LAKE TEWA - MODULAR LINER SYSTEM USING GCLS

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ABSTRACT

For the construction of a man made lake in 2008 at Jack's Point in New Zealand a unique modular future proof lining system was developed using bentonite GCL as the main liner elements. The main feature of the lake lining system is that provisions were made during design and construction that allowed the further expansion of a 5 ha sized lake (currently completed) by using a modular design. A key benefit is that future expansion can occur without the need to lower the lake water level or adversely affect the recreational water quality. These were some of the requirements made by the client. The lining system was developed as there were no other options available within the project scope and budget that offered the same flexibility, innovation, future proofing and long term project security as the chosen solution. This paper provides details of the modular lake lining system. Design considerations and construction details are presented in detail and potential uses of this modular lining system shown for other uses in civil and environmental engineering.

1 BACKGROUND

Jack's Point development is near Queenstown in the lower South Island of New Zealand. With more than 1,200 ha development area it will feature over 1,300 residential homes, a lakeside village with hotel accommodation, restaurants and shops, a luxury lodge, a championship golf course and over 35 km of hiking, biking and equestrian trails. Jack's Point was originally a large sheep station located between Lake Wakatipu and the Remarkables Ski Field. The developer is Jacks Point Limited, with Darby Partners being engaged as masterplanners. Whilst the golf course and rural residential living zones were already developed, the proposed village centre is expected to be developed over time.

In 2007 one of the main development stages of Jack's Point was initiated with master planning to set out the locations of the new golf club house and residential developments around the village centre as well as commercial hotel complexes near the future water front. Although the greater site is located near Lake Wakatipu, no direct access or views are available from the proposed village area. Hence, a man made, 6 ha to 8 ha, large lake was intended to be constructed as the centre of the village. The man made lake was intended by the landscape designers and master planners to be a focal point of the development, reflecting the greater site setting. The 18 hole golf course, the new golf club house, future hotel complexes and residential and commercial village development were intended to be wrapped around the lake edges. The proposed master plan, shown in Figure 1, indicates several large bays with waterfront developments, an island for residential housing and a wetland area intended for stormwater treatment prior to discharge into the lake.

Figure 1: Site location and development master plan.

The intention by the client was to construct the lake in its final shape, depth and form to accommodate the proposed development around its edges. This would have included all the proposed water front retaining walls and associated infrastructure around two large bays. The landscape designer's goal was to achieve a natural looking lake that fits into the alpine setting of the site.

The lake master planning was undertaken by Darby Partners. Kerr + Partners, Golder Associates and the University of Waikato undertook environmental modelling and Aurecon (formerly known as Connell Wagner) provided engineering input, including geotechnical investigations on liner and lake edge design.

Due to impeding global recession in early 2008 the client advised that a lake will be required to commercially drive the village development and golf course, however, the lake shape and size had to change to fit the revised budget. Further, all waterfront developments were suspended and bays were significantly reduced. Following further economic modelling the bays were removed from the construction schedule. The consultant consortium worked on a revised master plan to accommodate the client's vision.

Workshops and discussions with the client identified the following challenges for the design, construction and long-term maintenance of the lake:

- Consistently achieve recreational water quality
- Achieve natural looking lake edges
- Minimise on going maintenance costs, especially pumping
- Dispose stormwater from the village into the lake
- Achieve all year round high water clarity and visibility to the lake bottom
- Avoid or minimise any disturbance during later development stages, especially prevent water draw down once the lake is completed

This presented a challenge from two key perspectives. The environmental modelling and master planning identified several bays adjacent to the main lake body that could be established on an as-needed basis as the development grows in the future. The lake liner and edge design driven by Aurecon has to consider future proofing to undertake future development work without the ability to drain the lake or to reduce the water levels or to discharge large quantities of sediments into the main lake body. Discharge of sediments was perceived to be a no-go area by the client. The project team had to accommodate changing lake shapes and sizes in their models and designs without the benefit of knowing the final or intermediate stages.

2 ENVIRONMENTAL MODELLING AND LAKE MANAGEMENT

The partnership established by Aurecon with Kerr + Partners, Golder Associates and Waikato University meant that specialists in their respective fields were able to tackle the issues to find solution matching the client vision, needs and budget. The primary tool used to investigate and develop options for management of the health of the lake was a one-dimensional model called DYRESM-WQ. Professor David Hamilton of the University of Waikato co-developed this model and provided the modelling expertise for this investigation. This model, which predicts temperature, algae biomass, nutrient and oxygen levels, water balance and ice cover, was able to yield great insight into the dynamics of lake ecology that are vital to understanding the health of the lake.

Stormwater from urban areas may potentially be contaminated and a need for treatment prior to discharge was recognised. Initially all stormwater from the urban environment was destined for off site disposal. However, in order to reduce the long term operational costs the consortium investigated the option of discharging some stormwater into the lake, and as such reducing the water demand. The lake will be filled by pumping water from Lake Wakatipu and once the village develops, parts of the stormwater from roofs and selected hardstand areas will be treated in a wetland prior to discharge into the lake and therefore greatly reducing the water demand and pumping costs.

Based on environmental modelling the revised lake size is just over 5 ha. The depth of water is 4.5 m with a slightly sloping floor to facilitate drainage during construction. There is no water baseflow from natural water courses so all the input to the lake is either from stormwater discharge or needs to be pumped into the lake from Lake Wakatipu located some 100 m lower than Lake Tewa. Extremes of temperature within the local climate meant that the investigations needed to have a high degree of rigour to provide confidence that a suitable lake was designed and could be managed. The consequence of the lake suffering excessive algal growth, eutrophication, or other water quality issues would undermine the success of the development and as such was seen as the key risk from an environmental modelling perspective.

Key environmental model outcomes affecting the geotechnical design were:

- Maximum water depth of 4.5 m
- 500 mm freeboard above normal operational conditions to account for 1 in a 100 year event (1% AEP)
- Wind induced wave actions expected
- Ice formation in colder months expected
- No water draw down permitted during operational life (>50 years)
- Expansion potential to be available

The outcomes of the environmental modelling and lake performance were published by Kerr *et al.* (2009). This paper deals with the challenge to line the lake, to construct low-maintenance lake edges and to provide future extensions to the development.

3 SITE SETTING

3.1 CLIMATE

Jack's Point is some 10 km south east from Queenstown on the shores of Lake Wakatipu, and 5 km south of Kawarau Falls and the Queenstown Airport, see Figure 1. Photo 1 shows the aerial view of the greater Jack's Point area with the location of Lake Tewa indicated. The climatic and meteorological data relevant to the project were taken from Queenstown Airport Station using the NIWA Climate Website. The data comprised daily solar radiation, both short and long-wave, air temperature, air pressure, wind speed and daily rainfall. Based on the data, the environmental conditions for the exposed and submerged lining system were determined. The temperature varies seasonally from -10 degrees Celsius to more than 30 degrees Celsius.

Photo 1: View of the greater site with the Remarkable Mountain Range in the background and Lake Wakatipu in the foreground.

3.2 GROUNDWATER AND SURFACE WATER

A previous geotechnical investigation using borehole drilling indicated that groundwater is located at depth. Pump testing and piezometric monitoring was carried out to determine if wells are able to supply sufficient groundwater to fill and maintain the lake. Based on the data obtained it became evident that groundwater was perched and lenses were quickly depleted with little recharge rates. No groundwater aquifer with sufficient capacity for the required supply was sourced on the site.

The current surface water catchment includes approximately 180 ha of rural land including part of the Remarkables Mountain Range behind the development site as well as much of the development site itself. More specifically, however, there was no baseflow entering the lake and only storm flows were available to provide water to the lake. Thus, additional recharge with Lake Wakatipu water was needed.

3.3 SOILS

A review of past investigations and intrusive testing indicated that the site can be divided into two different geological domains. The southern part of the lake, near the golf club house, is underlain by glacial and lake bed sediments of fine sands, silts and very silty clays interbedded with coarse, well-graded and poorly-graded gravels with some cobbles. This material, commonly referred to as glacial till, is typical of this area and relates to soils deposited at the end of the last glaciation period during the retreat of the glaciers (Turnbull, 2000).

The northern part of the site is underlain by interbedded deposits of fine sand, sandy silts and clayey silts. Test pit excavations indicated that the upper soils layers were dilatant when saturated and turned into a dense liquid when lightly shaken. Test pit excavation during site investigations using heavy excavation plant had to be abandoned as vibrations from the on board hydraulic pump caused localised liquefaction. The moisture content of the clayey silt layers exceeded 60% and distinct vertical cracks infilled with dark organic soils were exposed during test pit excavations. This material is regionally known as 'blue pug'. These silty soils are underlain by sandy gravels and glacial till. Several of the test pits struck this coarse granular material at relatively shallow depths while others did not encounter the gravels. The change between the fine-grained and coarse-grained soils is distinct and likely related to old landforms such as infilled lake edges or oxbow lakes. Geological mapping determined that the soil layers are dipping moderately northwards (5-10° N). Metamorphic schist rock of the Haast Group is exposed across the site and is inferred to be located below the fluvial and glacial deposits at depth.

Soil testing was undertaken by Aurecon and Central Testing Services Ltd in Alexandra. Main properties such as dispersivity, colloidal suspension, particle size distribution and compaction testing were determined. The test results for silt and glacial till are discussed in detail below.

3.3.1 Silt

Typical moisture content of the *in situ* silts varied between 20% to more than 60%. The Maximum Dry Density was about 16 kN/m³ and Optimum Moisture Content at Standard Compaction was about 20%. Permeability testing of remoulded and compacted samples in a triaxial cell indicated permeabilities around 5.2×10^{-8}m/sec at 35 kPa to 70 kPa confining pressures. Pinhole Dispersion according to ASTM D4647-93 (reapproved 1998) indicated Class ND2 to ND3 – Intermediate to Non Dispersive; while the Crumb Test ASTM D 6572-00 indicated Non Dispersive. Fluid density testing indicated that after six hours all suspended coarse particles were sedimented and the remainder of fine particles remained in colloidal suspension. Observations on site indicated that large amounts of silt were eroded during rain events, causing significant rilling and erosion.

The contractor constructed test beds made from silts to determine suitability as a lining material. Infiltration tests indicated similar permeabilities to those derived from laboratory testing. One main disadvantage was that water within the test beds remained turbid due to suspended fines and was only able to be clarified using flocculants. Turbidity testing by Aurecon indicated that water did not clarify sufficiently after more than 20 days and that temperature variation within the sample container kept fines suspended. Test bed construction also highlighted the difficulties of handling this type of material.

3.3.2 Glacial Till

Based on particle size testing of the glacial till soils on the southern extent of the site, the soils are described as sandy gravels with minor silt and traces of clay. Test pit excavation and geotechnical logging of tailings indicated that the till varied greatly in places, sometimes being present as cobbly coarse gravel with minor sand, grading to fine clayey sand with minor gravel. Construction of test beds indicated very high permeabilities which was consistent with the lack of ponding on the site after even heavy rainfall.

4 LAKE LINER SELECTION

Based on the geological setting of the lake, especially with regard to highly permeable alluvial gravel layers in the southern lake area, and potentially erodible and dispersive soils underlain by highly permeable soils in the northern area the need for a lining system was recognised early on. Geosynthetic Clay Liners (GCL) and geomembrane lining solutions were investigated, as well as, import clay sourced from Bannockburn some 70km away. The options were compared using a cost-risk assessment, considering availability, construction constraints, risk and cost (Table 1).

Table 1: Risk-cost analysis.

		CONSTRUCTION							RISK			COST
Option	Type	Connections / Penetration	Installation on Base	Installation on Slope	Subgrade Preparation	Joints	Programme and Timing for Construction	QA/QC	Installation Damage	Leakage	Long-term stability	[$/m^2]
Compacted Fines	at least 600mm in three 200mm layers	3	2	3	1	2	3	3	2	3	1	1
Geomembrane	1.5mm LDPE double textured on slopes, smooth on base	3	3	3	3	3	3	3	3	1	1	2
GCL	Needle punched sodium bentonite composite	1	2	2	2	2	1	2	1	1	1	3

RATING	CONSTRUCTION	RISK	COST
1	Easy	Low	Low
2	Moderate	Moderate	Medium
3	Difficult	High	High

The environmental impact of importing 40,000 m³ of suitable fine grained fills from the nearest source and disposing of similar amount of soil on site was deemed to be unacceptable, despite the likelihood that this was the most economical solution. Further, the residual permeability of the compacted fines would result in groundwater seepage of 1,500 m³/day (30 mm/day), which was deemed to be unacceptable. A geomembrane solution was discarded due to lack of experience by the local contractor with specialist welding plant, the need for strict QA system to check the waterproofing of all welds, as well as the need to produce a suitably prepared subgrade. Thus, GCLs were the preferred option as no specialist welding or construction plant was required. The GCL option allowed for a tight construction schedule, installation was relatively independent of weather, the liner is a self-healing system, it is relatively thin and thus minimal undercuts were required and little preparation of the subgrade apart from proof rolling was needed.

After a tender process the selected product type was a bentonite clay liner made in Australia. Elcoseal X1000 was chosen for both basal and side slope lining. The GCL is a composite comprising sodium bentonite sandwiched between two geotextiles. The composite is needle punched to allow for shear transfer between individual layers.

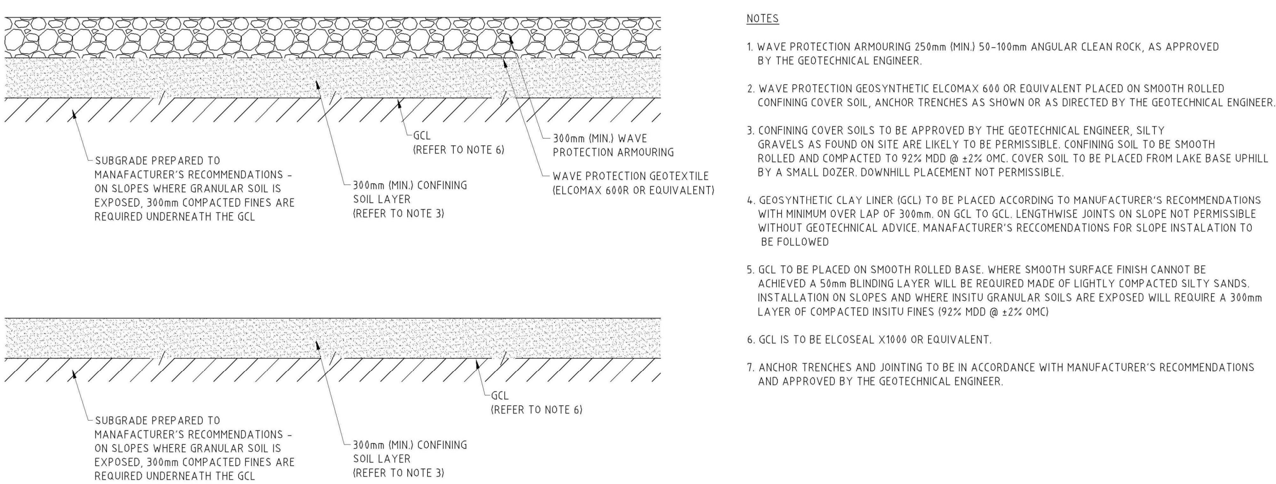

Figure 2: Typical cross section of the basal lining system (above with wave protection armouring).

5 DESIGN CONCEPT

5.1 BASAL LINING

The normal operational lake depth is 4.5 m, with an additional head of 500 mm during a 1 in a 100 year flood (1%AEP). The lake water is mainly pumped from the nearby Lake Wakatipu and distributed via diffusers on the lake bottom into several areas of the lake. Chemical analysis confirmed that Lake Wakatipu water is essentially fit for potable consumption with little impurities, minerals or chemical. Sodium bentonite was deemed to be suitable for lining. The chosen GCL comprised 270 g/m² non-woven cover geotextile, 3,700 g/m² bentonite clay and 380 g/m² non-woven carrier geotextile. The total mass was 4,350 g/m². The typical permeability co-efficient, measured according to ASTM D5887 is less than 2×10^{-11} m/sec, with the minimum average roll value (MARV) of less than $\leq 3\times10^{-11}$ m/sec.

Literature review indicated that with over 4.5 m water head product types with more bentonite are normally selected to provide lining solutions equivalent to a 1m thick clay liner. Calculations indicated that the resulting seepage and life cycle pumping costs with the GCL option are negligible and significantly more water is being lost due to evaporation than seepage.

The subgrade was very variable across the 5 ha of lake base. In the northern section fine silts required conditioning and proof rolling, whilst in the southern section the glacial till was undercut and replaced by *in situ* fines from the northern section. The site silts were excavated from the northern section to grade and proof rolled using a smooth steel roller with no vibrations. Where silts were used as a fill the silt moisture content was reduced to less than 35% by handling, spreading and air drying. For installation only light compaction was specified, i.e. 92% of Maximum Dry Density at +/- 2% of Optimum Moisture Content. Additionally a uniformly smooth subgrade was required. In the southern area the glacial till layers were undercut by 200 mm to 300 mm and replaced by lightly compacted conditioned silts. The GCL was then placed directly on the lightly compacted silts. The glacial till excavated from the southern section, essentially comprised of a sandy cobbly gravel was used as confining cover material. Approximately 300 mm of confining cover soil was placed with a light bulldozer (D3) immediately after installation of the GCL, with no compaction required. Where site trafficking was expected the cover layer thickness was increased from 300 mm to 600 mm to spread the wheel loads. To prevent installation damage no heavy tracked or wheeled plant was allowed across the completed liner sections. To allow complete water drawn down, if required at a later stage, the lake base was very gently inclined into a centrally located sump. Photo 2 shows the site half way through the construction period.

Photo 2: Construction period.

5.2 SIDE SLOPES

The chosen GCL liner can be installed at relatively steep angles as the two cover geotextiles and bentonite are needle punched to offer high shear resistance. However, relatively gentle slopes of 14º degrees (1V:4H) were chosen to reduce any likelihood of slope instability and allow access for people accidentally entering the lake. On the golf course side an additional safety bench was required. The installation of the GCL liner followed the same principles as the basal lining. The subgrade was prepared, the liner placed and confining cover soil spread. Depending on the selected lake edge a flat shelf or undulating terrain was produced and the GCL either anchored in a trench or continued above the 1% AEP line (1 in a 100 year event). The concept of lake edge design and typical sections are presented in a later section.

Rock armour was needed to prevent erosion of the confining cover material and exposure and subsequent damage of the liner. Following a review of the hydrological model, erosion from wave roll action was likely up to 1 m below the normal operational water level. In discussion and agreement with the client armouring was not placed higher than the 1% AEP level.

Rock armour material was chosen to conform to the following requirements:

i. A maximum particle size of 600mm, preferably quarry run rock and lie within the grading envelope in Figure 3.
ii. The Strength classification shall be R3 to R6 as defined in attached Table 2
iii. Degree of weathering classification shall be SW to UW as defined in attached Table 3

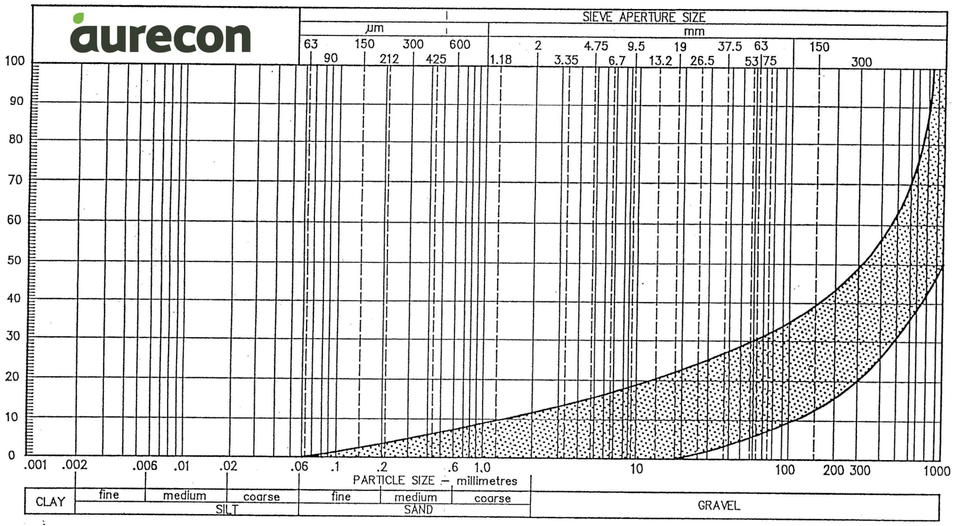

Figure 3 Particle Size Distribution for rock armour on lake edges

Table 2: Rock strength

Table 3: 3 Rock weathering.

UW	Completely unweathered, no discolouration or alteration present in rock mass
UW_{Fe}	Unweathered, iron stained defects; discolouration confined to defect surfaces; rock has maximum strength
SW	Slightly weathered; discolouration extends through less than 50 percent of the rock; no noticeable loss in strength of intact rock
MW	Moderately weathered; discolouration extends through at least 50 percent of rock with noticeable loss in strength, particularly near defects; unweathered relics retain maximum strength
HW	Highly weathered; discolouration, ie iron staining extends throughout; total rock has reduced strength
CW	Completely weathered; rock is totally discoloured and decomposed to soil, but original rock fabric (eg schistosity) is recognisable.

Strength	Consistency	Field Identifications	Approximate Range of Unconfined Compressive Strength (MPa)
R0	Extremely Soft	Can be indented by thumb nail	Less than 1
R1	Very soft	Crumbles under firm blows with the point of a geological pick, can be peeled with a pocket knife	1 to 5
R2	Soft	Can be peeled by a pocket knife with difficulty, shallow indentations made by a firm blow of a hammer end of a geological pick	5 to 25
R3	Average	Cannot be scrapped or peeled with a pocket knife, specimen can be fractured with a single sharp blow of a hammer end of a geological pick	25 to 50
R4	Hard	Specimen required more than one blow with a hammer end of a geological pick to fracture it	50 to 100
R5	Very Hard	Specimen requires many blows of the hammer end of a geological pick to fracture it	100 to 250
R6	Extremely Hard	Specimen can be chipped with a geological pick only	Greater than 250

5.3 PENETRATION DETAILS

Penetration of the liner was necessary in areas where structural elements, such as the reticulation pipes for lake water, piles and piers were to be installed. Figure 4 shows a modification of the manufacturer's recommended penetration detail that was adopted for pipes and piers. This detail was widely used in the modular lake edges where the reticulation system for the future expansion was already installed.

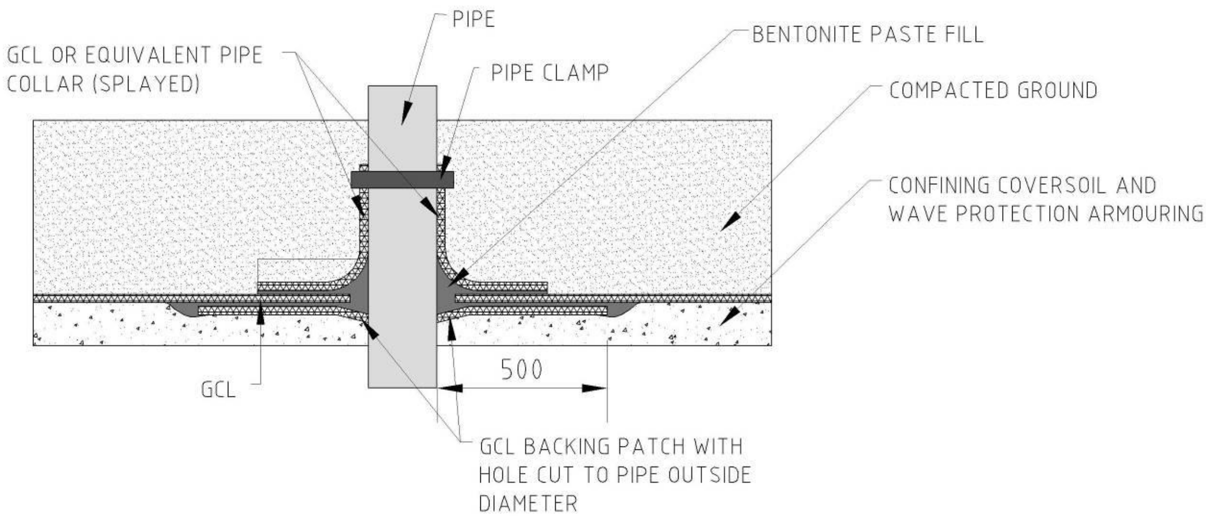

Figure 4: Typical GCL penetration detail (pipe penetration shown).

5.4 CONNECTIONS TO INFRASTRUCTURE

Relatively impermeable connection details were required to attach the GCL to infrastructure elements such as the new outlet weir at the southern end of the lake (Figure 5).

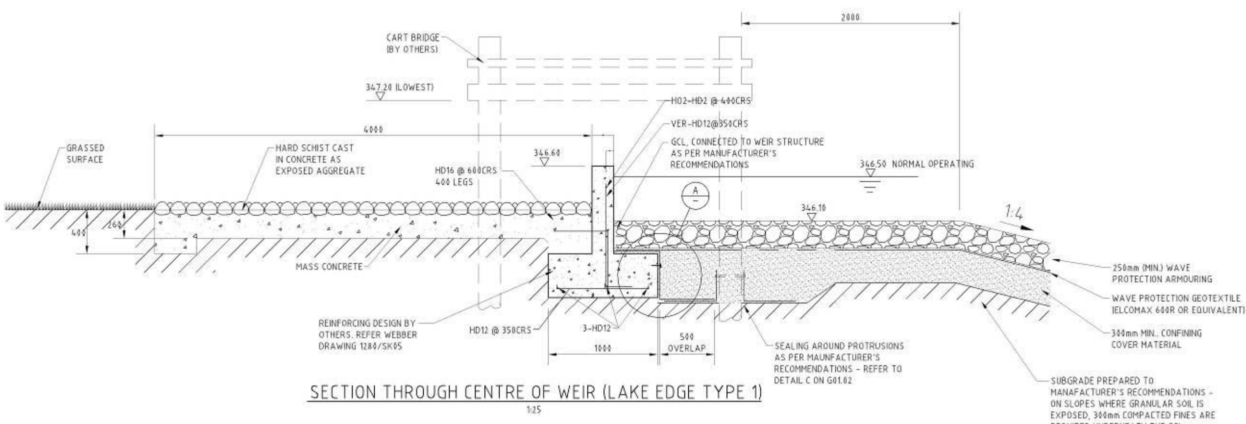

Figure 5a: Weir structure.

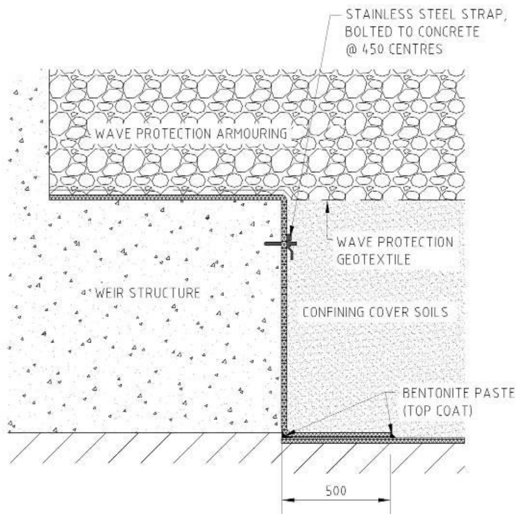

Figure 5b: Typical connection detail against hard structural elements.

5.5 LAKE EDGE DESIGN

The lake edges were primarily designed to resist erosion by wave action and to restrict vegetation growth. The depth of cover soil around the lake edges was kept to 300 mm across the entire lake area. Where root penetration was considered a risk, especially the densely vegetated riparian lake edges and wetland areas, at least 600 mm of cover soil was needed. A minimum of 200 mm rock armour was specified but typically 300 mm installed. The master plan and resource consents required the following operating levels and floor levels to avoid inundation:

- Normal operating level 346.50 RL
- 100 year flood level (1% AEP) 347.00 RL
- Minimum village floor level 347.67 RL

Several lake edges were developed to vary the lake environment and provide an attractive easily maintainable robust environment. A 3 m wide safety bench located 150 mm to 500 mm below the normal operational lake water level was generally used to catch people falling into the lake. Where a safety bench could not be established the maximum slope angle was 14° (1V:4H). The nominated architect team provided fascia cladding of all structural retaining systems using locally available durable non-erodible material, such as dry stacked schist rock.

Several lake edges were developed to meet the client's vision and architectural requirement without compromising the engineering specifications. Figure 6 shows a low height stone wall lake edge that was developed for the area around the weir structure near the golf club house. Figure 7 shows the edge around the 18th fairway with the safety bench and large boulders to prevent accidental access to the lake. Figures 8 and 9 show two types of vegetated soft edges which were used around the northern part of the 18th fairway and the wetland areas. Figure 10 shows a wetland edge where future development is likely to be undertaken, especially around the north-eastern island development.

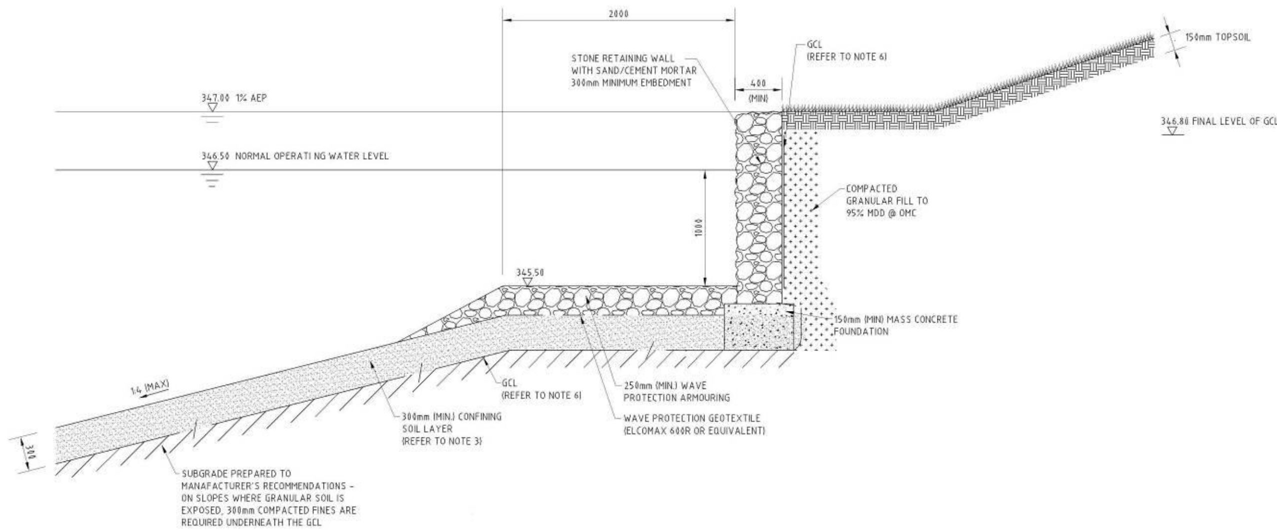

Figure 6: Low height stone wall lake edge.

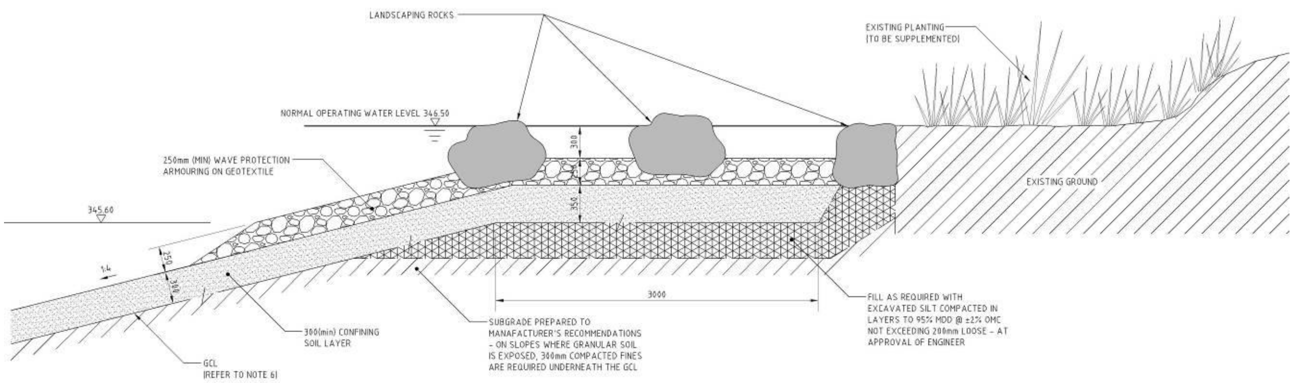

Figure 7: 18th fairway lake edge.

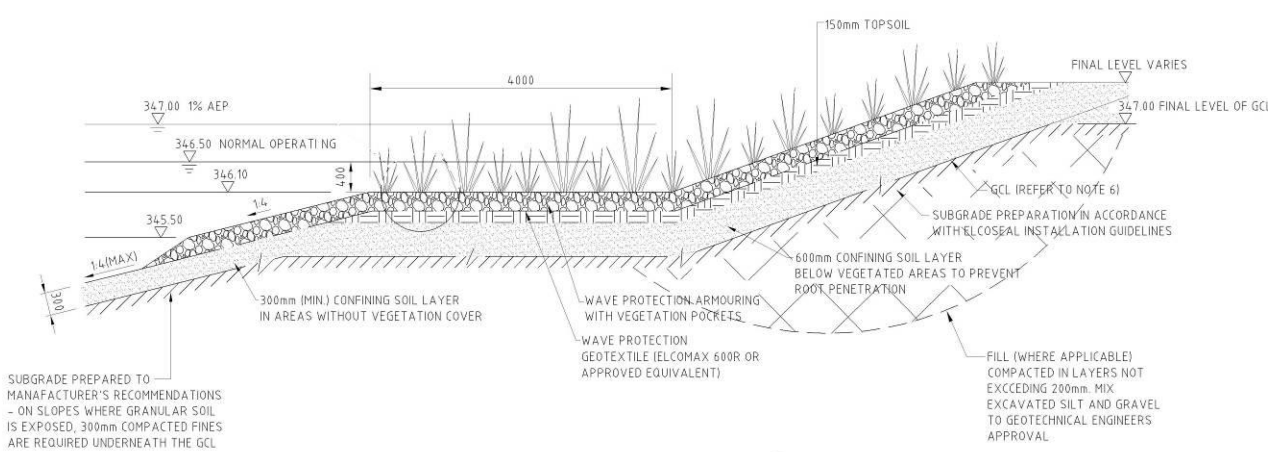

Figure 8: Vegetated soft edge

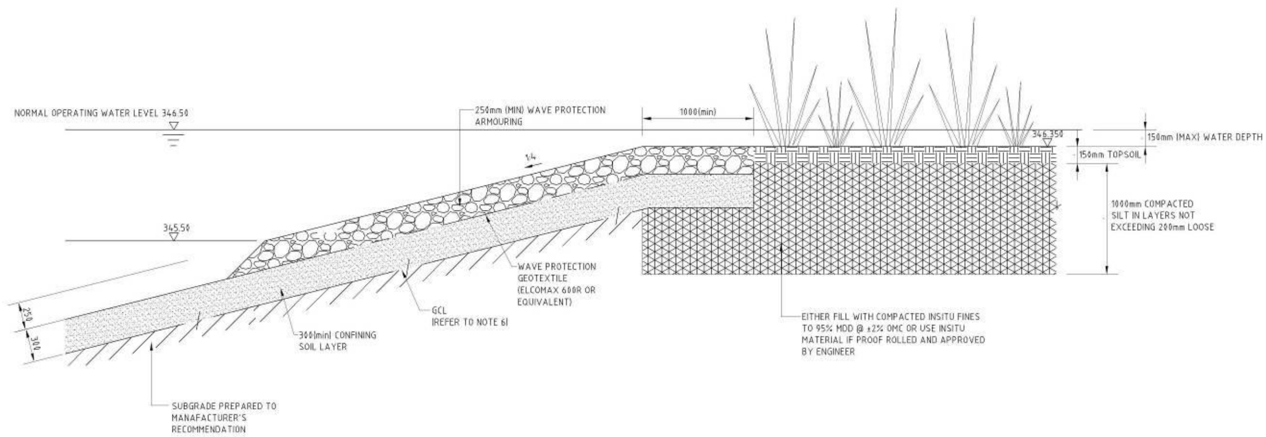

Figure 9: Vegetated soft edge and wetland transition area.

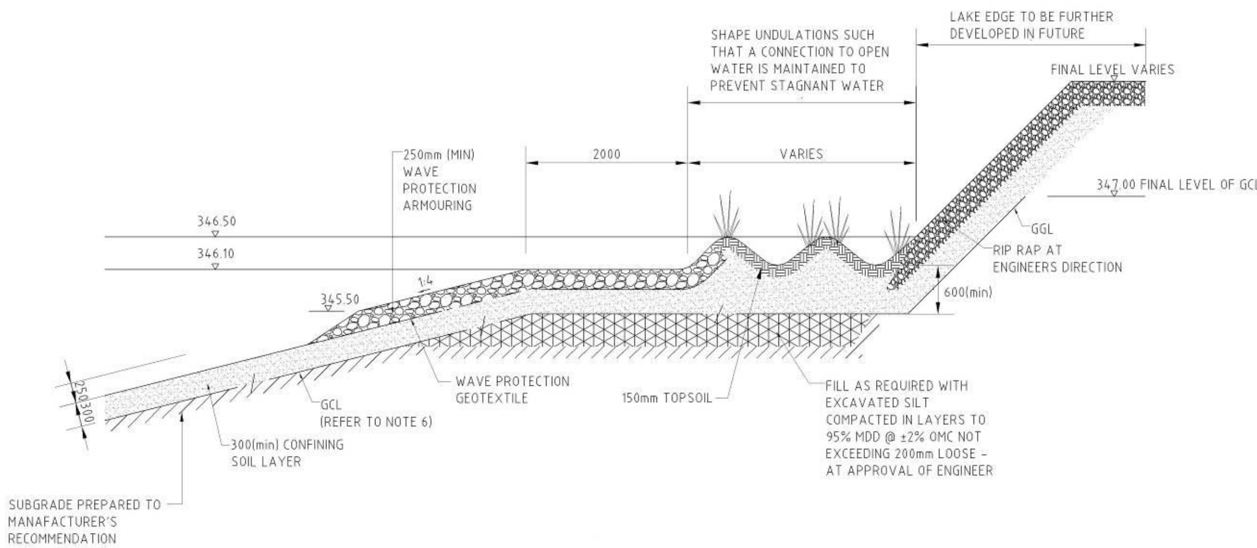

Figure 10: Island development vegetated lake edge.

6 MODULAR LAKE EDGE

At the time of final design in 2007 and with the impeding global economic downturn, the project scope and construction budget were reviewed and revised. The lake size was decreased from over 8 ha to about 5 ha and construction of the southe-astern bay and north-eastern island development deferred. The client intended to develop the lake with the option to continue development at a later stage. Figure 11 shows the revised lake size and proposed future expansion and development areas.

The modular lake edge was developed as part of this future proofing. The risks and difficulties associated with constructing the final edge after the lake was filled were perceived to be significant, particularly in reinstating a stable liner system as well as the effects on sediment discharge on the water quality and lake health. Hence the permanent lake edges were installed along the southern, western and majority of the northern lake fronts. The modular lake edge was installed along the eastern lake frontage where the majority of the village and commercial development it is likely to occur in the near future.

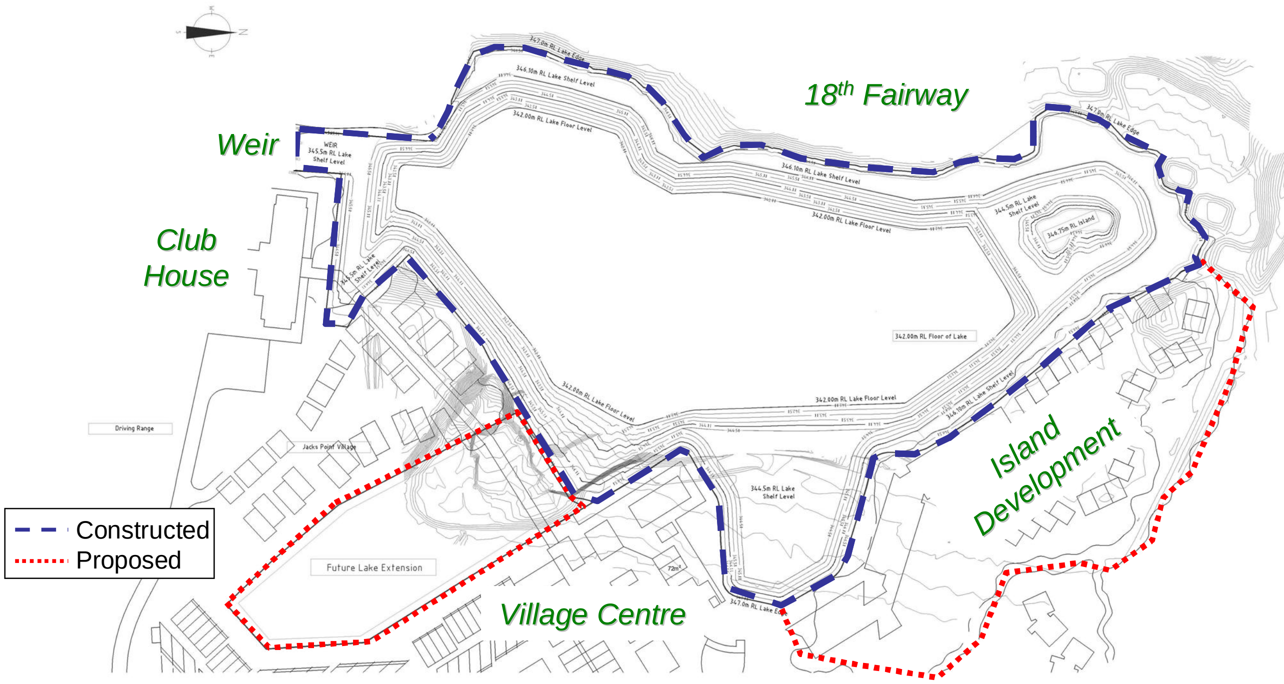

Figure 11: Constructed and proposed development areas.

The aim of the modular design approach was in line with the client's requirements that during later development stages the lake level is not to be lowered, most of the development such as retaining walls and basements are to be excavated in the dry, the high water quality is to be maintained in the long-term and discharge of sediments during construction is to be avoided.

The key challenge was to design and build a cofferdam and/or temporary lake edges that are visually identical and offer similar performance as permanent solutions, with the benefit that they can be easily modified and removed once the development proceeds further to expand the lake. Thus the liner was designed and installed in such a manner that removal of a cofferdam can be undertaken behind a silt curtain without the need to lower the lake level. Figure 12 shows a typical cross section indicating key components of the modular liner system.

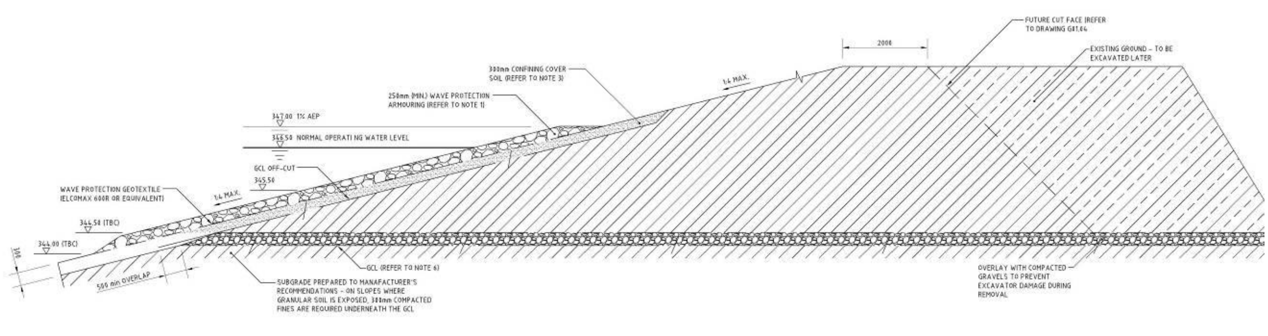

Figure 12: Cross section of the modular lake edge with typical components.

The GCL liner was installed at the future lake bed level, in this particular case the south-eastern bay bed level was slightly higher than the remainder of the main lake body. The GCL was covered with 500 mm of compacted gravel acting in this case as the confining cover material. The purpose of the gravel is to protect the GCL during embankment removal at a later stage. Once the embankment was completed the transition area and 'wet' embankment side was covered with a GCL that overlapped the basal GCL and formed a waterproof seal along the embankment or cofferdam side. Following GCL installation confining cover soil and wave protection armouring placed.

Two different temporary lake edge types were constructed. A cofferdam of till was constructed across the south-eastern bay and the main lake body. This area was used as a borrow pit and created a low lying depression that will form the south-eastern bay. The ‘dry’ side of the cofferdam in this area is exposed and appears like an earth dam. Around the island development, which is likely to proceed at a much later stage than the south eastern bay development, the entire cofferdam was buried and the areas landscaped to appear as permanent lake edge.

The key component of the system is the ability of the GCL to form a tight seal by simple overlap with no welding or any other mechanical connection being needed. The buried GCL can be exhumed and connected to the new liner system or infrastructure, using a similar detail as shown in Figure 5b. The cofferdam would then be removed from the land side using GPS controlled excavators (machine control) to minimise the risk of damage to the liner. Any migration of fines can be prevented by a floating silt curtain extending to the lake bed. At the end of construction any suspended sediments within the excavation area can be removed using flocculation. Figure 13 provides an indicative construction process that will enable construction of infrastructure elements and connection of all liner elements in the dry.

The key construction stages are as follows:

Step 1

- Remove part of the dry cofferdam in such a manner as to maintain global stability and prevent embankment failure similar to dam breach
- Create a working space to install the infrastructure elements such as retaining walls or piers, alternatively create the future bay area
- Exhume the GLC, fold it back and protect it from deterioration such as moisture swelling

Step 2

- Construct the retaining wall or pier, including foundation treatment or piling as required. Alternatively create the bay base and prepare the liner to be connected.

Step 3

- Prepare the connection between new and exposed liner. Allow a minimum of 500 mm overlap and fill joints with bentonite paste.

Step 4

- Install in main lake body a silt curtain and anchor it to the lake base.
- Use GPs controlled excavators to remove the cofferdam. Depending on application the dry side behind the cofferdam may need to be flooded to prevent a dam breach failure.
- Once the cofferdam is excavated use flocculation to remove suspended fines.
- Remove silt curtain and activate the pre-installed recirculation system to maintain lake health.

7 RETICULATION SYSTEM

Environmental modelling of the lake health and water quality indicated that several discharge points are required to allow recirculation of lake water and reduce the likelihood of stratification and associated lake health issues. Figure 14 shows a typical underwater intake and discharge point and pipeline. Based on discussions with the project team and client all infrastructure for reticulation was to be installed during the main construction phase to avoid underwater installation at a later stage. This was achieved by providing penetrations and piping with water intakes and outlets to allow later water recirculation. Where pipes protruded through the liner and cofferdam a stop valve was installed (Figure 15).

Figure 16 shows the completed reticulation system currently installed. The system layout was designed using environmental models and it considered development of several areas at different times. The ability to pump water into different lake areas was seen as the main contribution to successful lake health. In order to reduce the residence times in the lake and foster good water quality all irrigation water for the golf course is taken from Lake Tewa, whilst Lake Wakatipu is used to top up Lake Tewa. The current lake shape was selected in such a manner that naturally occurring currents maintain a stable system, whereas the shape of the proposed development areas will require additional reticulation to promote water recirculation. The bay water discharge point will be installed at the far southeastern corner to create a water flow into the lake centre. Similarly the proposed island development will require water recirculation to reduce the risk of stagnant areas developing, with effectively a small river flowing down the east side of the island.

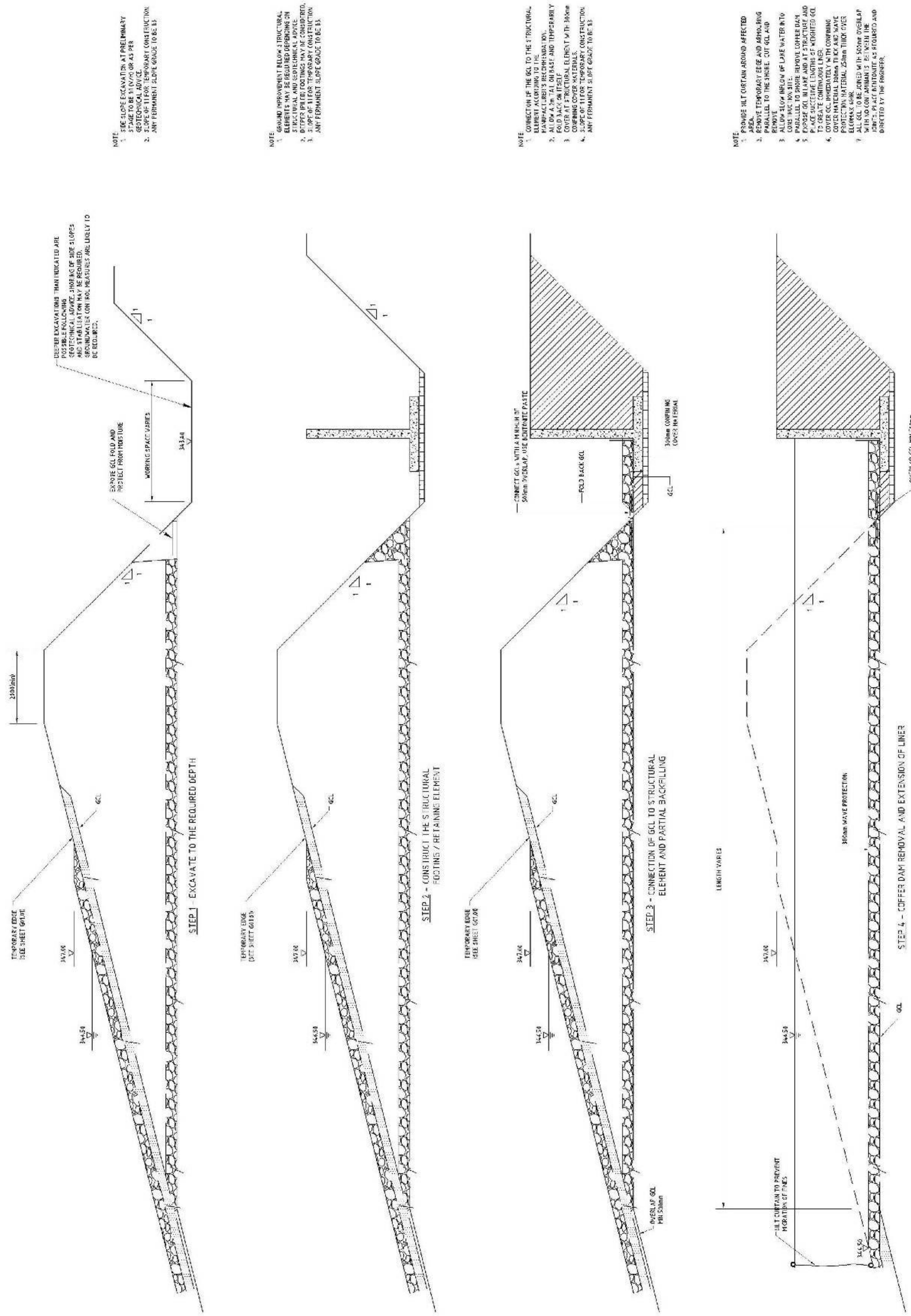

Figure 13: Proposed future construction process using the modular lake edge.

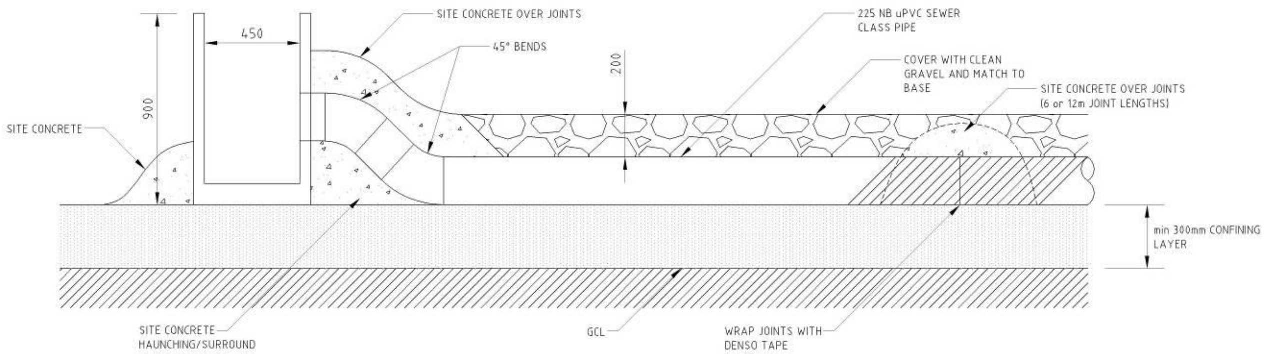

Figure 14: Typical underwater intake and discharge point and pipeline.

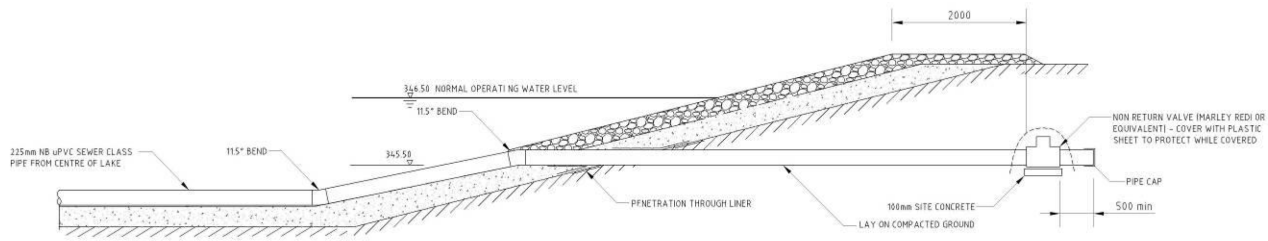

Figure 15: Penetration detail through a temporary lake edge with buried stop valves.

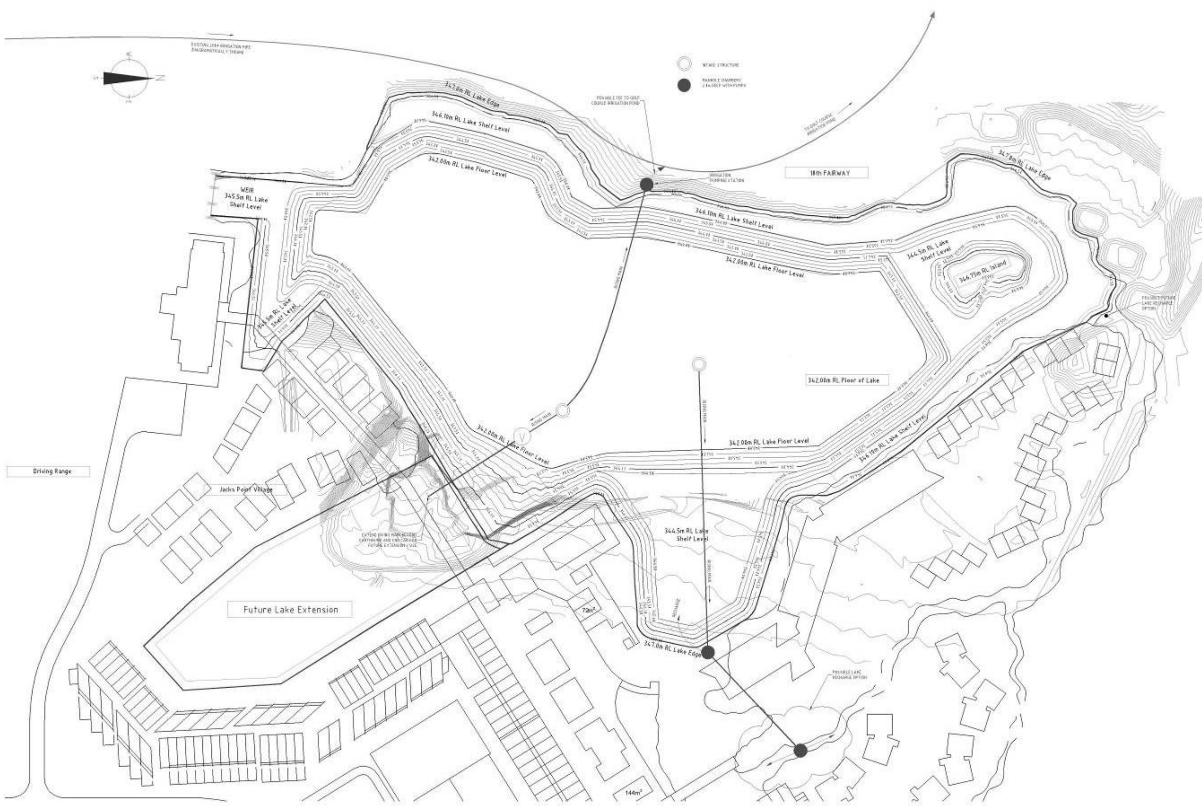

Figure 16: Reticulation system currently installed.

8 DISCUSSION AND CONCLUSIONS

The liner system was installed in a very efficient manner with minimal delays and the contractor completed the construction programme on time. The lake, christened Lake Tewa upon completion, has become the centre piece of the Jack's Point Village development and to date performs as intended by its designers, with latest results confirming that the intended water quality has been achieved and maintained. In fact the latest test results indicate that only algae that thrive in high quality water are present.

The seepage losses to date are negligible and the GCL appears to perform as designed and intended. Photo 3 shows the lake being partly filled. The modular lake edge is shown with confining cover soil, wave protection armouring and an exposed recirculation pipe.

In this case a man made lake was designed to be modularly expandable. In other industrial applications such as mining operations or waste containment the ability to contain fluids and expand the storage area without draining the reservoir may be of great benefit.

Photo 3: View along the modular lake edge and partially filled lake.

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