

*Appendix 1 to IPENZ Practice Note 21 Part 2: Clay Liners for Ponds*

# FDE Pond Design and Construction with Hauraki 'Marine' Clays

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# 1. Introduction

The engineering principles for Farm Dairy Effluent (FDE) pond design and construction presented in IPENZ Practice Note 21 (PN21) *Farm Dairy Effluent Pond Design and Construction* should apply to all such ponds constructed in New Zealand.

However, the Hauraki Plains (the Plains) area has a unique geology for which a modified design and construction approach to FDE ponds can be appropriate. In some parts of the Plains, the firmer 'brown' clay which overlays the predominant Hauraki softer 'blue-grey' marine clays are of sufficient thickness and proximity to the surface that it can be practical to excavate a pond directly into this 'brown' clay and rely on its naturally low permeability to achieve a very low but acceptable leakage rate.

To assist the reader, a *decision tree* has been developed. This flow chart (Figure 1.2) illustrates the decision steps necessary when the Hauraki 'Marine' clay geology profile is present.

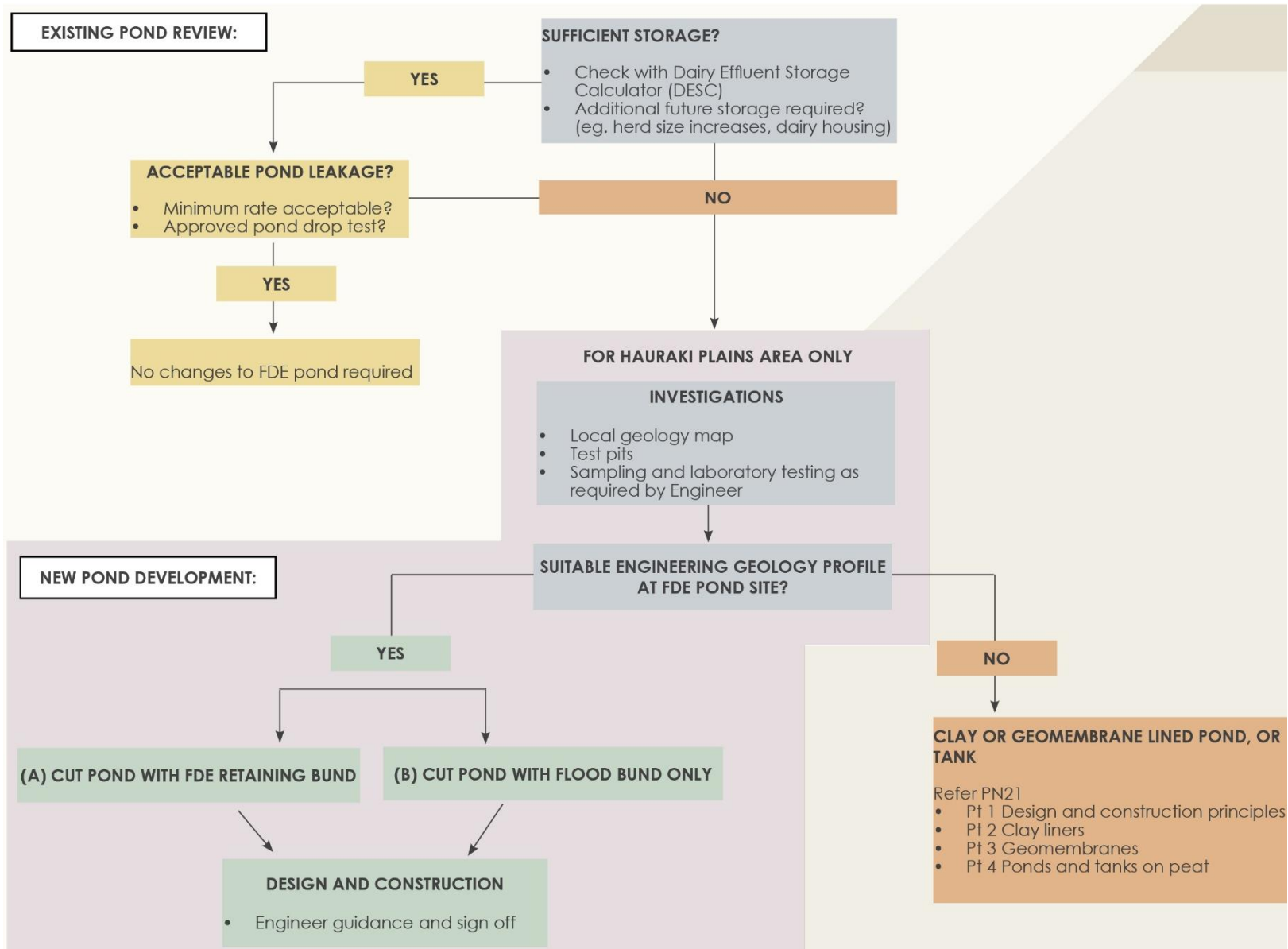
Because of the variable subsurface geology and the engineering challenges that this creates, the early involvement of an experienced Engineer is essential to ensure professional sign-off can be provided (if required) to the Regional Council.

## Objectives of PN21 Part 2 App 1

- To characterise the geology and identify geographic locations where suitable Hauraki 'Marine' clay materials for FDE ponds can be expected
- To identify relevant engineering properties and describe how these influence FDE pond construction
- To develop a specific methodology for the investigation, design and construction of ponds from these clays



*Figure 1.1: Pond Under Construction*



*Figure 1.2: Decision Tree - for FDE Pond Design and Construction with Hauraki 'Marine' Clays*

## 2. Geology

### 2.1 HAURAKI 'MARINE' CLAYS

Clay soils are made up of miniscule plate like mineral grains that have been formed from the weathering, alteration and physical breakdown of rock fragments. These are generally deposited in large rivers, deep seas and estuaries.

Estuarine formed 'blue-grey' clay soils found across the Hauraki Plains are colloquially known as Hauraki 'Marine' Clays. They can occur close to the ground surface level but can also be present at greater depths where they can be overlain by peat and more geologically recent colluvial deposits. These clays are typically interbedded with thin layers of peat, sand and shells, are generally 'blue-grey' in colour but where they are near the surface they tend to have a firmer weathered 'brown' layer of variable thickness as illustrated in the pit below.

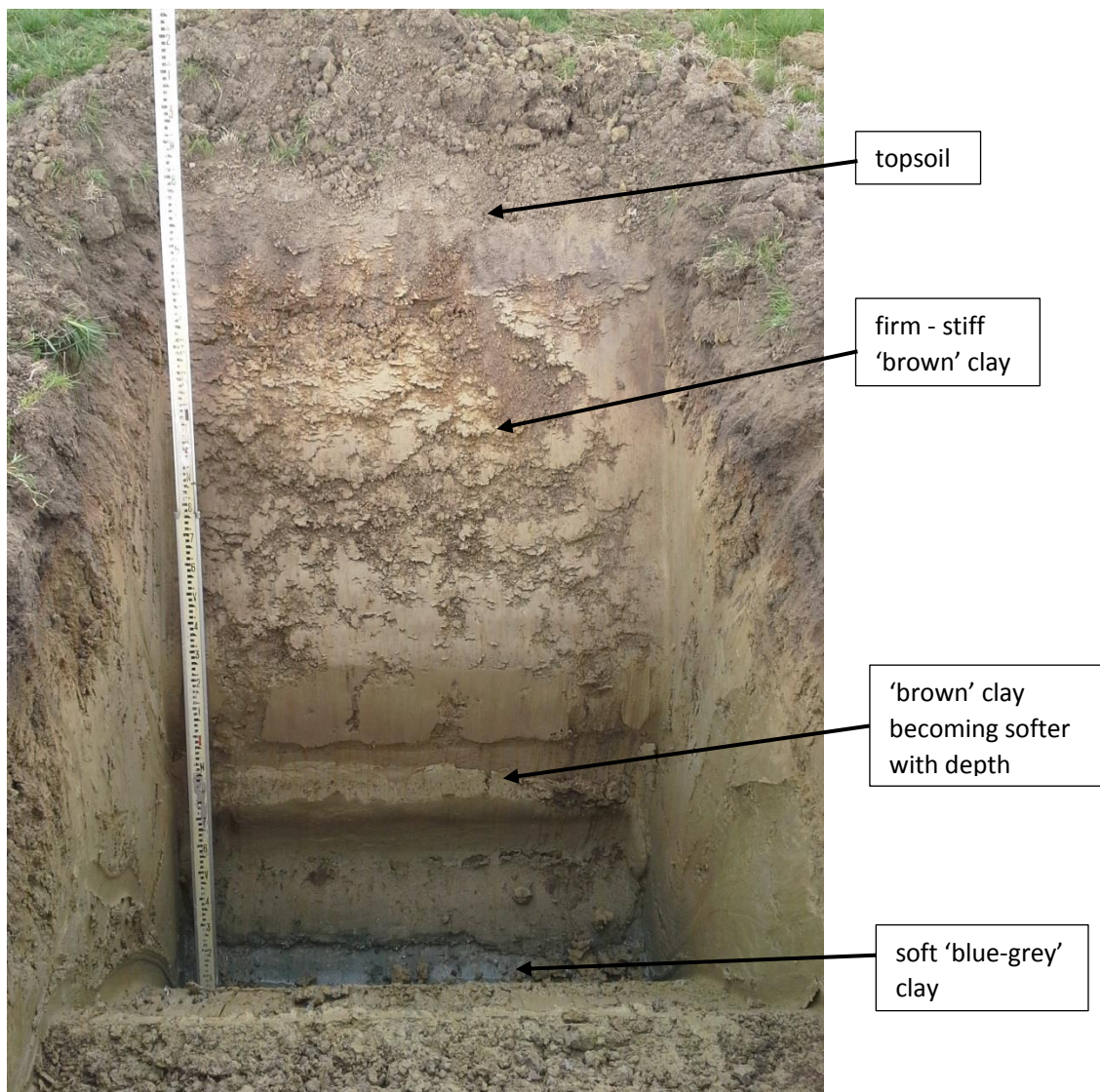


Figure 2.1: Typical Hauraki "Marine" Clay Soil Profile

On the east and west margins of the Plains the clay may be overlain by sand and silt washed down from the adjacent hill sides. To the south there is a mix of the predominantly sandy soils and the clay which has been buried under sandy soils eroded by former river channels is now infilled with layers of sand, silt, clay and peat.

Peat and organic soils are found all over the Plains at the ground surface and in buried layers within the marine clays and sand/silt deposits. Occurrence of the peat is highly variable presenting as small isolated pockets in surface depressions as thin continuous layers but also as deep thick deposits in the central Plains area.

## 2.2 SUITABLE LOCATIONS

A Hauraki 'Marine' Clay location plan as presented in figure 2.2 below has been developed using published geological maps, historic borehole and other information to assist in identifying where:

- The top of the clay layer is likely to be more than 2.5 metres below the ground surface; and
- Areas where the clay layer is likely to be less than 5 metres thick.

The significance of these two criteria to FDE pond designers are:

- If the top of suitable clays is more than 2.5 metres below ground level, the influence of it on final pond design will be reduced to the point where 'conventional' pond design issues as described in PN21 dominate; and
- If the bottom level of competent clays are less than 5 metres below ground surface level then there is a risk of there being too thin a layer of suitable clay beneath the pond base to be confident of achieving a low permeability naturally sealed pond.

For all ponds a specific onsite assessment needs to be made of the remaining *insitu* 'brown' clay below the intended pond base level.

## 2.3 PROFILE VARIABILITY

Organic clays or peats occurring within the Hauraki 'Marine' clay profile can be very soft and compressible. They can also generate preferred flow paths for groundwater and methane generated by the decomposition of the peat. These layers can increase the settlement and instability risk of pond perimeter bunds.

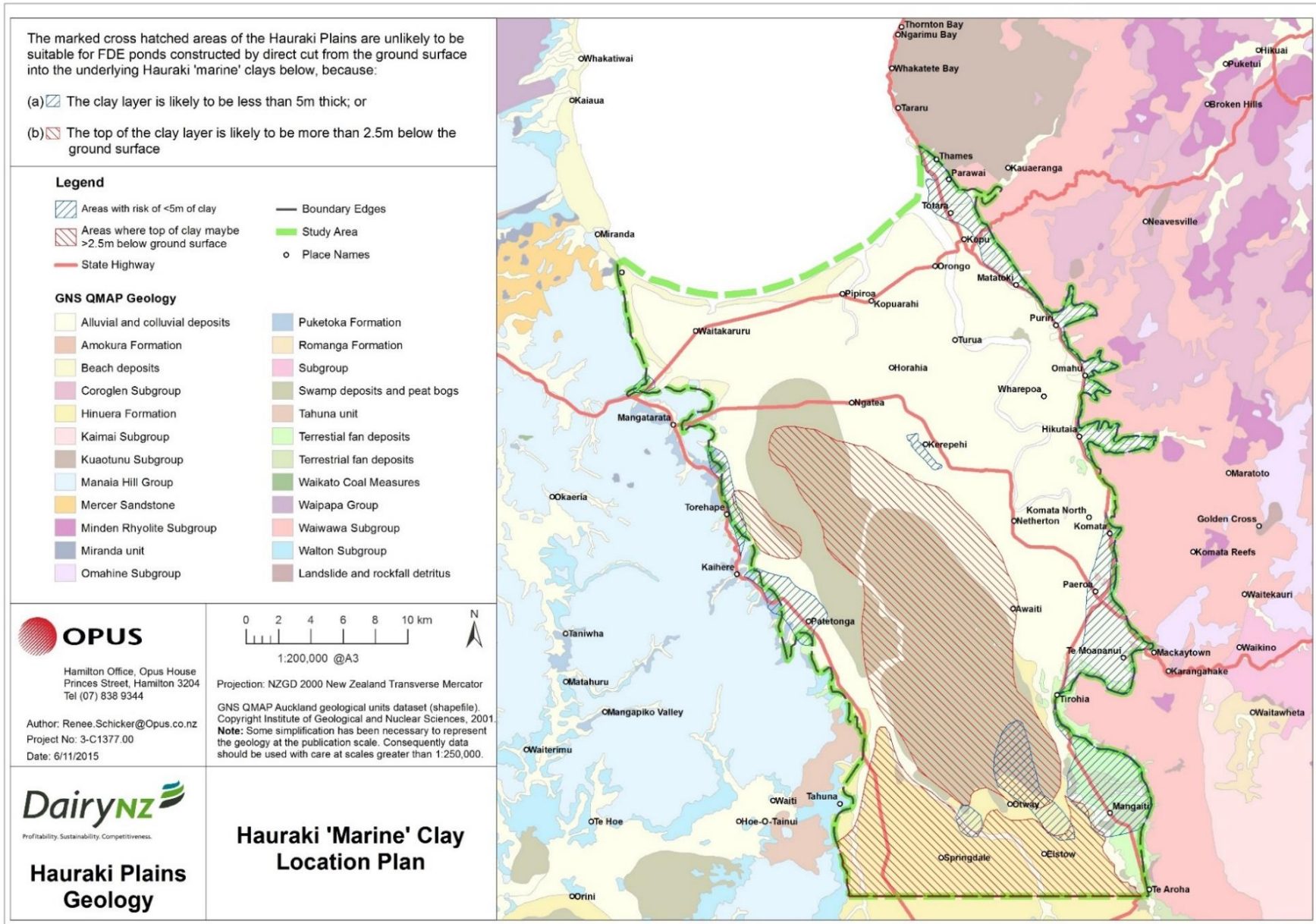
Sand and shell layers within the excavated sides of a pond can lead to inflows of groundwater and conversely outflows of effluent. Where significant inflow occurs it can also cause erosion of the layer, undercutting the sides and promoting instability.

While Hauraki 'Marine' clay soils are usually firmer and have more strength near the surface, they soften with depth to the approximate water table, then slowly increase in strength with depth below this. The most firm soils are the near surface oxidised 'brown' clays which overlie the deeper below water table 'blue-grey' clays. The depth at which this transition occurs is critical to pond design decisions and will vary from farm to farm.

Where sand or peat layers are absent from the 'brown' clays, and more than 1.0 metres below the base and sides of a pond, these sites can be suitable for excavating directly into to construct a complying FDE storage pond.



This 'brown' clay, and other near surface firm to stiff clays, are also usually suitable for reuse in construction of liners and bunds.



*Figure 2.2: Hauraki 'Marine' Clay Location Plan*

## 3. Engineering Properties

### 3.1 SHEAR STRENGTH

The term shear strength is used to describe the magnitude of the loading that a soil can sustain and is an indicator of a soils strength.

Importantly, soils of shear strengths below about 70 kilopascals (kPa) are sticky, become increasingly difficult to work with and compact without a bow-wave forming in front of the roller. Below 50 kPa these soils become unworkable.

Conversely, stiffer soils, typically above 120 kPa may not breakdown and remould as needed to achieve minimum compaction and voids targets.

The actual strength at which the clay can become too difficult to work depends in part on the size and weight of roller used, as well as water content. While a lighter roller may work more effectively than a heavier roller on a softer clay, additional roller passes and reduced lift depths may be necessary to achieve the required compacted density.

### 3.2 CRACKING

Marine clays have high plasticity contributing to a high shrinkage and swell capability on drying and wetting. Summer cracking in these clays of up to 30 millimetres wide and up to 600 millimetres deep have been observed. In the winter these cracks close up as increased moisture availability causes the clay to swell.

If a clay liner is placed over a highly permeable stratum such as coarse sand, it will need to be over 1.0 metre thick to ensure that there is an intact 450 millimetres depth of clay liner at all times, or alternatively be protected from drying out by topsoil cover or continually maintaining some effluent/water in the pond.

### 3.3 PERMEABILITY

The recommended acceptance level for a 450 millimetre thick clay liner is a permeability of not greater than  $1 \times 10^{-9}$  metres per second. For clays with test values marginally above this, and if there is a clay layer thickness significantly greater than 1 metre below the finished base and sides of the pond, then no further sealing should be required.

However, each case should be assessed by an Engineer, and the possible seepage rate for anticipated effluent heads compared against the equivalent for 450 millimetres of clay liner. Allowance for possible shrinkage of the clay as described will also be necessary.

### 3.4 SETTLEMENT

Previous earthworks in the Plains area indicates that a 2 metre high bank constructed of Hauraki 'Marine' clays can consolidate and vertically settle under its own mass by 200 to 400 millimetres with 60 to 80 per cent of this occurring in the first year after construction.

In areas with compressible peat layers beneath this, settlement risk is significantly increased. Common issues and solutions associated with working in peat areas are addressed in PN21.

## 4. Investigations

### 4.1 SITE INVESTIGATIONS

The purpose of site investigations is to provide accurate information into the design.

The first step is to locate the proposed pond site on the Figure 2.2 geology map to predict the likely materials profile and expected depth that a pond might be able to be excavated to.

Investigations should then be undertaken by an experienced Engineer or Geologist and include a minimum of four test pits excavated to a depth of at least 4 metres. So that an assessment of shear strength against depth can be developed, field testing should include shear vane tests.

Key Observation	Comment
Presence, thickness, strength of the stiffer 'brown' clay layer	The viability and performance of a pond cut directly into the 'brown' marine clay is dependent on the clays consistency, thickness and proximity to the surface.
Depth to the top of the softer 'blue' clay and its strength	If the underlying strata is too soft it may not be possible for overlying compacted material to achieve the necessary percentage of compaction (and permeability). Adopting an alternative design, or installing a synthetic pond liner may be more practical.
Presence or sand, shell or peat layers in the upper 4 metres of the ground profile and if its occurrence is localised or extensive?	Where unsuitable sand, shells and peat layers are present, an assessment should be made as to the practical feasibility of removing any such layers. Options are: a) Unsuitable <u>localised</u> layers can be excavated out at least 1.0 metres back along from the face of the pond slope. To provide a sealed lining to the pond this area can be "chased-out" and replaced with excavated firm 'brown' clay and given sufficient compaction; or b) Where unsuitable layers are more <u>extensive</u> or numerous, then other pond construction (or tank) options will need to be considered.
Groundwater level (GL) and level risen to if water flow is from a sand or permeable layer	The dry appearance of test pits in clay may not mean the groundwater level is below the pit level but be reflective of the low permeability of the clay preventing side seepage into the pit.

Table 4.1 Key Observations

A final investigation step is to confirm by using available earthworks equipment that the excavated clay can be compacted to a point where it will:

- Meet the permeability criteria
- Be strong enough to form stable slopes
- Not be so soft it will form a wave in front of the roller used to compact it

- Not be so stiff it will not compact properly

This investigation sets the standard of compaction that can be achieved on site. A target of 95% maximum dry density with a voids content of less than 10% is usually possible.

## 4.2 LABORATORY TESTING

If it is intended to use excavated clay soils to construct bunds which will be effluent retaining then sufficient test pit samples will need to be taken for:

- A laboratory compaction test (dry density/water content relationship)
- A permeability test at the target maximum dry density

Hand shear vane tests on compaction test samples at the laboratory will provide a useful means of result comparison later during construction.

- |   |
|---|
| <ul style="list-style-type: none"> <li>• As Hauraki clays are typically soft and wet there are associated constructability risks.</li> <li>• An adequately firm subgrade surface will be required to roller compact fill on to achieve target compaction.</li> <li>• Risk can be reduced by setting the excavation maximum depth limit for the base of the pond just above the brown-blue clay boundary. The depth to the 'blue-grey' clay and the strength of the 'brown' clay must be continually monitored during construction.</li> <li>• Digging deeper into the clay increases the chances of uncovering unexpected seepages. The 'blue' clay is mostly saturated and below the watertable and can lead to buoyancy lift of the pond base when effluent is removed from operational ponds.</li> </ul> |
|---|

Table 4.2: Limitations of Working with Hauraki 'Marine' Clay

## 5. Design

### 5.1 BUNDING

All FDE ponds require a bund of sufficient height constructed around the top of the pond incorporated into its design to cut off the inflow of surface water, including flood water.

All bund construction will require removal of topsoil and undercutting down to the top of the competent 'brown' clay. Note that the height of the bund effectively starts at this level, even though it may be below the surrounding ground level.

There are two bund construction options for below ground cut ponds available depending on whether the bund itself is intended to retain FDE as illustrated in figure 5.1 below.

Bund Retaining Options	
<b>Option (A) FDE Retaining Bund</b>	Construct with suitable excavated firm 'brown' clay, tested and placed in accordance with PN21.
<b>Option (B) Flood Bund Only</b>	Construct with excavated clay and some roller compaction.

Table 5.1 Bunding Options

### 5.2 POND SIZING

All ponds must be designed to provide sufficient FDE storage as determined by Massey University's Dairy Effluent Storage Calculator (DESC). Where the flood bund option is adopted, the volume contained above the level of the bund base must not be used for FDE storage, or as a working "freeboard".

Often the limitation with shallow soft soils is that to obtain the required storage volume only a relatively shallow pond can be excavated, but this requires a larger pond plan area with an increased rainfall catchment.

### 5.3 ADDITIONAL DESIGN RECOMMENDATIONS

All designs should follow the good practice guidelines as detailed in PN21 with the following additional recommendations:

- Position the base of the pond a minimum of, either 500 millimetres above the top of any soft clay, or 1.0 metre above a permeable layer – whichever is the deeper.
- If groundwater is present in a sand or permeable layer below the intended pond base level, ensure there is sufficient clay left above this layer to prevent base heave from hydrostatic uplift. The minimum clay thickness required to achieve this is best determined by an Engineer.

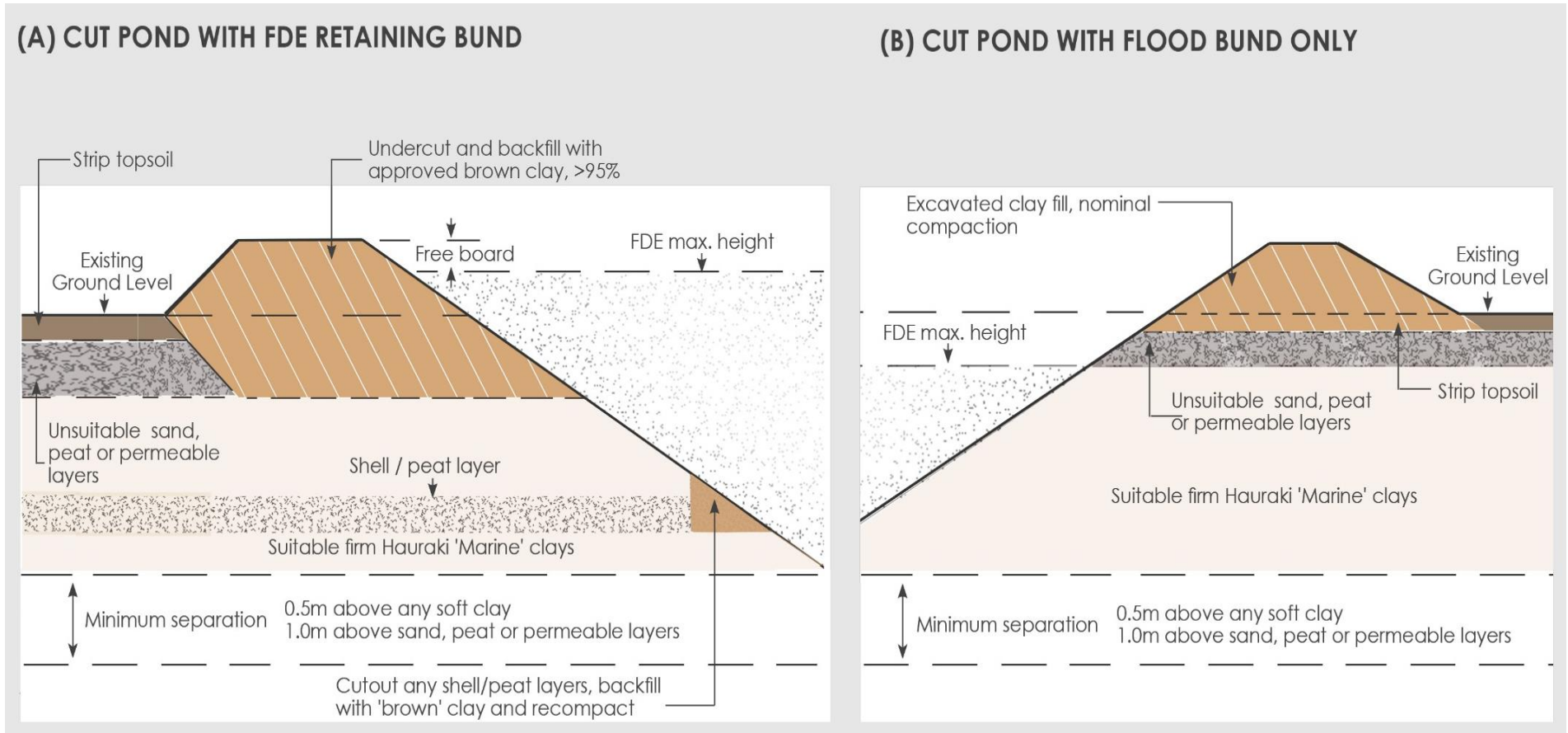


Figure 5.1: Bund Construction Options



## 6. Construction

### 6.1 BUND CONSTRUCTION TESTING

#### 6.1.1 *Option A* – Cut Pond with FDE Retaining Bund

For *Option A*, the fill placement, compaction and testing practices for constructing the bund as described in PN21 should be followed, and in particular:

- The relationship between shear vane strength, the percentage of air voids achieved and the target permeability must be established from prior laboratory testing.

These results can then be used as a basis to monitor the onsite compaction to confirm that density and air voids percentage is being achieved by using a hand shear vane together with less frequent Nuclear Density Meter (NDM) measurements. A shear vane is a very useful tool for monitoring changes in soil shear strength with changes in the compactive effort being applied.

- By carrying out an Engineer supervised trial compaction in advance of the main construction works for the bund, the optimum layer thickness and number of passes required by the chosen roller to achieve the target compaction can be established.

Using this approach, quality assurance site testing during construction using the NDM may be reduced to the minimum as shown in PN21 Part 2 Table 6.1.

#### 6.1.2 *Option B* – Cut Pond with Flood Bund Only

For *Option B*, less compaction for bund construction than *Option A* can be acceptable as the formed bund only needs to retain surface and flood water. No on site testing is necessary. However, if localised sand, shell and peat layers are encountered, these will need to be “chased-out” and suitably backfilled and compacted to provide a seal.

As it will become less apparent over time where the maximum FDE level that the pond has been designed and constructed to is, it must be clearly marked with large coloured timber pegs or similar markers so that it is not over filled.



Figure 6.1: Trial Compaction Area Preparation

## 6.2 HEALTH AND SAFETY

When a pond is constructed, regardless of location, the pond becomes a construction site and is controlled by the Health and Safety at Work Act (2016). This means that all physical construction works must be risk assessed and managed so as to ensure a safe site for all who are conducting work there. There may be maintenance requirements throughout the life of the pond such as de-sludging and pump maintenance and these must be allowed for at the earlier stages.

## 6.3 ENGINEER SIGN-OFF

All FDE ponds will require Engineer direction for both the investigations programme and construction monitoring because of the complexity of the materials and conditions likely to be encountered.

Testing records and written observations with supporting photos will need to be kept, for example to confirm that any sand, shell or peat layers, or other issues encountered have been satisfactorily resolved. Some basic as-built drawings showing the completed pond dimensions, including the height(s) from the top of the bund down to the designed maximum FDE level, is also essential.

This approach is critical to ensure professional signoff for both the design and construction of the pond can be provided to the Regional Council (if required). As described in PN21 Part 1 section 7.5, a Suitably Qualified Person (SQP) should be a Chartered Professional Engineer (CPEng) or Engineering Technology Practitioner (ETPract), or alternatively a Professional Engineering Geologist (PEngGeol).

- Construction should be planned to be completed over the summer months. A wet spell in autumn can leave a pond partially constructed for months over winter. Early morning dew in autumn can lead to surface skidding and having to continually strip the wet surface, or allow drying out before placing more material.
- Some standard construction plant will get bogged in the soft clay and long reach excavators may be required. Compaction plant with a sheepsfoot roller on both the front and rear axles enables continual traction.
- Hauraki 'Marine' Clays tend to form a 'bow wave' in front of rollers being pushed along rather than being compacted. Lighter rollers, thinner lifts and more roller passes are usually required.
- After stripping topsoil to a stockpile, an initial compaction trial should be carried out under the direction of the Engineer with these test results setting the compaction methodology for the earthworks
- Sides and the base of the pond must be continually monitored for unacceptable layers of sand, shells or peat
- Frequent shear vanes tests in combination with NDM tests must be used to control compacted bund soil density and air voids

- Active involvement by an experienced Engineer is essential to ensure professional sign-off can be provided (if required) to the Regional Council.

*Table 6.1: Some Good Construction Practices*