LOSS OF SUPPORT FROM BELOW – FAILURE OF WASTEWATER TREATMENT LAGOON

Azam Khan & Neil Crampton - Pattle Delamore Partners Ltd, Auckland

ABSTRACT

One of the continued risks for operating and managing lagoons and earthen storage structures for wastewater treatment systems is the structural integrity of the embankments.

A food processing plant became the victim of a sudden collapse of an embankment of an existing anaerobic lagoon as a result of collapse and expansion of a nearby sinkhole or tomo. The breach in the pond embankment resulted in the release of effluent into the nearby stream via overland flow and via underground flow through a natural tunnel system in limestone that underlies the site. The discharge affected the water supply of a rural township for several days.

This paper explains the risks identified at the site, it also outlines the likely mechanism of failure and the post failure mitigation undertaken by the owner of the treatment plant.

Various resource consents were applied for and granted post failure to allow minor residual discharges through the natural system to continue into the nearby stream. This allowed the owner to sustain its business activities while remediating the site.

KEYWORDS

Wastewater, lagoon, failure, karst, tomo, sinkhole

1 INTRODUCTION

A Waikato based meat processing plant operates a sheep/bobby calf meat processing and integrated rendering plant on the outskirts of Te Kuiti Township in South Waikato. The wastewater from the site is collected and then treated on-site in a lagoon based biological wastewater treatment system. The wastewater treatment system comprised three anaerobic lagoons and a sequencing batch reactor (SBR) lagoon. The final treated wastewater discharged into the Waitomo District Council sewer system as a trade waste.

On the night of 9 - 10 March 2007, ground cracking around an existing sinkhole (tomo) depression breached the integrity of one of the anaerobic lagoons. Wastewater flowed out of anaerobic lagoon through the failure crack system into the sinkhole, essentially emptying the lagoons of its liquid contents and partly emptying a connected lagoon. Partially treated wastewater subsequently entered the Mangaokewa Stream via surface and underground flow paths from the sinkhole.

The meat processing plant is located on a secondary ridge near the bottom of the Mangaokewa Stream valley approximately 2 km south-east of Te Kuiti. The meat processing plant and the wastewater treatment system are shown in Photo 1. The anaerobic lagoons at the site are located on elevated ground approximately 200 m north-east of the meat processing plant and the SBR is located adjacent to the north-east edge of the plant area.

Prior to the failure, the primary screened effluent was pumped into the northern corner of Pond 1 and flowed into Pond 2 via an open channel located at the southern corner of Pond 1/Pond 2 embankment. The anaerobic treatment in Pond 1 relies on various biological processes to allow reduction of biochemical oxygen demand and mineralisation of proteins. These processes also involve spatial changes in pH in the pond. Wastewater from Pond 2 was piped under gravity to Pond 3 and subsequently down to the SBR. All anaerobic lagoons are unlined, but the SBR is fully lined.

Photograph 1: Aerial Photo Showing Meat Plant – Te Kuiti

The operational wastewater level in Ponds 1 and 2 were similar because of gravity flow, and around 12 m above the base of the nearby sinkhole depression. The operational level of Pond 3 is approximately 3 m lower than that of Ponds 1 and 2. The outside embankments of both Ponds 1 and 3 drop steeply into the tomo depression with large trees and a retaining wall located on the Pond 1 embankment.

The topography of the site has gently to moderately sloping ground with some broad gullies and rounded ridge crests. The regional geology indicated that the site is overlain by upper Te Kuiti Group limestone and calcareous sandstone with basement sandstone/siltstone (greywacke) at depth (Edbrooke, 2005). Investigations indicate the geology immediately beneath the meat plant's wastewater treatment lagoons area is likely to comprise a very thin layer of siltstone/mudstone overlying limestone. Soils at the site are typically volcanic ash, weathered siltstone and/or slope colluvium.

2 LAGOON COLLAPSE ASSESSMENT

2.1 KARST FEATURES AND PRESENCE AT THE SITE

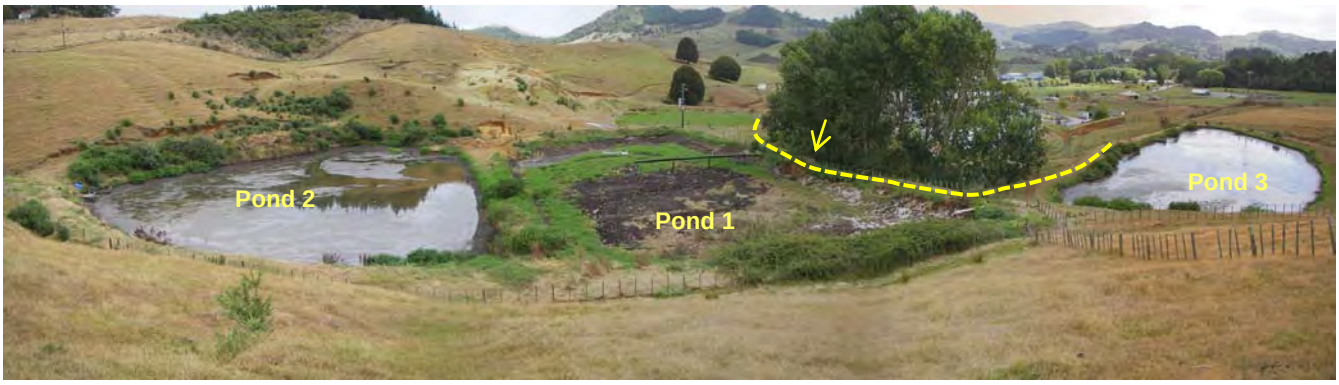
Karst refers to a set of physical conditions, landforms, and bedrock attributes that can be present in areas underlain by bedrock that is soluble in water. In the South Waikato region, especially in and around Te Kuiti, features occur in areas underlain by limestone.

The karst areas often have low density of surface water drainageways, closed depressions with internal drainage, sinkholes, thin soils, hard groundwater and bicarbonate chemistry in streams. Water is the controlling factor in the development of karst features. Groundwater in a mature karst region generally flows through bedrock joints and solution conduits that form an interconnected, horizontal drainage system underground. This drainage system is further enlarged by the effects of hydraulic erosion and scouring resulting in underground caverns that are supported by bridging of soil and/or rock.

Sinkholes are a typical surface feature in karst areas. A sinkhole is a hole formed by localised (gradual or rapid) sinking of the land surface into an underground cavity; it is characterised by a roughly circular outline and a distinct break in the land surface. Sinkhole depressions (tomos) are present at ground surface in and around the property. The main sinkhole at the site of interest occurs adjacent to Ponds 1 and 3 (see Photo 1). The tomo is approximately oval shaped being about 30 m across (NW/SE direction) and about 40 m long (SW/NE direction).

2.2 SINKHOLE COLLAPSE

The collapse of the sinkhole was significant as all the liquid from the main anaerobic lagoon (Pond 1) drained in addition to some liquid from Pond 2 that was hydraulically connected to Pond 1. A series of photos taken post-failure show the extent of the cracking around the anaerobic lagoons.



Photograph 2: Anaerobic Lagoon (Pond 1) showing the cracking line and scarp (arrow)

A fissure up to 1 m wide and 3 m deep formed around the southern part of the sinkhole crack system and locally between Pond 1 and 3. An example of the large fissure near the sinkhole is shown in Photo 3.

Photograph 3: Fissure Formation near the Sinkhole

The predominant scarp that formed on the inside embankment of Pond 1 is shown in Photo 4.

Photograph 4: Pond 1 Scarp on the inside Embankment

2.3 FAILURE ASSESSMENT INVESTIGATIONS

A series of engineering geology investigations (PDP, 2007a) were carried out soon after the failure to determine the cause of the collapse. These included failure mapping, failure movement monitoring, limestone outcrop mapping, historical aerial photograph interpretation, and geophysical investigation including resistivity imaging and ground penetrating radar.

A detailed inspection of all failure features (mostly ground cracks) was carried out to determine the nature and extent of the failure. The failure features were marked with spray paint, surveyed and details such as crack openness and displacement were recorded. This information was then compiled onto an engineering geological map (Figure 1).

Monitoring lines were set-up to measure immediate post-failure slope movement and to identify gross slope movement over a period of time. No movement, outside the margin of error had been recorded at the monitoring sites for a period of 2 months after the collapse.

A programme of geophysical investigations including resistivity imaging and ground penetrating radar (GPR) was carried out following the pond failure. Investigation of preferential groundwater pathways between the tomo and the Mangaokewa Stream as well as investigation of subsurface conditions in other parts of the property was carried out. The geophysical investigations were also undertaken to confirm the path of sinkhole and spring connection.

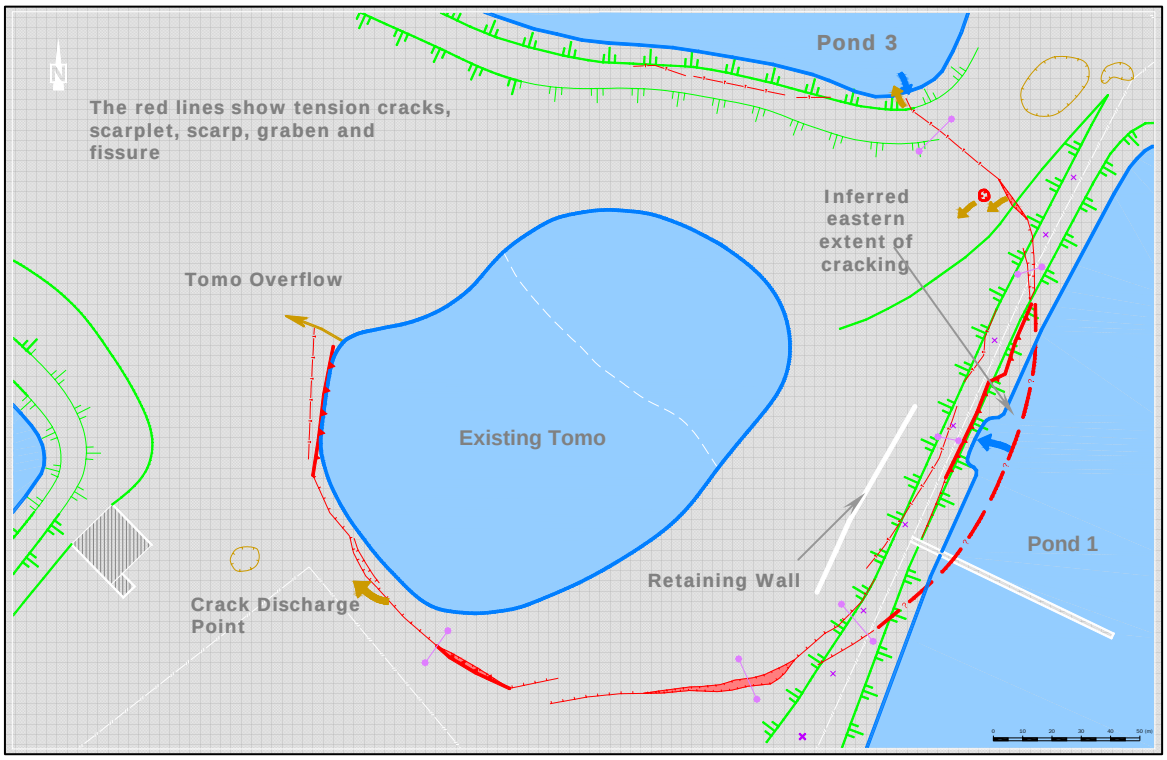


Figure 1: Failure Mapping around the Sinkhole

The investigations carried out indicated that once the failure occurred, the crack system, shown in Figure 1, opened progressively allowing the Pond 1 wastewater to flow south into the cracks. The wastewater flowed down and exited the fissure system near the sinkhole, discharging overland into the sinkhole as shown in Photo 3. There was also a small amount of wastewater that flowed from Pond 1 into Pond 3 and then discharged into the sinkhole through a "discharge hole" between Pond 1 and Pond 3. Wastewater from the crack system filled and over-topped the sinkhole and discharged to Mangaokewa Stream via the site's stormwater drains. Wastewater also flowed through the base of the sinkhole into the underground tunnel system linking the sinkhole with a spring daylighting between Rangitoto Road and Mangaokewa Stream some 350 m directly south-west of the sinkhole. The water level in the sinkhole dropped slowly in the days following the failure.

Information gathered from the investigations indicated that the most likely mode of failure was expansion of the existing sinkhole due to collapse of supporting limestone into the underground tunnel system. Surface displacements indicate that the total amount of failure movement is likely to have been between 1 - 3 m. The main evidence supporting this failure mode is the oval shape of the crack system formed by the failure, its similarity to the existing sinkhole shape and its location around the existing sinkhole (Figure 1). Additional evidence was extension/opening being the principal movement component associated with the failure cracks. This suggested inward rotation (almost toppling) into the existing sinkhole cavity due to loss of support from beneath.

Other modes of failure were considered including slope failure of the Pond 1/sinkhole embankment and new tomo formation. The embankment failure mode was rejected because of the shape of the cracking, the absence of toe bulge or other signs of ground stress at the base of Pond 1 embankment and the predominant extensional cracking rather than lateral movement. The position of the failure cracking around the existing tomo points to expansion of the existing tomo rather than formation of a new tomo.

The trigger mechanism for the failure is not certain. However, collapse of the supporting limestone around the existing sinkhole is inferred to have been due to natural dissolution of the limestone by groundwater flowing through the underground tunnel, flow through the link zone between the tunnel and the sinkhole floor and percolation of rainfall down through the limestone.

There is a possibility that if Pond 1 was leaking, percolation of low-pH partially treated anaerobic effluent down through the limestone to the underground tunnel system could have caused accelerated dissolution of limestone. There was, however, no evidence to support this mechanism, for example, a change of vegetation diversity

where the underground water daylights near Mangaokewa Stream due to wastewater nutrient enriched spring flow.

Earthquake related ground shaking was dismissed as a trigger mechanism. There was no recorded earthquake around the time of the failure.

3 MITIGATION PROGRAMME

3.1 IMMEDIATE POST-COLLAPSE MITIGATION

As soon as the collapse was discovered on 10 March 2007, the company advised Waitomo District Council of the event and the Waitomo District Council stopped the town water supply and increased the disinfection of the water that was already held in its water storage facilities. The Waitomo District Council advised the Public Health Unit of the Waikato District Health Board and a public safety notice was implemented through the media that required all residents of Te Kuiti Township to boil water from the public water supply for the next 3 days. Environment Waikato was also advised and this triggered an immediate response from pollution control.

On discovery of the failure, the company undertook a site walkover to determine if any continued discharge was occurring from the site. The site staff walked the path of the stormwater discharge drain and determined that the overland flow from the sinkhole had stopped. At Mangaokewa Stream, a stream bank walkover was undertaken to determine if any other flow paths existed from the site and the sinkhole. Spring flow discovered near the river bank was found to be contaminated with wastewater. The company immediately organised an external contractor to isolate the spring discharge by excavating a sump and pumping the contaminated spring discharge into tankers for disposal directly to Waitomo District Council.

The land where the spring daylighted was not owned by the company, and not knowing the extent of the clean-up operations, the company negotiated a quick purchase of the land at around 5% above the market value with a purchase price of $199,000.

For the first two weeks after the pond failure, from 10 March – 25 March 2007, the company intercepted all the contaminated spring water, and trucked it off site for treatment. On 25 March 2007, the company installed temporary treatment ponds at the spring site. The treatment pond system comprised a primary settling pond of approximately 50 m^3, followed by a gravel filter with a volume of 12 m^3, followed by a chlorine disinfection contact trench. The pond design assumes a two hour settling time based on a peak spring discharge of 10 L/s. The observed flow rate from the spring is about 1 L/s in dry weather to 10 L/s in wet weather. The design was selected at 10 L/s after observing the flow rate following a 50 mm rainfall event on 12-13 March 2007. The general layout of the settling pond, gravel filter and disinfection channel is shown in Photo 5.

Photograph 5: Temporary Spring Flow Treatment System

Parallel to the temporary treatment system for the spring water, the company immediately stopped discharging the wastewater into the anaerobic lagoons. In order to allow continued processing, the company had to

discontinue the operation of the rendering plant and divert the primary treated effluent from the anaerobic lagoons to the on-site sequencing batch reactor treatment plant. In order to allow the increased aeration demand now imposed on the biological wastewater treatment plant, the meat plant obtained an additional 30 kW mechanical aerator from another meat processing plant in the Waikato area, whilst placing an order for a new unit that was sent to the meat company where the unit was loaned from. The amount of aeration in the SBR was increased from 45 kW to 75 kW to allow the reduction of biochemical oxygen demand as well as provide for some nitrogen removal.

The company also negotiated a temporary increase in the trade wastes discharge loading with the Waitomo District Council to allow the meat processing plant to continue its operations. Once the anaerobic lagoons were isolated, a concerted programme to empty the sinkhole of the sludge and wastewater was carried out for a period of two weeks with the material discharged to the Waitomo District Council sewerage system. This created some difficulties for the Waitomo District Council as the Council owned wastewater treatment plant was subjected to a substantial increase in the wastewater load possibly bringing the sewage treatment to the brink of process failure.

Once the ponds and the sinkhole water levels had dropped to the extent that there would be no risk of continued discharge through the crack system, the company started planning for the longer term remediation.

3.2 RETROSPECTIVE RESOURCE CONSENTS

To allow the meat processing plant to continue its operation a series of resource consents from Environment Waikato were applied for (PDP, 2007b, c). These included discharge permits to allow:

i. Fugitive discharge of contaminants into land and sinkhole resulting in discharge into groundwater and contaminating spring flow;

ii. Discharge of treated contaminated spring water to ground via a temporary treatment plant system;

iii. Discharge treated spring water to the Mangaokewa Stream and to discharge contaminants to ground at the point of diversion;

iv. Disposal of anaerobic biosolids onto land that had to be confirmed later;

v. Disposal of dewatered anaerobic biosolids into land as a monofill; and

vi. Discharge of odours to air as a result of biosolids disposal activities.

After the collapse of the lagoon, and prior to the granting of discharge permits for the discharge of treated spring flow, an informal agreement was reached between the meat plant, Environment Waikato and Waitomo District Council on the suitability of the temporary treatment system and the discharge of chlorine disinfected spring flow into the Mangaokewa Stream.

The resource consents were granted by Environment Waikato for all the activities. During the winter of 2007, the sludge in the ponds was removed. The sludge remained in the ponds during the summer of 2007 to progressively dry naturally. The company was not able to secure the disposal of anaerobic biosolids onto other land so continued to allow the sludge to dry further.

Towards the end of summer of 2007, Pond 1 was desludged and the material was moved into Pond 2 and other disused sludge ponds at the site for long-term field storage. The surface of the receiving sludge ponds was shaped to allow runoff to be collected and discharged together with the trade wastes.

4 ENVIRONMENT WAIKATO PROSECUTION

Environment Waikato determined that Section 15(1)(b) of the Resource Management Act, 1991 (RMA) had been breached and acted in accordance with Section 338(1) to prosecute the meat processing plant.

Section 15(1)(b) of the RMA states that:

> **15 Discharge of contaminants into environment**
>
> (1) No person may discharge any—

(b) Contaminant onto or into land in circumstances which may result in that contaminant (or any other contaminant emanating as a result of natural processes from that contaminant) entering water

unless the discharge is expressly allowed by a rule in a regional plan and in any relevant proposed regional plan, a resource consent, or regulations.

In its prosecution submissions, Environment Waikato alleged that the company was aware of the stability risk of the embankment between Pond 1 and the sinkhole. This was based on documents seized by Environment Waikato that showed that the meat plant had received specific engineering advice on this matter in October 2004, which required Pond 1 to be decommissioned.

The specific advice received by the meat plant stated that in terms of risk management, the instability of Pond 1 embankment was given a high risk rating although the probability of failure was assessed as low. The consequences, however, of any failure were assessed as being "catastrophic at worst and severe at best", because any failure would result in the release of "probably all of the contents of Pond 1" and "could possibly cause the failure and discharge of Pond 2". If the embankment failed the resultant flow of wastewater and sludge was predicted to be down the valley, through the adjacent farm and house and into the Mangaokewa Stream, upstream of the Te Kuiti Township water supply abstraction point. Environment Waikato further noted that the company was aware of the consequences as follows:

i. Pollution to the surface water in the sinkhole, filling the sinkhole with sludge and short term pollution of local groundwater;

ii. Discharge of sludge and other contaminants to land and to other property;

iii. Discharge of contaminants to Mangaokewa Stream;

iv. Destruction of property;

v. Possible contamination of the water supply of the Te Kuiti Township; and

vi. Possible loss of life of either employees or neighbours if they were to get caught in the flow path at the time of failure.

Whilst the above facts are agreed, it is the interpretation taken from the facts which was disputed during the environment court hearing. Environment Waikato determined that the company was aware of the risk and despite that, commencement of work to decommission Pond 1 was not completed with the degree of urgency that the situation required. Environment Waikato considered that Pond 1 could have been decommissioned as early as the summer of 2005/06. If this had occurred, Environment Waikato submitted that the risk of substantial discharge would have been reduced by stopping the use of Pond 1, as it would have not contained any wastewater and/or sludge. It was Environment Waikato's contention that the company assumed a known business risk by not completing the decommissioning of Pond 1 earlier. Environment Waikato further submitted that the company was complacent and carried on a "business as usual approach", which was not acceptable. In terms of culpability, Environment Waikato submitted that the company could and should have acted sooner but it did not and was reckless.

In its response, the company submitted that the circumstances which led to the lagoon collapsing were caused by external unforeseen events. The company therefore did not "expect the unexpected". It was the company's contention that the potential failure outlined in the engineering advice in 2004 related to long-term movement of the embankment and had nothing to do with the sinkhole instability in general. In this regard, the company submitted that its culpability should be viewed as inadvertent as opposed to reckless. The company submitted that the slope failure identified earlier would have resulted in the embankment having an arcuate headscarp and bulging at the base or toe of the slope, which did not occur.

The Environment Court determined that the issue of the company's culpability was in dispute as Environment Waikato submitted a degree of recklessness surrounded the offending, whereas, the company submitted that the event was sudden, catastrophic and unforeseen. The court concluded that based on the findings, Environment Waikato was not able to "prove to a very high standard of beyond reasonable doubt that the company was complacent or tardy in dealing with the decommissioning project and that this contributed to offending".

However, in terms of sentencing, the court determined that offending against S15(1)(b) RMA had taken place with the scale of the event being significant. Although the offending was neither deliberate nor reckless, it

needed to be balanced against short-term adverse effects and the scale of the event. The court concluded that the scale of the event and its public impact were the main factors highly relevant to the level of any fines imposed. The meat plant had pleaded guilty at the earliest opportunity and had mitigated the adverse effects of the offending in a dramatic way to the point of spending up to $600,000 for the clean-up, excluding the purchase of neighbouring land at $199,000.

The court established the starting point for the fine at $60,000 and allowed a full one-third discount for its guilty plea and co-operation, a further $10,000 for mitigating the adverse effects in a dramatic way and being entitled to be treated as a first offender. The fine was then set at $30,000 with 90% of the fine to be paid to Environment Waikato.

5 CONCLUSIONS

Ground cracking occurred around an existing sinkhole depression on the night of 10 March 2007 that resulted in the breaching an anaerobic lagoon at a meat processing plant in Te Kuiti. Partially treated wastewater and sludge entered and flowed down a crack system, eventually entering and filling the sinkhole. The overflow and underflow from the sinkhole resulted in wastewater being discharged to Mangaokewa Stream upstream of Te Kuiti public water supply abstraction point. This resulted in the residents of Te Kuiti being required to boil the drinking water for a period of 3 days. The discharge into the Mangaokewa Stream resulted in emergency response from Environment Waikato, Waikato District Health Board Public Health Unit and Waitomo District Council.

The most likely mode of failure was expansion of the existing sinkhole due to collapse of supporting limestone into the natural tunnel system under the sinkhole. The total amount of failure movement is likely to have been between one and three metres. The trigger mechanism for the failure is not certain. However, collapse of the supporting limestone around the existing sinkhole is inferred to have been due to dissolution of the limestone by groundwater flow and percolation.

An emergency response by the company resulted in the abandonment of all anaerobic lagoons (Pond 1, 2 and 3), the stopping of the rendering plant operation and clean-up of the contaminated spring flow as well as the removal of sludge from the anaerobic lagoons. The company also purchased a neighbouring property where the underground tunnel and spring from the sinkhole daylighted . The clean-up operations cost the meat processing plant an estimated $600,000 with the land purchase an additional $200,000. The meat processing plant was also found guilty of offending against S15(1)(b) of the RMA and was fined $30,000.

ACKNOWLEDGEMENTS

The meat processing plant is thanked for all the information provided for this paper.

REFERENCES

Edbrooke, SW. (2005). *Geology of the Waikato Area*. Institute of Geological and Nuclear Sciences 1:250,000 geological map 4. IGNS, Lower Hutt, NZ.

PDP (2007a). *Engineering Geology Assessment of Wastewater Ponds Failure*. Consultancy Report. June 2007.

PDP (2007b). *Fugitive Contamination of Land, Groundwater and Discharge to the Mangaokewa Stream – Application for Resource Consents and Assessment of Environmental Effects.* Consultancy Report. April 2007.

PDP (2007c). *Land Application of Biosolids -Resource Consent Application & Assessment of Environmental Effects.* Consultancy Report. October 2007.