limit for this media in the Losluj configuration. Nonetheless it was decided to build flexibility into this system so that different organic loading rates could be trialled. Sufficient turndown to trial a range of OLR from around 0.4kg $cBOD_5/m^3$.d to 1.0kg $cBOD_5/m^3$.d was required.

3.1.2 SOLIDS LOADING RATE

The solids loading rate (SLR) is not typically a design parameter of great importance for a BTF, because primary sedimentation removes a high percentage of the influent solids. Because there is no primary sedimentation with this BTF configuration, the solids loading rate will be significantly higher than for a typical installation and the potential for media clogging is high, along with reduced treatment performance. However, there is currently a paucity of design data, previous published research or full-scale trials documenting the effects of the SLR on BTF performance when operated in the proposed configuration. It was therefore decided to design the pilot as for a 'typical' BTF and investigate the effects of SLR at different OLR throughout the pilot study.

3.1.3 WETTING RATE

In a full scale BTF, a minimum wetting rate is required to keep the biomass sufficiently wetted and active. When the influent flow rate drops below this minimum rate, recirculation of the treated effluent typically occurs to maintain the wetting rate. Over the course of a typical day, the wetting rate caused by the influent flow will vary with natural diurnal fluctuation. The pilot plant would be required to operate either as a fixed flow system, or to follow the diurnal pattern, with recirculation to maintain the design wetting rate as required. The recycle flow contains less $cBOD_5$ (having been treated through the BTF already) than the influent and therefore dilutes the influent concentration. In addition to maintaining the minimum wetting rate, this can promote greater diffusion of $cBOD_5$ through the media.

3.1.4 SCALEABILITY OF RESULTS

A pilot plant of 4 metres diameter and 5 metres packed depth of media was specified to enable realistic results to be obtained, and to meet the original OLR criterion. Having sufficient diameter available would minimize any sidewall hydraulic effects that could result and interfere with a realistic hydraulic performance. Having sufficient media depth available was important, as carbon removal is often greatest in the upper half of the media, with the lower half performing a lesser treatment role. It would also allow the potential nitrification performance of the BTF to be assessed.

The performance of the distribution arms would be important. It is very important for a full-scale BTF to have even distribution of flow over the media to prevent sections drying out or clogging up. The distributor would be motorised to allow control over the wetting rate, and to incorporate capacity for a daily flushing cycle. A flushing cycle is necessary with BTFs to control sludge age, to remove non-readily biodegradable material and to assist in control of snails and flies. During a flushing cycle, the wetting rate is increased by increasing recycle pump speed and decreasing rotation speed of distributor arms. A functional flush cycle was considered necessary due to the potential for accumulation of "primary" solids in the media as well as excess biomass.

3.2 PILOT CONSTRUCTION

3.2.1 INFRASTRUCTURE

NCC staff made the decision to be 'hands on' with respect to the construction of the pilot plant. After considering several alternatives, it was decided to use a Timbertank™ tank filter shell. The tank for NCC has a woven PE preliner and a triple laminate PE liner and is 4 metres in diameter and 6 metres high. The tank sits on a concrete plinth approximately 1.1 m high making the overall height of the structure over 7 metres (see Photograph 1). The plinth base was graded and drains to a channel discharging into a PE tank of approximately 1400L (the BTF recycle tank). Built into the plinth are six 100 mm diameter ventilation ducts should forced air ventilation be found necessary. The interior of the tank is braced to support the distributor arm mechanism, and also to provide lateral support for the Timbertank™. These tanks are usually commissioned with a roof that supports the sides. Without a roof NCC considered a structural failure was possible and hence further bracing was included.

The PLC, air compressor and other miscellaneous equipment were housed in a 6-metre shipping container adjacent to the pilot plant.

3.2.2 DISTRIBUTOR ARMS

The four distributor arms and rotation mechanism were designed and constructed by NCC staff to ensure even wetting over the surface. Initially the exit holes were horizontal and 12 mm diameter. It was found that these holes blocked with fibrous material, most probably primary solids in the form of toilet tissue, and therefore the arms were replaced with new arms with fewer 20 mm holes exiting vertically. The distributor mechanism is powered by an electric motor on VSD drive, and has sufficient turn down to allow for a range of dose rates and a daily flushing cycle to be applied.

3.2.3 FILTER MEDIA

The selected filter media was Veolia Cascade Filterpak YTH 1120. This media was part of the consignment to the HDC full-scale plant. It was decided to use this media on the basis that it was readily available, cost-effective and results from a trial using this media could be more readily extrapolated to the use of structured media than vice versa. This media is manufactured from polypropylene, has a surface area of $100m^2/m^3$ and a void space of 95%. The dimensions are 187x51 mm.

3.2.4 INFLUENT

It is important to ensure the influent to the pilot plant is representative of what the full size plant will see. In Napier's case the full size BTF plant will only treat domestic effluent and non-separable industrial effluent. Napier is fortunate that much of the separation reticulation is in place and so a source of representative effluent was available at the proposed sewage treatment plant site in Awatoto. This was achieved by tapping into one of the pump trunk mains that bring domestic wastewater to the Awatoto site. A 0.75m parabolic screen is used to replicate the full-scale milliscreening plant.

3.3 PROCESS CONTROL

It was considered important that the pilot plant control system reflect the major functions of a full-scale plant. The pilot plant is controlled by a PLC linked to the main milliscreen control panel. To that end, full functional descriptions were prepared for the pilot plant and NCC staff implemented these in the local PLC. All functions of the pilot plant feed pump, recycle pump, distributor arm rotation speed and air sparge can be controlled. Flow to the pilot plant can also be linked to the total wastewater flow to the milliscreens so that true diurnal flow patterns can be tested.

Photograph 1: The Napier Pilot Plant, clockwise from left: pilot plant infrastructure, distributor arms and random dump media, PLC control system

3.4 PROCESS DESCRIPTION

Raw wastewater from the Awatoto trunk main passes over a 0.75mm static parabolic screen. The screened wastewater flows to the 1400L PE BTF feed tank. Filling of the feed tank is controlled by float valves, which operate an actuated valve on the trunk main. From here the wastewater is pumped to the BTF. The wastewater then passes through the BTF and the biodegradable material is treated by the biomass established on the media surface. After passing through the BTF, the wastewater flows into a 1400L PE recycle tank. Effluent from the recycle tank is then pumped back over the BTF to maintain the desired feed: recycle ratio and media wetting rate. Effluent from the BTF pilot plant not used for recirculation is discharged to the sump used by tankered liquid waste dischargers. Both the feed tank pump and the recycle tank pump can be VSD controlled, linked to flow meters on each line. Both tanks have air sparge systems installed in the bottom of the tank to assist in keeping organic matter in circulation.

4 PILOT COMMISSIONING AND INITIAL OPERATION

4.1 COMMISSIONING

The initial start-up phase intended to run the plant for several weeks to allow biomass to develop. After the development of the biomass the regular flushing cycle would commence.

The pilot plant was started at 1.2L/s feed and 2.4L/s recycle, with a distributor arm speed of 325 sec/revolution, equating to an SK value of 23 mm/pass. This is at the lower end of the typical SK value for a BTF loaded at this

OLR but slightly higher than initially recommended by the media supplier, due to concerns that the lack of primary sedimentation would results in solids accumulation in the filter media.

Initial growth of biomass on the media was good and COD removal rates were encouraging. Solids removal rates were about 40%. About four weeks after start-up, the quality of BTF effluent began to deteriorate and it became apparent that there was an excess of fibrous non-readily biodegradable matter (probably toilet tissue) on the media (Photograph 2). Clogging and clumping of matted material was observed on the media. Although a BTF is traditionally commissioned without using a flushing cycle in order to provide for more rapid establishment of the biomass, operating without primary sedimentation means that influent solids have the potential to accumulate, particularly within random media where the potential for hydraulic constrictions exists due to the large amount of horizontal surface area. At six weeks after start-up the BTF effluent quality was consistently poor. The decision was made to completely flush the BTF and recommission the plant.

Photograph 2: Media showing accumulated clumps of material after the 4 week start-up period with no flushing cycle. The clumps primarily consist of fine fibrous solid matrix, around which additional material, including bacterial mass, has built up.

The pilot plant was started again but this time with a daily flushing cycle. The flow regime was a constant 1.2 L/s feed and 2.4 L/s recycle, i.e 1:2 feed/ recycle ratio, with a daily three-hour flush cycle. During the flushing cycle the rotational speed of the distributor arms was reduced from 325s per revolution to 1300s per revolution and the feed/ recycle ration increased to 1:6 increasing the SK value from 23 to 95 mm/pass. The distributor arm gearbox used meant that further turndown was not possible. A glitch in the PLC code was also discovered which meant that the specified dose rate was not being achieved, and this was remedied. The plant biomass developed and the BTF ran satisfactorily at this regime.

4.2 INITIAL OPERATING PERIOD

In order to obtain data to support an application for a Resource Consent and to gain confidence and knowledge about running a BTF, the flow and load regime described above was left in place for about eight months.

4.2.1 DATA COLLECTION METHODOLOGY

Collection of data from a pilot trial can be both time consuming and costly. NCC wanted to put in place sampling that would be similar to that which would be undertaken in a full-scale plant for process control. In addition, the sampling needed to provide data to support a consent application and provide knowledge of this process. Due to the novel nature of the extended Losluj configuration, there was scepticism in some quarters as to what the overall discharge quality from such a plant might be.

The quality of Napier's domestic sewage was relatively well known due to pilot studies undertaken some years previously, and from this an approximation of flow rates necessary to achieve the specified OLR had been developed. It was also decided to install an online instrument (scanning spectrophotometer) to gain more complete and dynamic information on the influent quality once the pilot was operational. In addition to providing information for the pilot operation, this would facilitate full-scale design and assist in preparing the Resource Consent application.

The BTF plant would be installed to assuage or meet cultural and social concerns, and the key parameter of interest for this was biodegradable organic carbon. To provide ongoing process analysis data, a sample was taken at approximately 7 am each weekday morning from the influent and effluent and analysed for suspended solids, settleable solids and for COD. These tests were chosen because they are inexpensive, provide good control information and results are obtained quickly.

In addition to the daily sampling, twice per week samples were taken for $cBOD_5$, filtered $cBOD_5$, COD and filtered COD. The $cBOD_5$/COD samples enabled a ratio to be developed and the filtered $cBOD_5$ and COD was of interest to investigate the hypothesis that a BTF removes significant levels of filtered $cBOD_5$. Sampling also occurred over 24-hour periods when a wide range of analytes were chosen, and also during the flush cycle.

NCC identified that the flushing cycle was an area of concern for some members of the public due to the large amount of solids material discharged through the outfall over a short period of time. During the flush cycle, samples were taken every 15 minutes and analysed for suspended solids and COD. For this first part of the trial the flush cycle was run from 1000 hrs to 1300 hrs so that any measurements could be during daylight hours (under normal operation the BTF would be flushed in the early hours of the morning when influent flows are lowest).

Other sampling was undertaken to provide a full suite of results should questions be raised during the consenting process, and to determine the level, if any, of removal that would occur through the BTF. Major analytes included ammonia, nitrates, sulphide, heavy metals, oil & grease, bacterial content on influent and effluent; and settleability on the biosolids discharged during the flushing cycle.

4.2.2 COMMUNITY INVOLVEMENT

Several open days were conducted where members of the public were able to view the pilot plant in operation, and could ask NCC and consultant staff questions about the plant and process. An open day was also arranged during a flush cycle so that interested public could view that function.

5 ONGOING PERFORMANCE EVALUATION

5.1 PARAMETERS OF INTEREST

5.1.1 ORGANIC LOADING RATE

The Organic Loading Rate (OLR) is of key interest for the following reasons:

- **Financial –** The higher the OLR, the less media volume will be required, with a resulting saving in capital expenditure. This will be generated not only from savings in media volume, but also potentially from smaller process units, requiring smaller associated civil and mechanical works. If good performance can be maintained at a higher OLR, there is an opportunity to meet the aims of the scheme for a reduced capital cost.
- **Technical -** For a BTF operated without primary or secondary sedimentation; performance at different OLR is of great interest as the existing knowledge base is small.
- **Operational –** Operation under different seasonal conditions is also highly important, as the established biomass will react differently not only to differences in environmental conditions, but to differing influent and recycle flow rates.
- **Media –** The NCC BTF uses random dump media, which is less suited for higher OLR than structured media, due to the possibility of increased solids causing blockages across the horizontal services. Can this media cope with a higher OLR? What operational parameters need to be altered from accepted design standards?

- **Community expectations** – The BTF plant would primarily be installed to meet social and cultural considerations regarding wastewater treatment, transforming the human component of wastewater into bacterial mass. One way in which it might be possible to quantify this transformation is via the level of $cBOD_5$ removal through the filter. It was key to investigate whether the process could remove similar levels of $cBOD_5$ at different OLR. If performance at a higher OLR was poor, then a lower OLR may need to be specified so that community expectations regarding the level of treatment could be met.

The average organic loading rate applied to the filter since commissioning is 0.27 kg $cBOD_5/m^3.d$, which includes a period of lower loading during initial start up. For the period between 1 September 2008 and 3 February 2009 the average loading rate was 0.44 kg $cBOD_5/m^3.d$. Following on from the initial operating period, the investigation of performance of the BTF at different organic loading rates commenced. At the end of May 2009 the organic loading rate was increased to a nominal 0.6 kg $cBOD_5/m^3.d$.

5.1.2 FLOW REGIME AND WETTING RATE

For the first 8 months of operation, the pilot plant operated on a fixed influent and recycle flow regime. Whilst this was acceptable for initial commissioning and for general assessment of performance, it became necessary to operate the pilot on a flow regime that more accurately reflects the reality of diurnal flow conditions.

A standard diurnal profile was developed (using fixed flow steps) that simulated a typical Napier diurnal profile. This diurnal profile was "adjusted" in the first instance to allow the daily flushing cycle to be observed by the community. This had the effect of reducing the overall organic load onto the filter slightly, as peak flows to the pilot did not coincide with diurnal peaks to the milliscreen plant and organic load concentrations vary during the day.

After these observations had been made, the flow was put onto fully automatic control (July 2009), with the feed flow being a percentage of Napier wastewater inflow, and the recycle pump controlled to maintain a desired wetting rate.

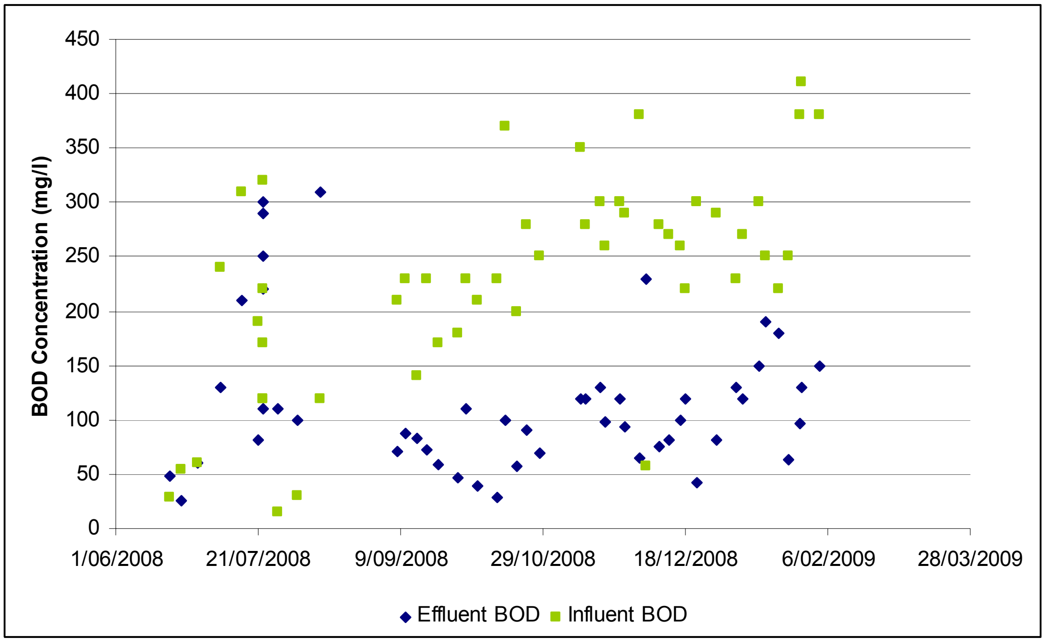
6 RESULTS

6.1 REMOVAL OF ORGANIC MATERIAL

6.1.1 SAMPLING RESULTS

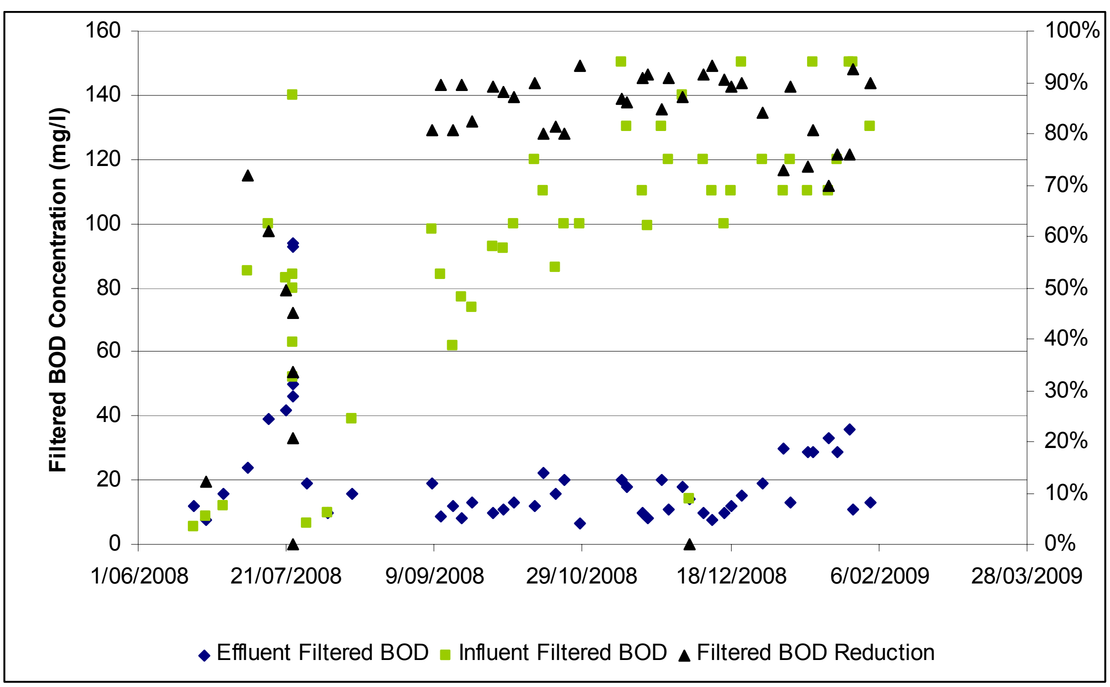
The variation of influent and effluent $cBOD_5$ for the operating period to date is shown in Figure 3. The commissioning period of around two months, between June 2008 and August 2008, shows highly variable effluent quality. This variability is attributed to the initial growth of the biofilm, the media clogging as described above, and the lack of a flushing cycle. Once the pilot was recommissioned, the effluent quality improved and remained more consistent with the median effluent $cBOD_5$ for the period since 08 September 2008 being 100 mg/L. As a comparison, the Hastings District Council (2005) consent application reported expected effluent total BOD in the range 50 – 60 mg/L. Total $cBOD_5$ removal at the Napier pilot plant for the same period averaged 60% and was generally lower than that reported for the Hastings DC pilot plant (approximately 75% - 88%).

Figure 3: Variation of influent and effluent $cBOD_5$.



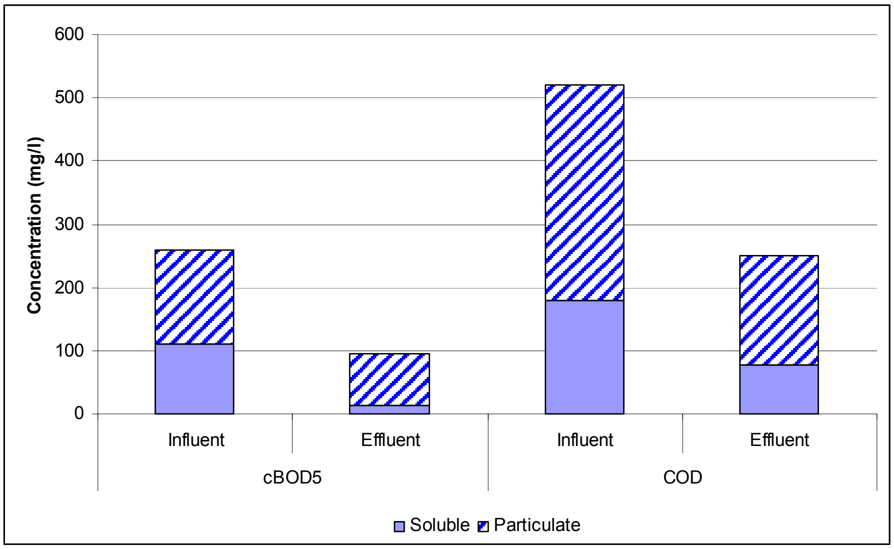
For the period after 08 September 2008, the removal of filtered $cBOD_5$ across the filter has been consistently above 80% (Figure 4). The effluent filtered $cBOD_5$ for this period was between 7 mg/L and 36 mg/L and the median value of 13 mg/L was comparable to the expected concentration of 13 mg/L reported by Hastings District Council (2005).

Figure 4: Variation of influent and effluent filtered cBOD5



For the period of stable operation (after September 2008) there is a clear reduction of organic material, measured as average $cBOD_5$ or COD, across the trickling filter (Figure 5). The overall reduction is due to reductions in both the soluble and particulate organic material although, as expected, there is a lesser reduction in particulate material.

Figure 5: Change in concentration of organic material across the trickling filter.



6.1.2 DISCUSSION

While the total $cBOD_5$ reduction is lower than that reported for the Hastings pilot, there are many unknowns in how the data from that study was collected and analysed and a direct comparison is not possible at this time.

The high concentration of volatile but non-readily biodegradable influent solids in the Napier wastewater (thought to be toilet tissue, which would typically be removed during a primary sedimentation process) that pass through the BTF may entrain particulate $cBOD_5$. In order to ensure these solids do not accumulate in the media, a flushing cycle is very necessary, as demonstrated during the initial commissioning period. Therefore particulate $cBOD_5$ may be flushed out along with these solids. In addition, at the design OLR, there was not a great deal of evidence of established biofilm growth in the filter. Photograph 3 shows media collected from different depths through the filter. There is strong algal growth at the top of the filter. Further down in the filter, a very thin film of biomass replaces the algae. It is postulated that this biomass is established primarily in response to the soluble $cBOD_5$. Whether the biomass comes onto contact with the particulate fraction will depend on the flow path of influent wastewater through the random media. Due to the large amount of horizontal surface area on this type of media, it is possible that due to a regular cycle of entrainment of $cBOD_5$ in primary solids and subsequent flushing, contact between the established biofilm and the particulate $cBOD_5$ might be limited.

Photograph 3: Media collected from different depths of the BTF. Closest petal is from the top of the filter, showing strong algal growth.

Where the wastewater contains a high level of soluble $cBOD_5$, a BTF operated in this configuration at an OLR of 0.4 kg $cBOD_5$ /m^3.d gives good treatment performance, with high overall $cBOD_5$ removal. As the particulate fraction of a wastewater increases, total $cBOD_5$ removal may decrease due to the difficulty of retaining the particulate $cBOD_5$ in the BTF for long enough, or establishing sufficient contact between the biomass and this fraction.

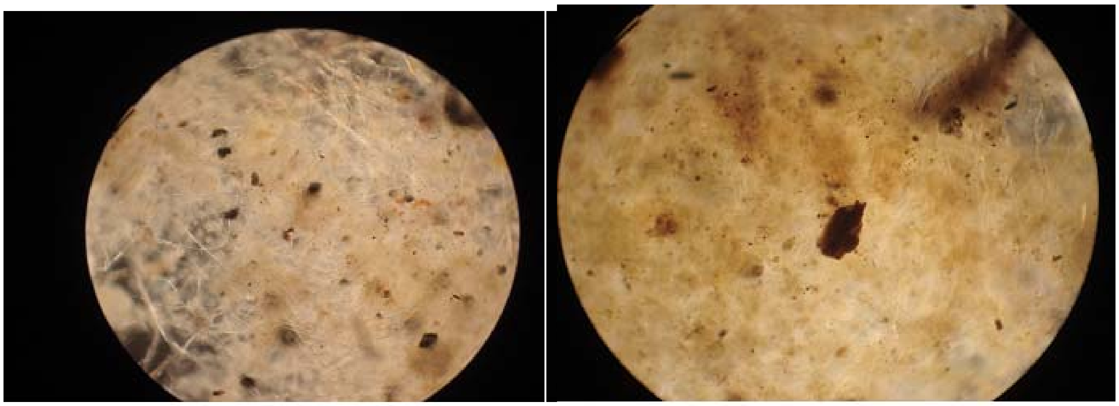
The level of treatment achieved by the Napier BTF at the OLR of 0.4 kg $cBOD_5$ /m^3.d was considered sufficient to achieve community expectations.

6.2 VARIATION OF TOTAL SUSPENDED SOLIDS (TSS)

6.2.1 EXPECTED REMOVAL

The concentration of suspended solids in the effluent was less important for this configuration than the transformation of wastewater into new bacterial mass. Indeed, because of the non-biodegradable nature of a high proportion of Napier influent volatile solids (shown in Photograph 4), and the fact that the soluble organic carbon is being transformed into additional solids, it was not expected to achieve significant solids removal.

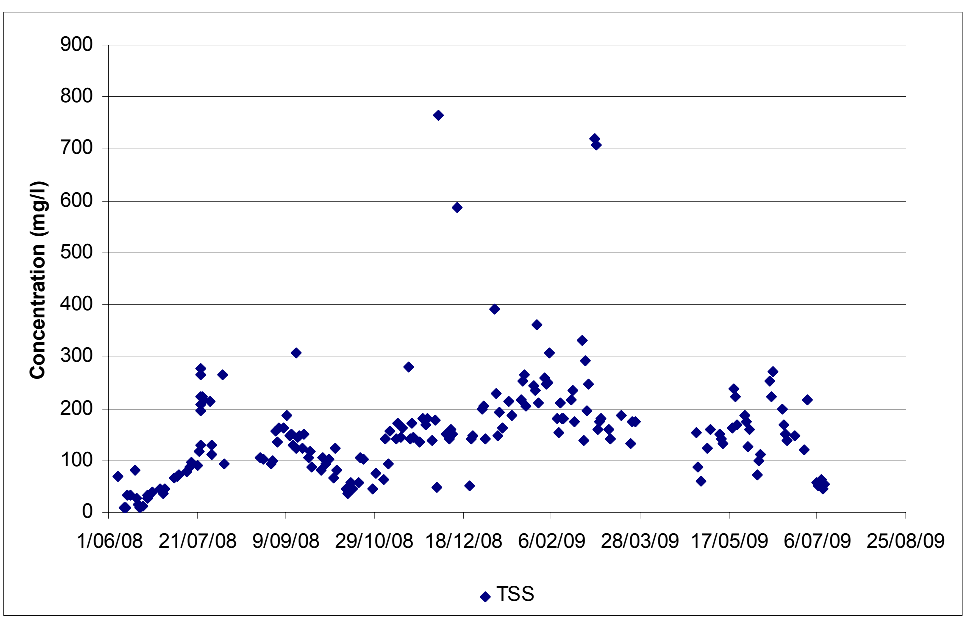
Photograph 4: Low magnification microscopy showing a matrix of fine fibrous solids present in both influent (left) and effluent solids sample. These solids are volatile, but not biodegradable in the BTF, and thus pass through it



6.2.2 SAMPLING RESULTS

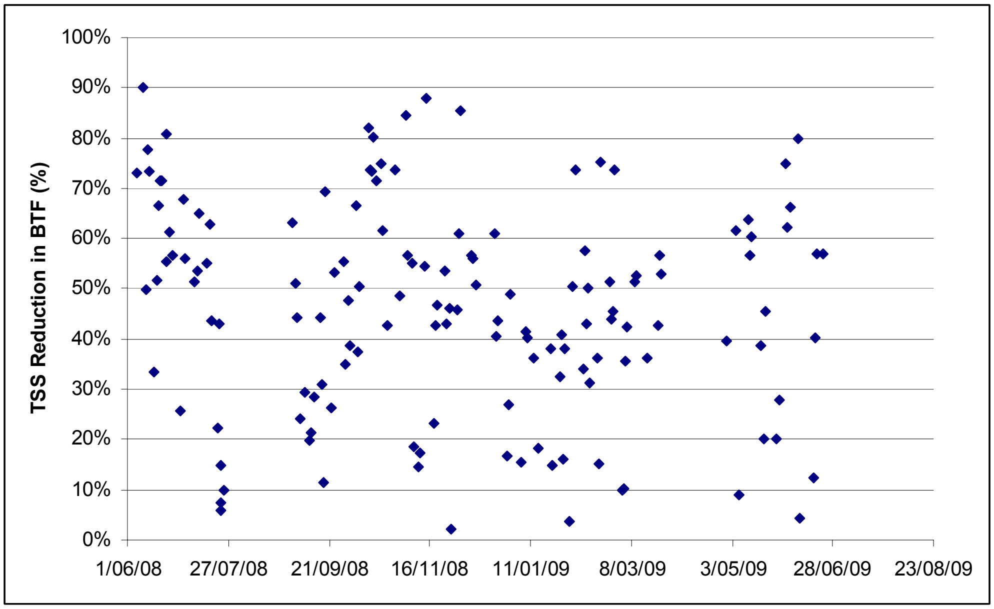
The effluent TSS data for the duration of the trial so far are shown in Figure 6. For the initial commissioning period, the dosing and flushing intensities had not been optimised and solids were accumulating in the filter. These solids were flushed through and the plant put back in to service with the recommended dosing intensity and flushing routine. Since then, the effluent solids concentration has generally remained around 150 mg/l, which is in accordance with the expected effluent quality of 120-160 mg/l reported in the Hastings resource consent application.

Figure 6. Variation in effluent TSS following initial commissioning.



There is no consistency in the percentage reduction of TSS across the trickling filter (Figure 7), which could be attributable to a number of causes including accumulation of solids in the filter followed by washout of solids, a high proportion of non-biodegradable solids in the influent or a high soluble organic load in the influent contributing to higher solids production. All of the samples were grab samples, so the timing of sloughing of solids influences the solids content.

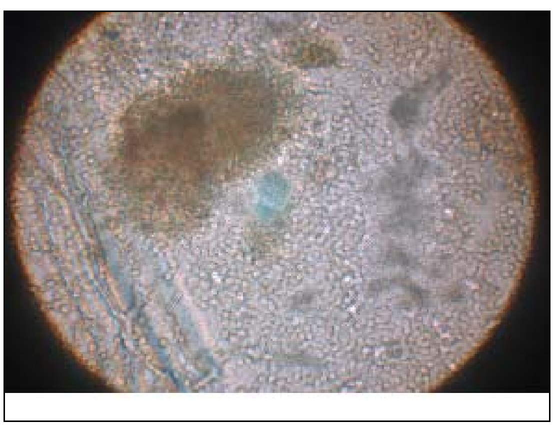
Figure 7. Reduction of TSS in BTF. There is no discernible consistency in the removal achieved.

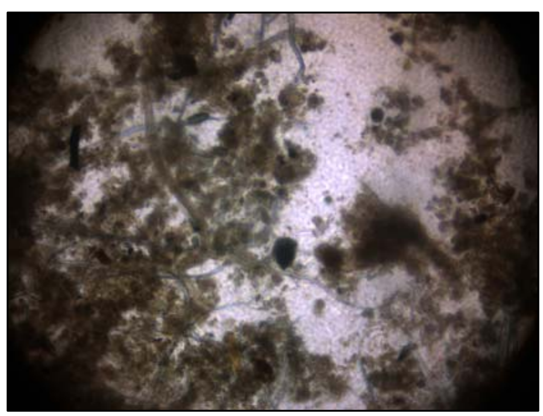


6.2.3 TRANSFORMATION OF SOLIDS

It was necessary to attempt to demonstrate that the influent wastewater was being transformed into new life forms, as this was the basis of the process. Photograph 5 shows the difference between influent (screened) solids and BTF effluent solids using high magnification microscopy. There is a large increase in bacterial numbers, and in the quality of bacterial content. Excellent bacterial flocking is shown, with > 85% of the field of view covered. This clearly shows the difference in character between the samples, which is not so obvious at lesser magnifications

Photograph 5: High magnification microscopy of influent (left) and effluent solids samples





6.3 COMPARISON WITH INDUSTRY DESIGN EQUATIONS

A number of empirical models to define trickling filter performance have been developed, although most of these are based on having final clarifiers installed after the trickling filter. It was of interest to assess how suitable these equations are for adapting to the extended Losluj configuration, as they typically do not take into account the SLR. The pilot plant was of sufficient scale to enable this to be done.

Using the Germain equation, developed for trickling filters, and a design approach for a trickling filter – solids contact process as outlined in Metcalf & Eddy (2004), predicted effluent quality was calculated for each influent sample and compared to the actual effluent data.

$$\frac{S_e}{S_o} = e^{\frac{-kD}{q^n}}$$

Equation 1. The Germain equation, an industry standard empirical model for BTF design

Where:

S_e - $cBOD_5$ concentration of settled filter effluent, mg/L

S_o - Influent $cBOD_5$ concentration to the filter, mgL

k - Wastewater treatability and packing coefficient, $(l/s)^{0.5}/m^2$ (based on n=0.5)

D - Packing depth, m

q - Hydraulic application rate of primary effluent, excluding recirculation, $L/m^2.s$

n - Constant characteristic of packing used

Standard industry coefficients for domestic wastewater were used, with an influent temperature of 15^{o}C. The model does require temperature correction, but did not show much sensitivity to variations in temperature that are industry standard for biological carbon removal (i.e. 15 – 20 ^{o}C) The results (Figures 8&9) show a reasonable correlation between the theoretical and actual effluent quality, with a tendency to under rather than over predict the effluent solids slightly, which is consistent with the fact that the model does not take into account the non-biodegradable fraction of solids. This demonstrates that empirical models could be used to estimate the effluent quality for a BTF plant operating in this way, at the organic loading rates of 0.4 and 0.6 kg $cBOD_5$. As the solids loading rate to the filter increases with increased organic loading rate, it is expected that it may have an increasingly distorting effect on the empirical model and standard coefficients may need modification. It is intended to assess the suitability of the empirical model at higher OLR as the pilot testing programme continues.

Figure 8. Comparison of Measured TSS in BTF Effluent and TSS predicted using Empirical Model

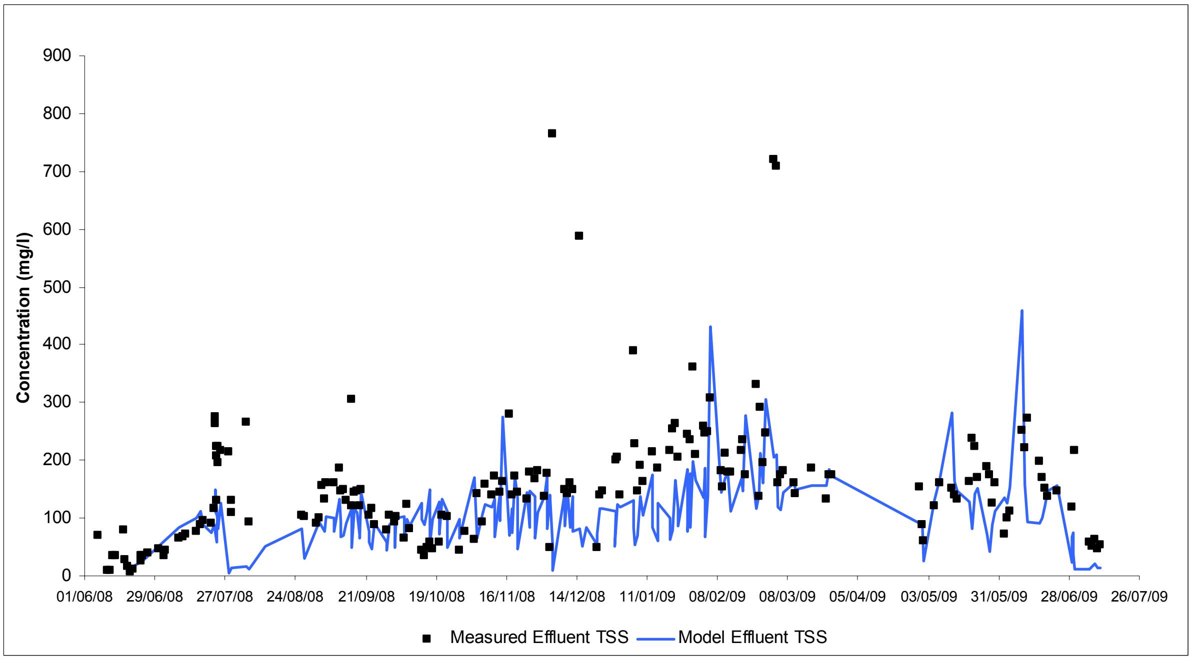
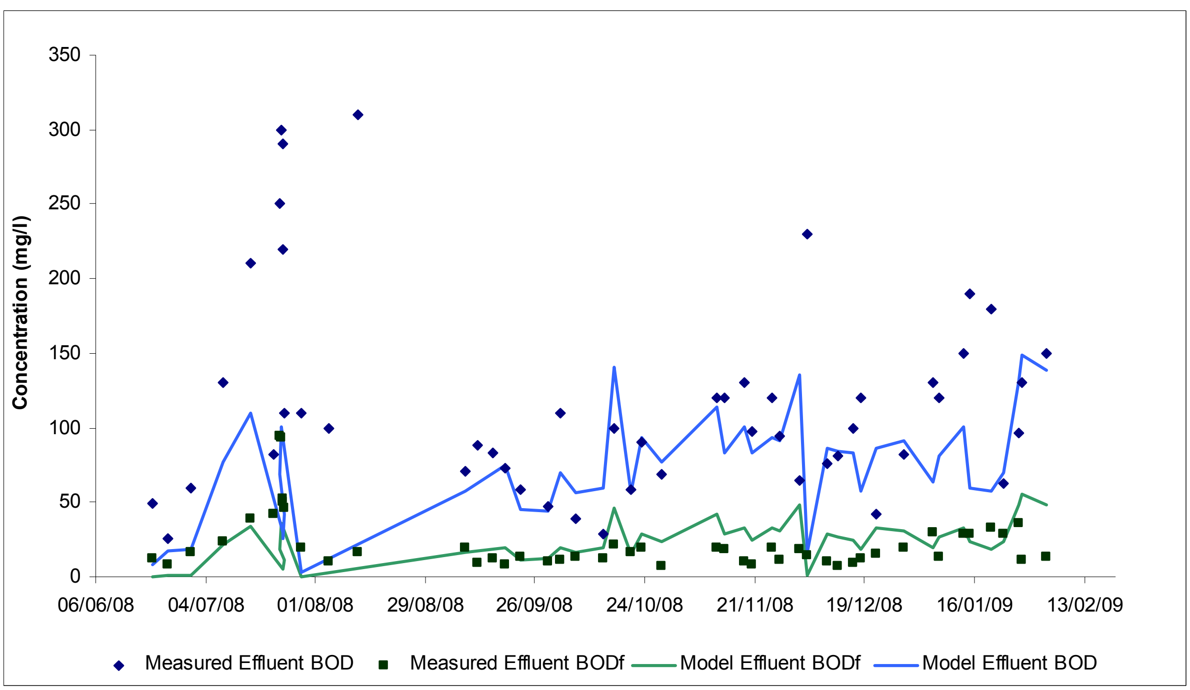


Figure 9. Comparison of Measured BOD in BTF Effluent and BOD predicted using Empirical Model



6.4 ONGOING PILOT TESTING

6.4.1 INCREASED ORGANIC LOADING RATE

For the period 26 May 2009 to 10 July 2009, influent and effluent COD and TSS analysis has been carried out to assess the impact on performance of the change in organic loading rate. The average results are summarised in Table 1 from which it can be seen that there is little change in the COD reduction between the two loading rates. The solids reduction appears to have decreased since the increase in organic loading rate which could be due to increased biomass yield at the higher loading rate, increased non-biodegradable solids over the plant, reduced breakdown of influent particulate material or a combination of all. A further factor could be the apparent cycle of solids accumulation and washout. Further operating data at the higher organic loading rate is required to confirm the change in solids reduction.

Table 1: Performance Variation of BTF with Organic Loading Rate

Parameter	**Unit**	**Organic Loading Rate (kg $cBOD_5/m^3.d$)**	
		0.4	**0.6**
Influent COD	mg/L	499	392
Effluent COD	mg/L	264	214
COD Reduction	%	48	53
Influent Solids	mg/L	227	184
Effluent Solids	mg/L	148	142
Solids Reduction	%	43	28

6.4.2 ONGOING RESEARCH

The pilot will continue to be operated over the next 12 – 24 months, including when the full scale plant becomes operational, in order to provide a comparison between the pilot and full-scale operations. Results from the pilot will be used to eventually select the design Organic Loading Rate. In addition to the organic and solids loads, nitrification performance and pathogen removal are future parameters of interest.

7 CONCLUSIONS

The pilot study has been invaluable in assessing the suitability of this process for the Napier Community. To date it has demonstrated that the extended Losluj configuration can be successfully operated at a design organic loading rate of 0.4 kg $cBOD_5/m^3.d$, in terms of satisfying community expectations of transformation of human waste into bacterial biomass. Organic carbon removal through the process is good, and of the order expected in a BTF loaded in this way. Particulate removal may be restricted by the presence of influent solids that would otherwise have been removed with primary sedimentation, particularly at higher organic loading rates. The potential for solids accumulation in the media must be mitigated with suitable dose rates and a daily flushing cycle.

NCC staff strong involvement in the project has given them confidence in the process and a good understanding of how the full-scale plant will function. By involving the community in the study, wider understanding has been developed, leading to greater acceptance of the aims of NCC with respect to its overall wastewater strategy. An application for Resource Consent is currently being prepared for the BTF process.

Research will continue to assess how best to operate the pilot under different flow and load regimes.

ACKNOWLEDGEMENTS

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