DEWATERING GUIDELINE

Version	TRIM	Phase	Date	By
1	16/1290755	Final	3 November 2016	SCIRT 1001-CN-GE-GL-0001

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Glossary of Terms

Aquifer	Soils or rocks that contain sufficient saturated permeable material to yield viable quantities of water to wells and springs
Confined Aquifer	Groundwater in soils or rocks that is isolated from the atmosphere by low permeability formations
Artesian Aquifer	A confined aquifer containing groundwater pressures at or above ground level
Unconfined Aquifer	Permeable soils or rocks in which the water table is exposed to the atmosphere through the overlying materials
Piezometer	A device used to measure the static groundwater height to which a column of the water rises against gravity, or the pressure (the piezometric head) of groundwater at a specific point
Sump	A shallow excavation
Well	Deep excavation with permeable casing
Well-point	A perforated pipe connected to a suction line
SCIRT	Stronger Christchurch Infrastructure Rebuild Team

Principal Stages in Assessment and Implementation of Dewatering

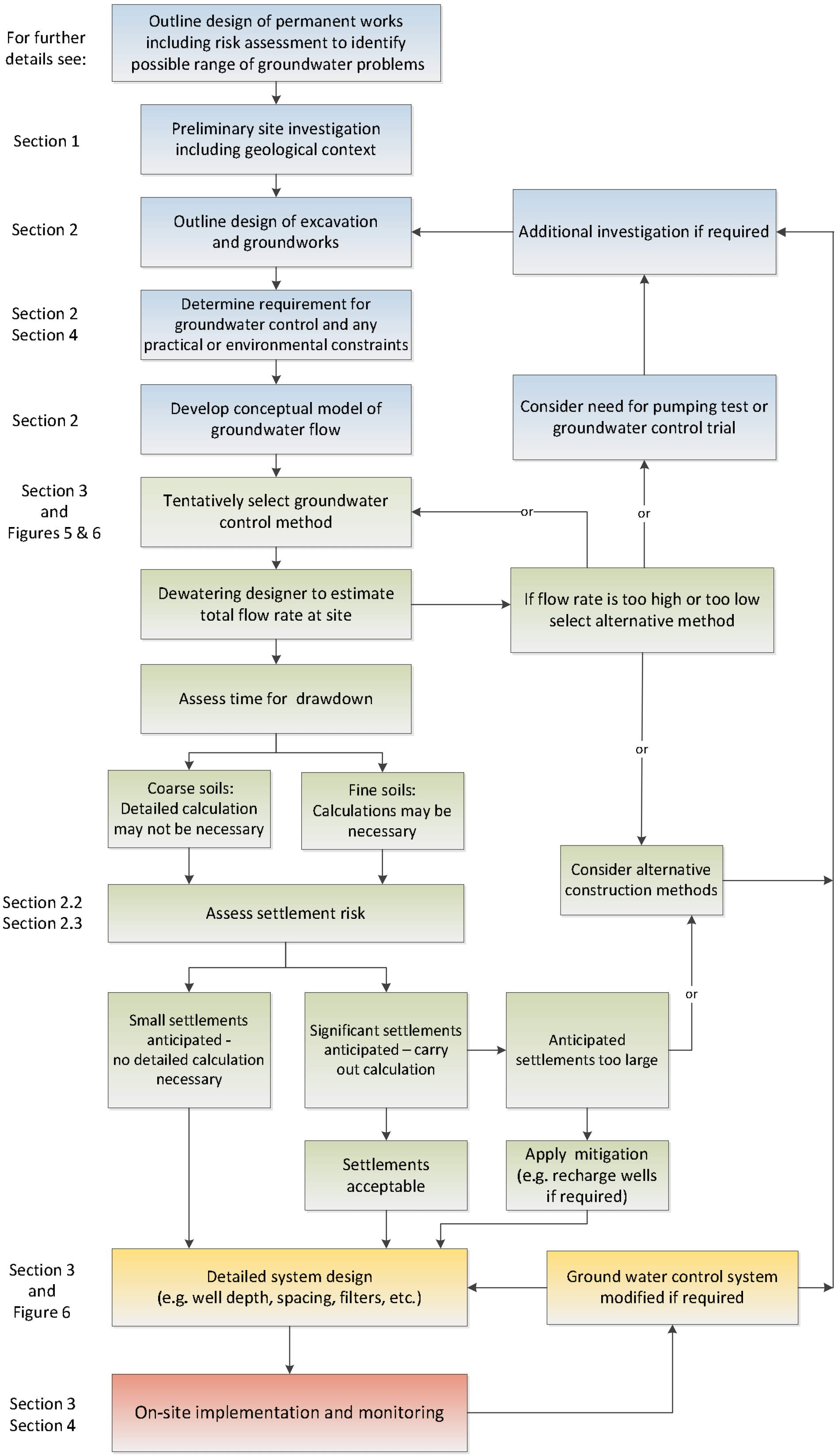


Figure 1 Assessment and Implementation Flowchart (Source: CIRIA C515, [SCIRT Modified])

1 Introduction

1.1 Purpose

Uncontrolled or improperly controlled groundwater can cause piping, heave or reduction in the stability of an excavation. High groundwater levels could affect the stability of foundation soils such that they become unable to support a structure.

Control of groundwater can be achieved by lowering the groundwater pressures; for example by intercepting seepage that would otherwise emerge from the slopes or the base of an excavation to improve stability of the excavated slopes and avoid unwanted displacement of, or loss of material from, the slopes or base of the excavation.

When temporary works dewatering methods applied during construction are not appropriate for site conditions, significant adverse effects on construction productivity can result. Construction programme may be delayed and additional capital expenditure is frequently required for construction and for remedial works; these costs can be substantial. Review of dewatering risk and potential dewatering solutions during design will allow appropriate allocation of budget, considering the risk profile for the project. Active design of temporary works dewatering appropriate for the site may require an additional upfront cost, but will commonly result in an overall project cost saving.

This document sets out frequently used options for effective construction dewatering in Christchurch and provides general guidance on method selection, design and monitoring. It also attempts to set out a process for assessment of the relative risk of a dewatering project.

1.2 Scope

This document sets out:

- The geological context of Christchurch and its influence on dewatering practices
- An outline of dewatering practice, available methodologies and considerations for selection
- Discussion of potential problems during implementation, their consequences and their mitigation
- Guidance on mitigating environmental effects and consenting conditions with which the dewatering may be required to comply
- Tools to assist consistent assessment of the dewatering risk profile for projects
- Minimum dewatering design actions
- Potential project specific risks and anticipated dewatering works for incorporation in a project
- Guidance for accidental interception of artesian aquifers or large inflows

Methods to reduce hydrostatic pressure beneath the bottom of an excavation are divided into two categories:

- Drainage: interception and removal of groundwater from the site by gravity drainage or pumping from sumps / trenches, well-points or pumping wells; and
- Isolation: blocking the inflow of groundwater, typically by sheet-piling, grout curtain or slurry wall

During construction it is generally desirable to maintain the groundwater level at least 1 m below the bottom of an excavation to achieve suitable working conditions. Groundwater may need to be maintained at a lower depth in silts and silty fine sands (1.5 m to 3 m below) to avoid disturbances resulting in “spongy” conditions in the excavation.

1.3 Geological Context

1.3.1 Aquifers in Canterbury

The gravel aquifers are primarily recharged by seepage from the Waimakariri River in the area to the north-west of Christchurch City and by infiltrating rainfall on the plains to the west (beyond the inland edge of the low permeability Christchurch Formation surface strata).

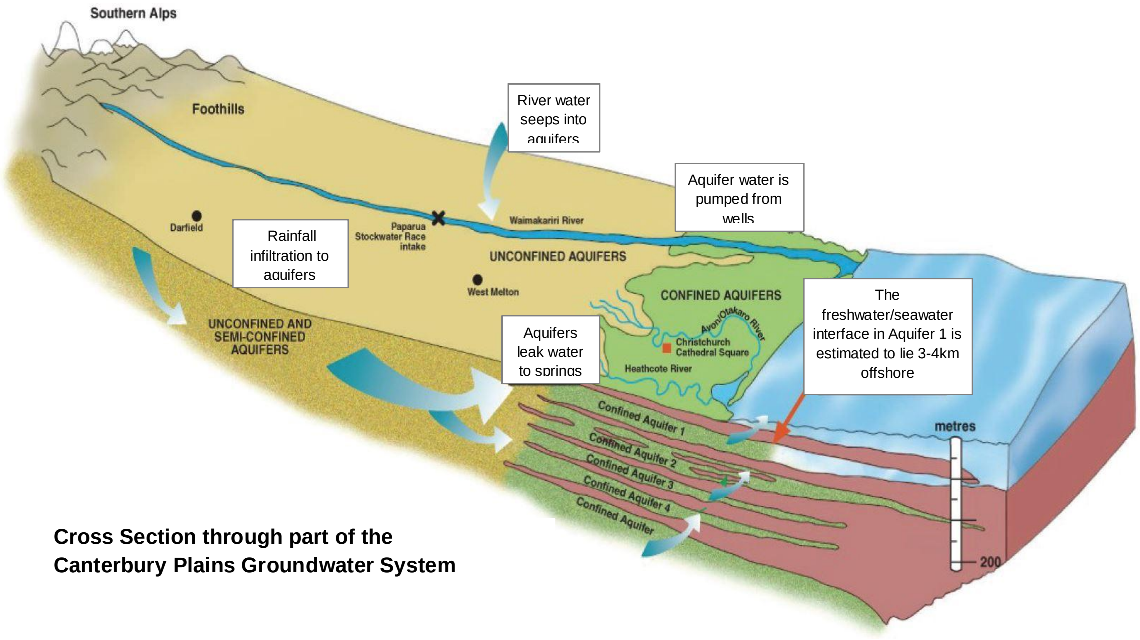


Figure 2 Illustration of the Aquifer Systems beneath the Canterbury Plains (Source: Weeber, 2008)

Perched groundwater can be found in the highly variable Springston and Christchurch Formations and will respond rapidly to surface rainfall events. A median groundwater surface mapped by GNS Science (2013) shows that groundwater in these formations is typically found at 1 m to 4 m depth although seasonal variation can be up to 3 m between winter and summer levels.

The uppermost artesian aquifer known as Aquifer 1 or the Riccarton Gravels is commonly found in Christchurch at approximately 20 m to 30 m depth. This is an extensive horizon of sandy gravels with cobbles, and contains substantial volumes of water usually under pressure, with aquifer pressures becoming stronger toward the coast. This aquifer is hydraulically connected to the Waimakariri River and the spring-fed streams across Christchurch, usually through artesian spring vents. Well yields in excess of 50 l/s are common. If large excavations approach the Riccarton Gravels from above, upward leakage can occur through the excavation.

1.3.2 Why is it important to understand the Nature of the Aquifers?

Knowledge of where groundwater is coming from and the pressure state it may be under is important when attempting to effectively dewater the area to be excavated. The selection and implementation of a dewatering system needs to suit the characteristics of the aquifer as it exists at the site.

Understanding the Christchurch aquifer system is also important in planning and avoiding effects on the excavations, surrounding structures, existing environment and other water users.

The distribution of confined and unconfined aquifers is indicated in Figure 3. This implies that much of the Christchurch area is underlain by a confined aquifer with variable artesian pressures. The artesian pressures can be expected to be encountered 2 m to 5 m below the ground surface in western parts of Christchurch and possibly up to 2 m above existing ground level in eastern parts.

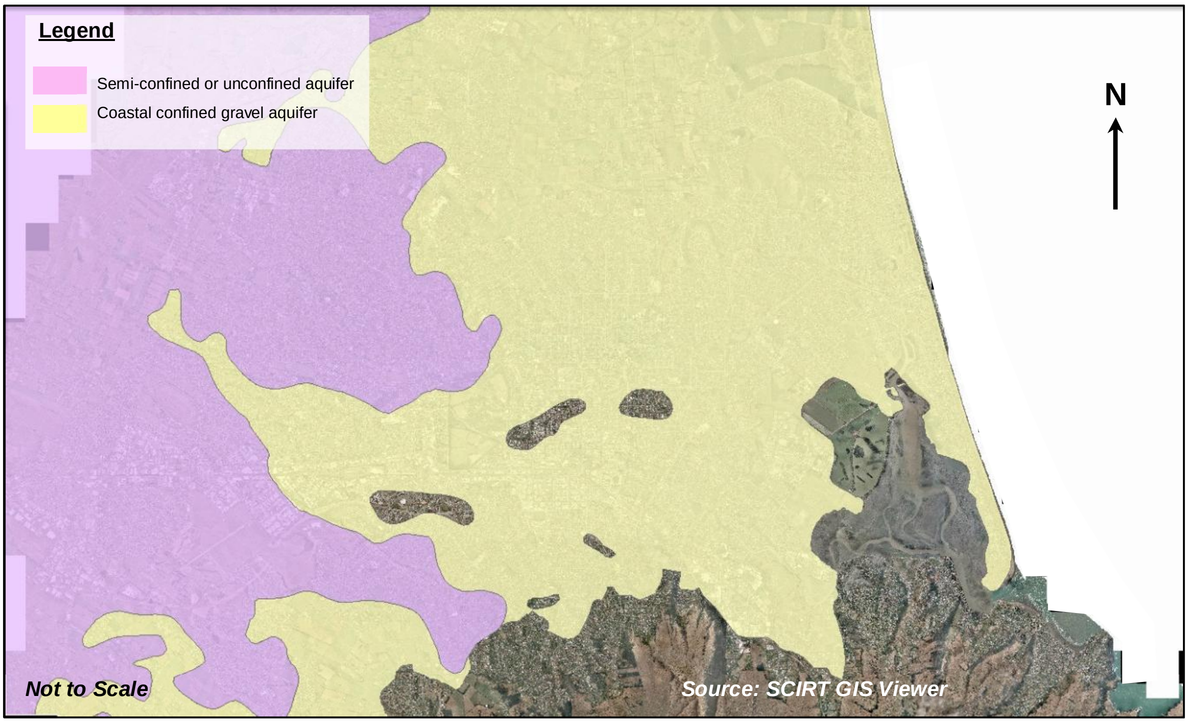


Figure 3 Distribution of confined and unconfined Aquifers beneath Christchurch

1.3.3 Soils in Canterbury

The Christchurch aquifer system has been formed from glacial and river derived silts, sands and gravels, deposited during the alternating glacial and inter-glacial periods over the last 500,000 years. Deposition of silts, sands and gravels during ice advances (glaciations) formed fans of unsorted outwash on the inland Canterbury Plains. During the warmer interglacial periods, rivers reworked these outwash deposits and re-deposited them further down the Plains as sorted silts, and sandy and gravelly strata.

During the same time period, along the coastline, rises in sea level during interglacial periods have resulted in the reworking and re-deposition of finer grained (silts and sands) in fluvial, marine, estuarine and dune deposits. These fine grained deposits are thickest at the coast.

This sequence of glacial and interglacial periods in the Christchurch area has resulted in the formation of permeable glacial and river-derived gravel layers originating from the inland area to the west, inter-fingered with low permeability marine and estuarine sediments which thicken in an easterly direction.

Brown and Weeber (1992) describe the geology of the Christchurch area. The major stratigraphic units comprise the surficial Springston and Christchurch Formations, with the underlying Riccarton Gravel Formation containing the upper-most artesian aquifer. Weeber (2008) provides a more detailed map showing isopachs (contour lines of equal thickness) of fine grained deposits exposed at the surface and the zone across which groundwater pressures become flowing artesian (Figure 4).

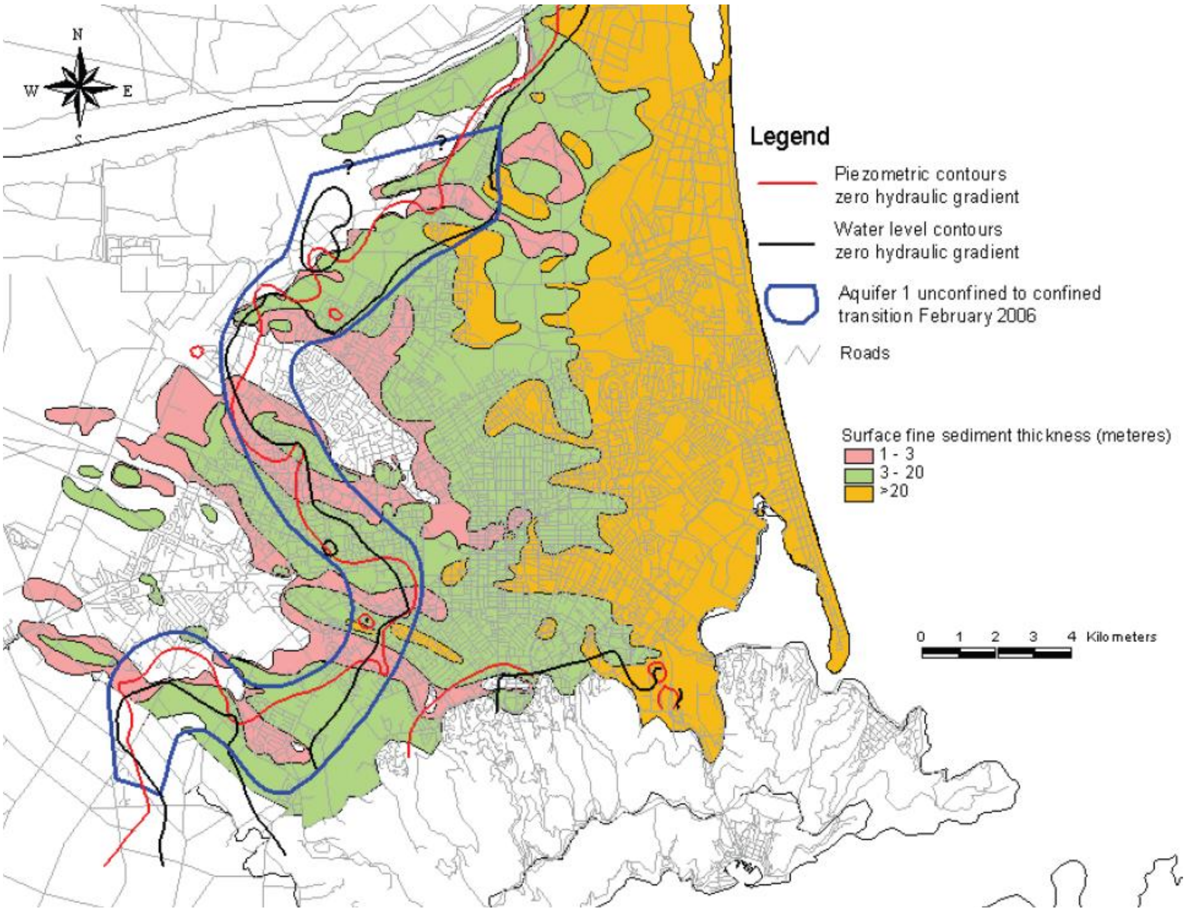


Figure 4 Aquifer 1 transition from downwards (west) to upwards (east) hydraulic pressure gradient superimposed on the surface fine sediment thickness (isopach) map (from Weeber, 2008)

The silts and clays found in Christchurch are fine grained, less than 0.06 mm in diameter. They occur in discrete layers of a few centimetres to several metres in thickness. The silts and clays have low permeability. Thinner layers of slits can also cause localised perching of groundwater.

Sandy gravel deposits are coarse grained (with sand 0.06 to 2 mm diameter), usually up to cobbles / boulders. The sands and gravels are typically permeable and could yield larger volumes of water when pumped. Even thin layers of sand and gravel interlayered with silts can yield large flows if continuous. If the water in these sands and gravels is under pressure, the flow rate into a well or excavation could be higher until the storage component is exhausted.

Groundwater can also flow vertically across silty horizons and if the surface area of an excavation is large, upward vertical flow from underlying artesian aquifers can be significant. An extended pumping period of several weeks may be required to observe the effects of lowering the groundwater table.

Figure 5 shows grain size plotted against soil grading and the combinations best suited to the various dewatering options. The figure also demonstrates that flow under gravity is reduced when grain sizes fall below that of very fine sand.

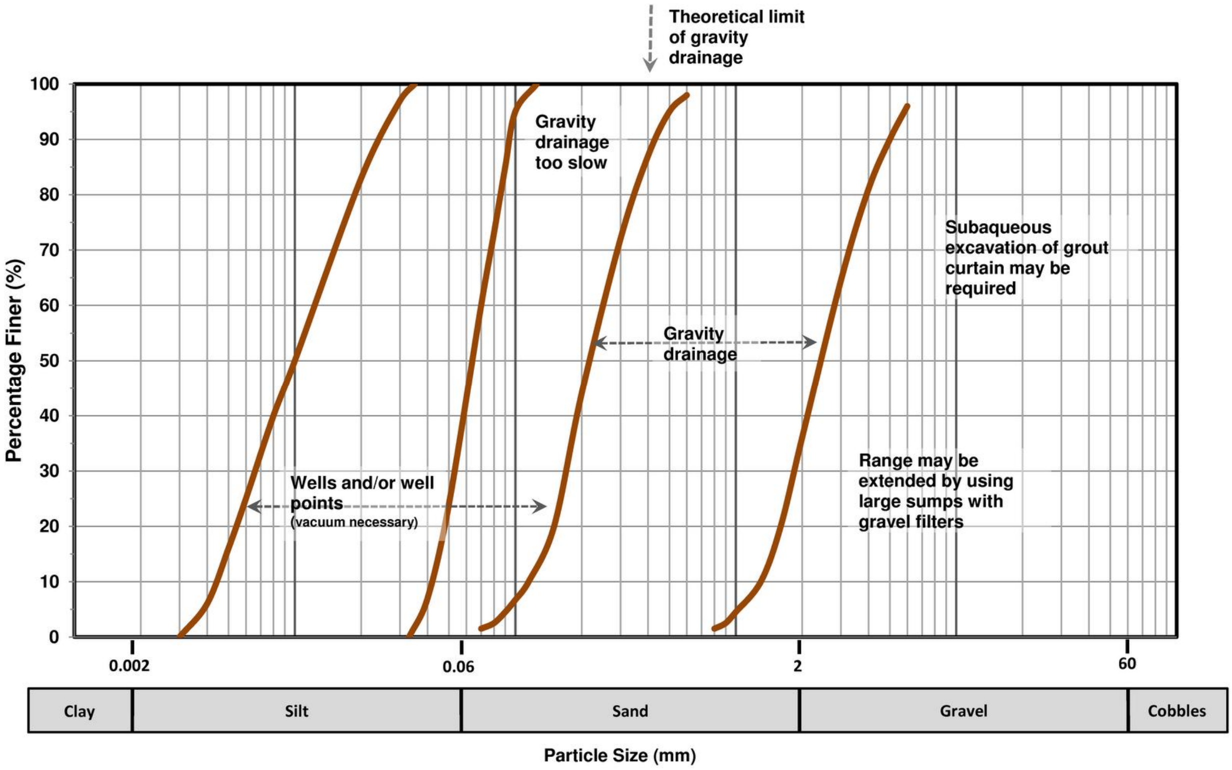


Figure 5 Dewatering Methods Applicable to Various Soils, from M. R. Hausman (1990)

Figure 6 shows permeability plotted against required groundwater drawdown and the combinations best suited to the various dewatering options. A summary of the soil gradings (from) and how these typically relate to Christchurch soils is also shown.

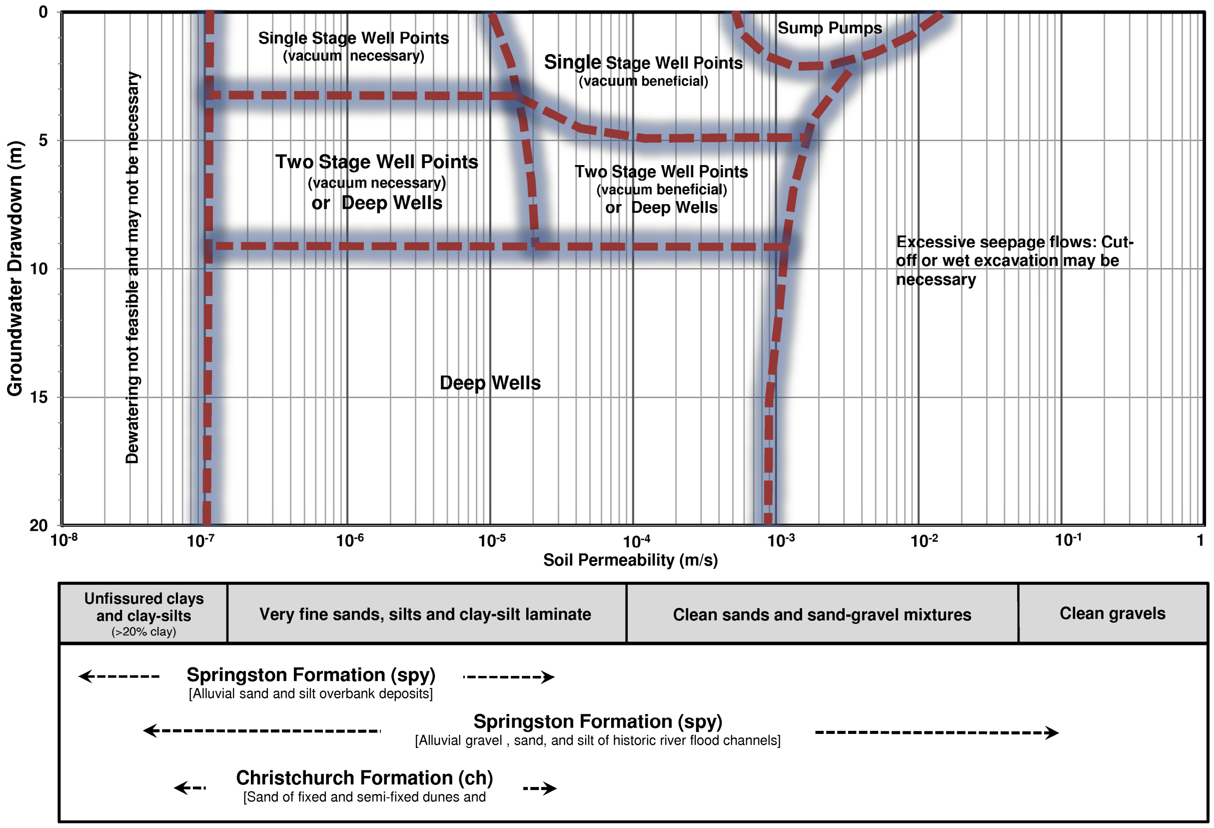


Figure 6 Range of application of pumped well groundwater control techniques adapted from CIRIA C515 (2000)

1.3.4 Why is it important to understand the Soil Profile?

The permeability of the soils will control how groundwater is released when pumped. This means that understanding the materials in and around a planned excavation will be crucial to selecting the appropriate dewatering system.

Typically pumping rates are highest at the initial stages of dewatering in order to achieve the necessary drawdown, after which, the pumping rate can usually be reduced to maintain groundwater at the desired level. The initial release of water and long term yield are dependent on the soil properties.

For example, in the central city, silts are typically found to approximately 4 m depth, below which, a gravel layer can commonly be found. The silts will not yield a lot of water but the gravel layer can yield >100 l/s. In this case if a well pointing system were used, it may not be sufficient to lower groundwater; high yielding pumping wells may be required, perhaps in combination with well-pointing (refer Section 4).

An evaluation of the methods for determining site-specific permeability characteristics is set out in Table 1. Table 2 expands on some of the items in Table 1, describing common geological problems, some Christchurch specific case study data, and some issues commonly encountered on site. The lists are not intended to be exhaustive.

SUGGESTED HIERARCHY OF TECHNIQUES TO CONSIDER FOR THE DETERMINATION OF SITE PERMEABILITY CONDITIONS

Table 1 provides a list of techniques that may be used to determine ground permeability. The methods are listed in approximate order of cost and reliability. Key references are identified and should also be consulted.

Table 1 Methods for Determining Permeability of Soils

Method No	Method Type	Description	Brief Details	Order of Cost
1	Empirical	Assignment from bore logs only	Based on soil descriptions from logs, assign order of magnitude permeabilities to the various strata identified from reference to typical values for soil type	· Lowest cost method · Design hours only incurred
2	Empirical	Estimation using Hazen Method	Estimate order of magnitude of permeability from particle size distribution (PSD) curves Only possible if PSD tests are available	· Low cost if PSD data available; otherwise test pits or boreholes, sampling and laboratory grading tests required.
3	Laboratory Method	Constant Head Test	Applicable for soils with relatively high permeabilities, in the order of 10^{-2} to 10^{-5} m/s	· Relatively low cost test but requires samples to be obtained from test pits or boreholes
4	Laboratory Method	Consolidation and Triaxial Cell Test Methods	Applicable for soils with relatively low permeabilities, in the order of 10^{-6} m/s or less	· Relatively low cost test but requires samples to be obtained from test pits or boreholes
5	Field Method	Slug Tests	For use in the saturated zone within a borehole only. Response data measured when the water level is caused to rise or fall rapidly in the borehole by adding or removing a "slug" of water. A long heavy object can also be added to achieve the displacement.	· Requires boreholes to be drilled · Test carried out within the drilled hole but permeability can be too high for these tests to be successfully carried out in some formations in Christchurch (i.e. response is too quick to record accurately) · Lower cost than pumping tests and can be completed over a shorter timeframe · Gives an indication of the permeability immediately adjacent to the borehole

Method No	Method Type	Description	Brief Details	Order of Cost
6	Field Method	Pumping Tests	Installation of a submersible pump in a borehole (well), pumping at a selected rate (constant rate test) recording the drawdown in the pumping well and nearby observation wells as pumping proceeds and the recovery of the water level on cessation of pumping.	· Most costly and time consuming option but also the most reliable over wider areas · Appropriate for long term or deep dewatering projects · Involves pumping over periods of 24 hrs to 7 days, monitoring, and detailed analysis of data

1.3.5 Summary of Ground Issues

Table 2 Potential Ground Problems and Issues Commonly Encountered on Site

Issue No	Subject	Discussion / Key Technical Details / Case Study Information
1	Christchurch Specific Experience and Case Studies: Groundwater levels	The Canterbury Geotechnical Database contains a summary of the GNS Science Median Groundwater Surface Elevation records that are readily available. This database can be consulted in the first instance for an indication of the water level on any site of interest.
2	Christchurch Specific Experience and Case Studies: Risk of encountering artesian aquifers, and springs	The vast majority of excavations to be carried out will be less than 5 m deep. The uppermost artesian aquifer in the Christchurch area is the Riccarton Gravels which commonly occurs at over 20 m depth, and therefore this aquifer is unlikely to be encountered. Note that upward groundwater flow gradients can be felt when excavations approach the depth of this aquifer, and not only once the aquifer is encountered. Springs can be encountered on job sites. A Christchurch specific study by GNS (2013) refers to springs which existed prior to the Sept 2010 earthquake as well as new (earthquake induced) springs. It is recommended that this document be referred to as part of the desk study work.
3	Christchurch Specific Experience and Case Studies : Peat	Dewatering in areas of peat can cause significant ground settlement due to the high water content of the peat. Christchurch specific site investigations have encountered peat in the following areas (list non-exhaustive): St. Albans, Westminster Park in Shirley, Bromley, Linwood, Marshlands, Cranford Road in Papanui.
4	Christchurch Specific Experience and Case Studies : Shallow gravels	Shallow gravel layers can complicate spear installations and lead to high inflow volumes. Mitigation is to carry out sufficient geotechnical desk study and if necessary, site specific investigation so that appropriate dewatering methods can be designed and implemented. This issue has previously been encountered in Merivale.
5	Christchurch Specific Experience and Case Studies : Project specific permeability values	Permeability (k) values have been estimated from falling head tests in boreholes, and falling and rising head tests in standpipe piezometers.
6	Site issues – sheet piles cannot be driven to depth required	Unless ground conditions are considered, there is a risk that dense layers may be encountered during driving of sheet piles that prevent installation. Mitigation is to carry out a formal, checked sheet pile design prior to starting work on site.

2 Pre-construction Dewatering Assessment

2.1 Introduction

This document presents simple to use tools and checklists to use during the pre-construction stages when assessing the various risks associated with projects which include dewatering.

A non-exhaustive table of key dewatering related risks is presented in Appendix A to aid in formation of the project Risk Register and Inspection and Test Plan (ITP).

This Guideline contains the following sections, these being some of the key issues to be covered during the dewatering design stage:

Forming the ground model, assessing permeability, and further geotechnical investigations:

- Estimation of the radius of influence due to the dewatering
- Estimation of the flow rate required to achieve the drawdown
- Estimation of the potential settlement due to the dewatering

2.2 Key Dewatering Design Steps

2.2.1 Forming the Ground Model, Assessing Permeability and further Geotechnical Investigations

In order to form the ground model for the project, it is suggested the following steps are followed, which would be best carried out by a Geotechnical Engineer or Engineering Geologist:

- Refer to desk study sources such as geological maps, the Canterbury Geotechnical Database, past investigation data and aerial photos and/or do a site walkover
- Refer to Table 1 for methods available for determination of site permeability
- Perform a high level assessment of the risk of encountering contaminated soils during construction (refer Section 4.3.2)
- Perform a high level assessment of the risk of encountering contaminated groundwater during construction (refer Section 4.3.2)
- Perform a high level assessment of the risk of encountering gravels within the excavation depth
- Perform a high level assessment of the risk of encountering artesian groundwater conditions
- Decide, taking into account the complexity and risk associated with the project, if there is sufficient information to define the ground model adequately or whether site specific geotechnical investigations are required. Refer to the information in Section 6 of CIRIA Report 97 (1992) for guidance.
- Undertake an assessment of the likelihood that the proposed project could induce ground settlements adversely affecting existing property or infrastructure. Develop a settlement monitoring plan (as required).
- Commission a hydrogeologist to perform design where risk matrix recommends it (Table 4 and Table 5).

2.2.2 Risk and the ITP

Source knowledge from contractors who have previously worked in the project area. This experience, whether good or bad, should be considered in the assessment of the dewatering risk.

Issues that could be considered during the dewatering design include those in Table 3. The list is intended to initiate discussions and is not exhaustive. Discussion of the items in Appendix A and in the resource consent conditions may also trigger entries on the ITP.

Risks identified during the dewatering design should be assessed to consider the overall risk profile for the project.

Table 3 Suggested List of Items for Consideration in Dewatering Design

Item No.	Subject	Description / Key Issues to Discuss
1	Ground Conditions	· Is the ground model adequately defined? · Is further ground investigation needed? · Consider the details within CIRIA Report 113 (1986)
2	Construction Methodology	· Is dewatering necessary? · Can the project be completed using an alternative method?
3	Construction Methodology	· What dewatering method is proposed / appropriate? · Consider the details within CIRIA Report 113 (1986) and CIRA Report 97 (1992)
4	Construction Methodology	· How will removal of silt be managed? · What rate of silt removal is tolerable? · What criteria or trigger levels will be used to indicate that silt volumes removed are becoming too large?
5	Effects on surrounding Ground and Structures	· Discuss the results of the calculations of radius of influence, quantity of water to be pumped, and estimated ground settlement (see later sections of this Guide) · What structure / infrastructure is nearby that could be affected? · Is drawdown or drawdown-induced settlement likely to affect nearby structures / infrastructure (including water levels in existing wells)?
6	Proximity of nearby Watercourses	· Are watercourses nearby? · How will the risk of piping erosion be managed? · What triggers will be used to indicate that piping is occurring? (High silt content or water volumes?)
7	Ground Stability Issues	· Are there slopes nearby that could be destabilised by the dewatering?
8	Environmental Issues	· If pumped water is to be disposed of within a stream, what silt volumes are appropriate?
9	Environmental Issues	· Is it possible that contaminants could be pumped in abstracted groundwater? · If so, how will this be managed?
10	Aftershocks	· What effect would a large aftershock have on the proposed method and excavation?
11	Stakeholders	· How will the method affect residents and road users? · How will this be managed?
12	ITP and Monitoring	· What ground level or groundwater monitoring is appropriate? · What are the items that should be included on the Inspection and Test Plan?

2.3 Assessment of Dewatering Risk

This section provides a basis for assessment of the risk category of any dewatering project being considered (Table 4) and the subsequent identification of the minimum temporary works design actions that need to be carried out (Table 5).

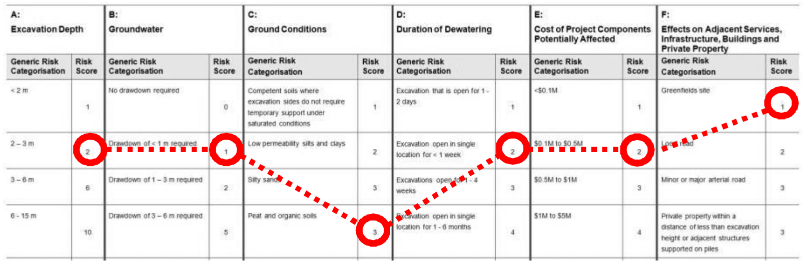
Table 4 Dewatering Risk Category Number

A: Excavation Depth		B: Groundwater		C: Ground Conditions		D: Duration of Dewatering		E: Cost of Project Components Potentially Influenced by Dewatering		F: Effects on Adjacent Services, Infrastructure, Buildings and Private Property	
Generic Risk Categorisation	**Risk Score**	**Generic Risk Categorisation**	**Risk Score**	**Generic Risk Categorisation**	**Risk Score**	**Generic Risk Categorisation**	**Risk Score**	**Generic Risk Categorisation**	**Risk Score**	**Generic Risk Categorisation**	**Risk Score**
< 2 m	1	No drawdown required	0	Competent soils where excavation sides do not require temporary support under saturated conditions	1	Excavation that is open for 1 - 2 days	1	<$0.1M	1	Greenfields site	1
2 – 3 m	2	Drawdown of < 1 m required	1	Low permeability silts and clays	2	Excavation open in single location for < 1 week	2	$0.1M to $0.5M	2	Local road	2
3 – 6 m	6	Drawdown of 1 – 3 m required	2	Silty sands	3	Excavations open for 1 - 4 weeks	3	$0.5M to $1M	3	Minor or major arterial road	3
6 - 15 m	10	Drawdown of 3 – 6 m required	5	Peat and organic soils	3	Excavation open in single location for 1 - 6 months	4	$1M to $5M	4	Private property within a distance of less than excavation height or adjacent structures supported on piles	3
> 15 m	12	Influencing surface water bodies within or adjacent to site	7	Intercepting moderate to high permeability gravels	6	Excavation open in single location for > 6 months	5	> $5M	5	State Highway	4
		Contaminated Groundwater	10	Running sands	10					Railway lines	4
		Drawdown of > 6 – 9 m required	10	Contaminated Soils	10					Historical structures founded on shallow footings	4
		Intercepting artesian aquifer	10							Critical infrastructure vulnerable to settlement	5

Calculation of Risk Profile for Dewatering Project

Risk Category Number (RCN) = A x B x C x D x E x F

Calculate the Risk Category Number by multiplying the assessed risk scores for the project under each of the six risk areas



EXAMPLE

Notes:

1. The risk scores provided are indicative and will vary between projects; a level of judgement and experience are required during selection.
2. When selecting the risk score for ground conditions consider all available information and select the category which, on average, best represents conditions. Greater emphasis should be placed on field derived data where available.
3. The RCN provides a high level broad assessment of project risk. Refer Table 5 for risk and recommendations.

Table 5 Recommended Minimum Dewatering Design Actions

Dewatering Risk Category Number (RCN from Table 4)	Risk Consequence	Recommended minimum level of temporary works design actions
0 - 10	**Low**	· No project specific dewatering study is required · Implement dewatering methodology based on local past experience
11 - 75	**Medium**	· Perform high level desktop study assessing ground conditions and dewatering risks for the project area · Select appropriate dewatering methods considering constraints, risks and specifics of the project · Perform simple hand calculations to verify appropriateness of proposed dewatering temporary works design
76 – 2,500	**High**	· Review the Artesian Pressure Aquifer Map (Figure 3) to check that excavations are at least 10 m above known artesian aquifers; if less than 10 m revert to Very High risk actions · Carry out desktop study assessing ground conditions and dewatering risk · Confirm ground conditions and soil grading by drilling at least one borehole · Consider specific project components where the dewatering risks are elevated · Consider appropriate construction methodologies · Perform calculation for dewatering design (simple to complex as appropriate) · Develop and implement a simple Settlement Monitoring Plan where necessary · Closely monitor for suspended solids in dewatering discharge and their accumulation in the sedimentation tanks · Ensure that the estimate provides adequate allowance for dewatering costs and residual risk
2,500– 187,500	**Very High**	· Review Artesian Pressure Aquifer Map (Figure 3) · Review detailed geotechnical report for the project, considering dewatering risks and specific project elements · Commission an appropriately qualified and experienced hydrogeologist or geotechnical engineer to provide professional advice on dewatering

Dewatering Risk Category Number (RCN from Table 4)	Risk Consequence	Recommended minimum level of temporary works design actions
		· Where appropriate, perform additional site investigations (e.g. field permeability testing, well pump testing) · Perform analyses to assess potential effects of dewatering (simple or complex as appropriate) · Develop and implement Settlement Monitoring Plan · Implement condition surveys of adjacent private property prior to commencing works · Closely monitor for suspended solids in dewatering discharge and accumulation in sedimentation tanks · Ensure that the estimate provides adequate allowance for dewatering costs and residual risk

2.4 Incorporation of Dewatering Design Requirements and Risk

The designer should consider the dewatering risks and the details of an appropriate dewatering methodology for the project. The designer should then include an adequate allowance for dewatering within the estimate, through review and consideration of the following:

- The project specific RCN along with a summary of the key assumptions or assessments which have been done when developing the RCN
- The minimum level of dewatering temporary works design required for the project (refer Table 5)
- Details of required environmental effects mitigation or environmental constraints on the project
- The appropriate dewatering methodology for the project considering site conditions, the project design and RCN number. Refer Section 3 for recommendations.

3 Dewatering Practice

3.1 Sumps and Sump Pumping

3.1.1 Description

Sump pumping can be used in high to moderate permeability soils such as gravels and sand and gravel mixtures. It is simple and cost-effective to install and can be used together with sheet piles to limit the volume of inflow. The excavation geometry, soil type and inflow rates will dictate the required pumping capacity. If the bottom of the excavation has a very shallow grade and water cannot flow in the trench base, or extends over large distances, multiple sumps may be required in order to remove surface water.

The key limitation is the potential instability of the soil under the water table surface generated by flow into the excavation which can cause piping and hence rapid loss of floor and side slope stability, leading to the risk of heave and undermining and settlement.

A secondary concern with sump pumping is the disposal of the abstracted fines-laden water. Once sump pumping begins, some of the sand and fines in the soil will initially be removed from within the immediate vicinity of the sump. For this reason, the discharge water should be passed through a sedimentation tank.

The requirements for a sump are:

- Depth – sump should be deep enough to drain the excavation and drainage network, allowing for the pump intake level and some accumulation of sediment
- Size – sump should be much larger than the size of the pump to allow space for sediment ingress and cleaning
- Filter – the sump should be perforated or slotted, typically with a hole size or slot width of 10 – 15 mm and surrounded with coarse gravel (20 – 40 mm)
- Access – to allow removal of the pumps for maintenance and removal of sediment in the sumps

It is often necessary to form temporary sumps to control groundwater as an excavation is progressed. For prolonged pumping, the sump should be prepared by simply installing a short pipe section with a free-draining coarse gravel base, or a ring of sheet piles around the sump area to cover the full depth of the sump, and installing a perforated steel pipe or mesh cage inside the sump area then surrounding the pipe/cage with graded filter material (the sheet piling could then be withdrawn).

If possible, install the suction hose midway into the sump and ensure that the suction hose is not placed at the base of the sump as pumping may unnecessarily mobilise in-situ fines. To avoid or minimise potential sediment mobilisation, over excavate the low point of the sump and fill sump with poorly graded fill (ballast or large rounds) to raise suction inlet from the base of the sump excavation. This will aid in maintaining a constant flow of water from the sump and avoid pump cavitation.

If sediment quantity exceeds environment thresholds, connect the hoses from the pump to the primary treatment area and ensure that this does not spill to the road surface. Direct the discharge to the sediment tank or receiving area.

Note: suction pumps have limited lift of about 7 m to 8 m. A submersible pump will be needed if a greater lift is required.

Subject to analyses, sheet piles can be driven sufficiently deep to prevent base heave or piping failure (i.e. boiling) in the bottom of the excavation.

A short section of open pipe with a gravel layer at its base can be used as a sump and the sump/s can be located to the side of the excavation.

To reduce removal of fines, the suction inlet could be protected by adding a filter fabric under the free draining gravel layer as described above.

The following summarise the key advantages and disadvantages of sump and pump systems:

Advantages

- Relatively low cost
- Mobile
- Easy to install and operate
- Only operating during site construction works

Disadvantages

- Typically mobilises in-situ sediment and results in the need for suspended solid treatment
- Cannot be used for running sands
- Potential to take and discharge sediment into environment
- Most common dewatering method to breach consent conditions

3.1.2 Monitoring

The outflow from an unfiltered pump sump should be monitored by taking samples of water and checking the proportion of fines being transported. If fines are being continuously recovered or there are indications of potential excavation instability, the excavation should be backfilled and a different dewatering method considered.

3.2 Well-point Systems

3.2.1 Description

A well-point is a small-diameter (about 50 mm) pipe having a perforated section near the bottom which is covered with a screen. The well point is inserted into the ground and water is drawn by a dewatering pump. The lower end of the pipe has a driving head with water holes for jetting. Well points are connected to riser pipes and are inserted in the ground by driving or jetting. The riser pipes are connected to a header pipe which is connected to a vacuum pump. Pumping draws the groundwater into the well points, through the header pipe and then it is discharged, typically to the stormwater system. A typical 150 mm well-point dewatering pump is able to pump 50 to 100 well-points. It is recommended that standby pumps are retained to cover for mechanical failure or other stoppages.

Well-points are installed at regular intervals (typically at 0.6 m to 3 m spacing) on one or both sides of an excavation, or in a loop around the perimeter of an excavation, and are linked to a header main connected to a pump. They should be installed if an excavation is within 0.5 to 1.0 m of the static groundwater level and are generally installed to penetrate 1 m to 3 m below excavation level.

Well-pointing is effective in soils that are primarily sand size or soils with sand interlayers. In gravels it is likely that the spacing would need to be too close to be practical and in clays drawdown would be very slow.

Well-pointing has the advantage of being quick to install in a range of soil conditions, the equipment can be re-used around different excavations of different sizes, and they can draw down the groundwater level by 4 m to 6 m.

3.2.2 Well-point Spacing

The number of well-points and their spacing depends on:

- Soil permeability and expected seepage flow rate
- Soil layering and risk of perched water levels
- Excavation geometry and perimeter length
- Required drawdown

3.2.3 Soil Permeability

For high permeability soils ($k > 10^{-3}$ m/s) well-point spacing is typically 1.0 to 1.5 m irrespective of whether the soils are uniform or interlayered.

For moderate permeability soils ($k = 10^{-3}$ to 10^{-5} m/s) well-point spacing is typically around 1.5 m (to 3.0 m if only shallow drawdown is required, i.e. < 3 m) or 1.0 to 2.0 m if the soils are interlayered or there is a risk of perched water levels.

For lower permeability soils ($k < 10^{-5}$ m/s) well-point spacing is typically 1.5 to 2.0 m or 1.0 to 2.0 m if the soils are interlayered or there is a risk of perched water levels.

The maximum capacity of a standard 50 mm dia. well-point with a 0.75 m screen length and 0.5 mm filter mesh is about 1 l/s in a uniform high permeability soil; the minimum could be as low as 0.2 l/s in uniform lower permeability soil. The spacing of the well-points is therefore dictated by the length of the excavation and the flow required to achieve drawdown. If the spacing needs to be less than about 1 m, then an alternative dewatering option or double rows of well points should be considered.

Interlayered soils and perched water levels

In interlayered soils close well-point spacing is likely to be required (at 0.75 m to 1.5 m) to allow drainage of all layers.

Required drawdown

The main limitation on a well-point system is suction lift; in the Christchurch area (near to sea-level) this is up to 8 m. This means staged well-points placed on berms at increasing depth may be needed if a drawdown of more than about 6 m to 7 m below ground level is sought.

3.2.4 Filter Packs

Use of a filter pack around each well-point to provide a vertical drainage path and allow the well-point screen to be matched to the soil grading, must be considered where either the soils are strongly interlayered such that there is perched water to be drained, or in finer grained soils.

In fine soils (e.g. uniform fine sand) a filter pack is required to avoid persistent pumping of fines. For a well-point installation medium to coarse sand is generally suitable as a filter material but in some cases a more carefully matched grading will be needed (see well filter design below).

3.2.5 Installation Issues

When installing well-points make sure that the ground is clear of all gravel and tar seal. This is best done by digging a trench along the line of points or using an auger and drilling down to good sand before jetting the well-point down.

When points are installed it is important that they are all the same length and that the screens are at the same level, as the water can be preferentially drawn down to the top of the highest screen. This could allow air into the system and reduce the overall effectiveness of the well-pointing system. This situation could also occur where soil variability causes differential inflows across the well-points.

When well-points are jetted in it is important to take note of the ground conditions they are being jetted into. If the ground has sand layers mixed with layers of clay then enlarging the annulus surrounding the well-point could be considered to help smooth the interception of water across the water-bearing strata.

Once the well-point is at the required depth and diameter, the water jetting flow needs to be shut down until it is only just flowing out of the ground. At this time a sand or gravel pack can be added to the annulus around of the well-point. The low flow of water can assist with flushing sediment from the annulus and allowing the packing material into the annulus around the well-point. The idea is to get a consistent column of sand or gravel around the well-point.

If the well-points are in the ground for an extended period of time and the flow seems to be slowing it could be because the screens on the well-points are clogging up. This can be overcome by dropping the vacuum from the header line very quickly and back flushing the well-point.

It is important to check the whole system every day for air leaks as it does not take many leaks to reduce the vacuum and the amount of water being pumped. To ensure the well-point system is working, simple checks such as checking: that all joints are done up tight so they will not suck air; that the rubber ball and keeper pin located inside the base of the of the screen are in place and in good condition; and that the screen itself is not damaged in any way that will allow sediment to be sucked through the well-point. If sediment laden water is persistent over time or is severe, this can create voids and additional unplanned settlement of the excavation or structure.

The following summarise the key advantages and disadvantages of well-point systems:

Advantages

- Clean discharge – because the water is being drawn from a clean layer, once it is correctly established the discharge is also clean and doesn’t require a great deal of treatment
- Targeted drawdown of the water table resulting in less discharge to the environment

Disadvantages

- Dewatering has to be close to the excavation or work area
- Best in uniform soil conditions
- Lead in times for work takes up more of the road environment
- Experience required for installation to gauge effective placement
- Limited yield and drawdown potential

3.3 Dewatering Wells

3.3.1 Description

A dewatering well is a drilled hole (drilled by cable percussion drilling or rotary drilling) completed with:

- a screen or slotted pipe section that allows entrance of groundwater
- a base plate or end cap
- a naturally developed or artificially placed filter pack around the screen to prevent entrance and loss of formation material (which may be formed by development of the well)
- an unscreened section below the screen of at least 1 m length which acts as a sump for any material passing the filter pack
- a riser to conduct the water to the ground surface
- a check valve to allow escape of water and prevent backflow and entrance of foreign material
- an annular seal around the top of the well to prevent recharge of the formation by surface water (typically bentonite seal with concrete pad)
- a cover and protection to avoid damage by works.

A pumping test must be carried out at the site to allow optimal design of the wells and an effective dewatering system.

A dewatering system that utilises wells must be designed by a hydrogeologist or suitably qualified geoprofessional.

A summary of some of the key considerations is given below.

3.3.2 Well Depth and Diameter

The well diameter must be large enough to facilitate a pump able to take the maximum anticipated flow to the ground surface. Frictional head loss in the well (well loss) needs to be considered in selecting pump capacity and therefore well diameter.

Well depth will generally be at least twice the desired drawdown level, however in finer grained materials the depth will be much greater than this because the drawdown curve will be much steeper. Allowance also needs to be made for installation of a submersible pump below the drawn down water level and ideally above the screen.

3.3.3 Well Screen Slot Size

The size of the openings in the well screen is governed by the grain size of the natural ground against which it will be placed or the filter pack that is placed around it. The openings need to be as wide as possible, but sufficiently small to limit the entrance of fines. In general the slot width should be less than or equal to 50 % of the grain size of the filter.

The aquifer map (Figure 2) should be consulted and where there is the potential for artesian aquifers to be encountered, a pilot hole should be drilled at each dewatering well location with samples collected at 1 m to 1.5 m depth intervals. Soil grading tests should be carried out on the collected samples. The well screen design should be based on the finest grading of soils in the selected screen interval, except where limited zones of unusually fine soils occur that can be excluded by use of blank sections of screen or controlled through a properly designed or placed filter pack.

The open area of the well screen also needs to be sufficiently large to maintain an entrance velocity less than 0.035 m/s at the design flow.

3.3.4 Filter

Design of the well with a filter pack around the screen (rather than relying on development of the natural ground to establish a filter against the screen) should be considered. To prevent infiltration of the aquifer materials into the filter and the filter materials into the well, in a way that does not create excessive head losses, filters should meet the following criteria: the filter should comprise a natural granular material; each filter gradation must meet the permeability criterion that 10 % to 15 % of the filter grading should be less than 5 times the 85 % to 90 % size of the natural aquifer material.

3.3.5 Well Spacing

Design of well systems is more complicated than well-point systems because wells rely on interaction of drawdowns that extend out some distance from the individual wells. This means that the variations in ground conditions over a wider area need to be considered.

Wells will typically be located 10 m to 50 m apart, depending on the permeability and variability of the soils, the geometry of the excavation, the time available to achieve drawdown and the potential effects of drawdown-induced ground settlements. Use of recharge wells, for example at the site perimeter, may need to be considered.

3.3.6 Discharge

Once the well is established correctly there should be very little sediment in the discharge, and a relatively small sediment tank is usually sufficient. The rate of discharge can be high so ensure a suitable outfall is provided. If pumping a high volume of water with high suspended solids, a check on where the solids are coming from should be made (i.e. is a void being created?). If additional pumping capacity is required to keep up with dewatering, it is likely that additional treatment devices will be needed.

The key advantages and disadvantages of pumping wells are summarised by the following:

Advantages

- Good for large excavations and over extended timeframes
- Clean discharge – because the water is being drawn from a clean layer, once it is correctly established
- Increased pumping capacity can overcome soil variability issues that can plague well-pointing
- In the right area it is very efficient at drawing down the water table level over a relatively large area and in overlying lesser permeable materials if given enough time
- Can be installed away from the work area i.e. the well and pump can be in the shoulder/berm to dewater a trench in the

Disadvantages

- It can draw more water than is necessary, dewatering more than the specific work area. This can cause issues for surrounding ground/structures depending on soil conditions e.g. peat layers.
- Can require longer lead in time for lowering the water table
- Require more design, planning and site testing

middle of the carriageway. May be useful where space is limited

- Submersible pumps can be much quieter which is better for noise sensitive areas

3.4 Method Selection

3.4.1 Data Required

Key data required for selection of a dewatering method are:

- Soil profile and soil type; permeability of each layer
- Extent of the area to be dewatered (excavation dimensions and depth)
- Existing depth to the groundwater table and the level to which it has to be lowered below this
- Proposed method of excavation and ground support
- Proximity of existing structures, water courses etc.

3.4.2 Conditions favouring Sump Pumping

- Well-graded sandy gravel, clean gravel, firm to stiff clay
- Unconfined aquifer
- Modest drawdown required and there is no immediate source of recharge (e.g. no stream nearby)
- Shallow excavation slopes or deep driven sheet piles
- Excavation by backhoe or dragline
- Light foundation loads
- Low risk of contamination of discharge water

3.4.3 Conditions favouring Well-pointing

- Sandy or interlayered soils including sands (permeability k = 10^{-3} to 10^{-5} m/s)
- Unconfined aquifer
- Drawdown of 5 m or less required, or up to 10 m where a large excavation area is available

3.4.4 Conditions favouring Wells

- Ground conditions too permeable for well-points to be viable
- Silty soils where correct filter grading design is needed
- Drawdown of more than 8 m required or drawdown over a wide area for a long period
- Access to the excavation and top of batter slopes needed, or congested sites (wells can be located away from working areas)

A good understanding of ground conditions in and around the site and ideally, pumping test data are required to demonstrate suitability.

Table 6 Summary of the Soils, Possible Issues and Commonly Used Dewatering Techniques

Soil Type	Grain Size (mm)	Groundwater Flow Rate	Possible Issues	Dewatering Methodology
Gravels / Cobbles	>2	High	Large flows of groundwater requiring wells if the excavation is to be deep, and likely trench sumps if excavation is just into the water table	wells and sumps
Sand	0.06 to 2	Low to medium	Trench stability low if sand allowed to run into excavation	well pointing
Silt	0.002 to 0.06	Low	Stability variable and water yields could be low requiring close spacing of well points; localised water table perching possible	well pointing and sumps
Clay	<0.002	Very low	Minimal trench stability issues; localised water table perching possible	well pointing and sumps
Peat	variable	Variable (low to high)	Specialist input required as dewatering peat can result in compression of the layers causing settlement and damage to surrounding land and infrastructure	specialist advice required
Mixed soils	variable	Variable (low to high)	With mixed soils the methodology is generally based on the predominant soil type	depends on hydrogeology and highest yielding unit

3.5 Accidental Interception of Artesian Aquifers or Large Inflows

3.5.1 General

While it is not anticipated that artesian conditions will be intercepted in most dewatering activities, there is nevertheless the possibility of interception of artesian or high flow conditions which can rapidly lead to failure of embankments and founding layers if not responded to rapidly and appropriately. This part of the guideline sets out a plan for preparing for and responding to artesian or high inflow conditions.

3.5.2 Preparatory

3.5.2.1 Operating Procedures

- Conduct sufficient geotechnical site investigations to determine if an artesian aquifer exists under the site within a depth that would likely be affected by the excavation and dewatering works

- If this situation is anticipated there should be means of closing off the dewatering well-pointing pipes or pumping wells being installed
- Contingency measures include prior location of a local supplier of Portland cement, grout additives, sand bags, bentonite and geotextile. If an artesian flow transporting sediment is encountered, time to remediate is crucial
- Understand grout mix design calculation procedure to stem flow. Artesian head is to be measured and the grout mix added to provide pressure balance. Care is required to not add too much grout as this can migrate down into the aquifer with adverse effects.
- Establish an emergency phone contact list; include phone numbers for ECan, the Engineer, the well-pointing or well drilling company, grouting contractor and local suppliers that may be of assistance.

3.5.2.2 Observer Equipment

- Cellular phone, camera
- Extensible pipe sections to check the height of artesian pressure in the aquifer
- Contingency grout mix design

3.5.2.3 Emergency Remedial Supply and Equipment

Well-pointing

- Non-coated bentonite chips for collar sealing
- Valve installed in all well-point pipes in suspect artesian pressure area
- Cement grouting equipment and supplies
- Geotextile and sandbags

Pumping well

- Non-coated bentonite chips for collar sealing
- Packers, riser pipe, pressure gauges and appropriate fittings. Artesian flow may be cut off with use of a packer system at depth within the well. Pressure gauges may be used to determine the artesian head and flow meters to determine rate of flow. This equipment is needed for high flow/ high volume artesian situations.
- Cement grouting equipment and supplies
- Geotextile and sandbags
- Polymer drilling mud. Use of a drilling mud will create a head differential to offset and suppress low artesian flows during pumping well advancement.

3.5.3 Implementation

3.5.3.1 General

This section outlines steps to be taken to control, stop, and seal groundwater flow during excavation. Avoidance of artesian aquifer interception and / or large groundwater inflows to excavations is mandatory to avoid:

- Piping of sands into the excavation or heave of silts
- Heave of the base of the excavation
- Excessive silt-laden discharge

3.5.3.2 Large Earthworks Excavations

In the case of uncontrolled aquifer inflows to larger excavations bound by sheet piles or similar, the following steps should be taken:

- **Assess the situation**. Determine if the flow is constant or increasing. Determine if the turbidity is constant or increasing. Determine if the flow is confined to the well-point/ pumping well or excavation.
- **Notify project engineer and/or project manager**. Be able to describe in detail the conditions and events prior to encountering the artesian flow. Email photographs and/or video, in real-time if possible. Determine primary strategy and a contingency plan should the primary strategy be insufficient to arrest the artesian flow.
- **Notify ECan and the Engineer**. Inform ECan and the Engineer of the situation and planned action items.

Emergency actions may include:

- Backfill the excavation until the depth of backfill is sufficient to control material transport in the inflow
- Extend pipe sections to allow measurement of the artesian pressure
- Control any discharge of water by established site erosion and sediment control measures
- Refill the excavation with water to the original level
- Reconsider the design of the excavation keeping in mind the level of artesian pressures (consider caisson construction and tremie concreting a gravity compensated base slab)
- Altering design to allow a casing to be “spun” into the “green” concrete to allow control of the artesian pressures
- If the aquifer pressures are modest and not above surrounding ground level, place a thickness of graded crushed aggregate on top to act as a controlled filtered exit. Design the thickness of the aggregate to avoid piping or heaving depending on the difference in height between the aquifer level and the depth to be excavated.

3.5.3.3 Shallow Footings and Pipe Laying

In the case of excavation of sumps or the laying of pipes, the method described for larger excavations could be used with the placement of well-graded aggregates which will allow water to continue to flow but avoid piping.

4 Mitigation of Environmental Effects

4.1 Dewatering Consenting

Environment Canterbury Consents are required for extracting groundwater for dewatering purposes and for the disposal of the discharge into water bodies or the stormwater system.

All sites that implement dewatering must have a copy of the discharge consent on site. The Engineer and Contractor needs to fully understand the conditions and lead-in times for activities covered by the consents.

Compliance with consent conditions can be demonstrated though the ITP for the project and associated quality assurance records.

4.2 Discharge to the Environment

It is standard practice to discharge dewatering water into the environment. Specific factors that need to be addressed are the siting of the discharge, the effects on the discharge location and the ability of the discharge environment to accept the volume of discharge.

When dewatering, be aware that not only is groundwater being extracted to lower the water table; it is also likely that there will be sediment mobilised by groundwater flow and also possible that contaminants residing in the groundwater will be drawn into the system. It is also prudent to be aware that the service being repaired or adjacent services may also introduce contaminants that could be discharged into the environment if appropriate management is not implemented. Ensure that all parties are aware of these variables and undertake appropriate monitoring and treatment. Potential methods include:

- Implementation of mitigation, such as devices to treat the discharge, to reduce or avoid adverse discharge of suspended solids or contaminants. Example methods are included in Environment Canterbury's Erosion and Sediment Control Guideline (ECan 2007).
- Appropriate design of the dewatering system to minimise the loss of fines from in-situ soils and avoid ground settlement
- Proper containment of any wastewater system being worked on and removal of septic water prior to works as appropriate
- In certain cases there may also be opportunities to establish methods that avoid mobilisation of groundwater, such as ground freezing.

Avoid adverse effects on surface water bodies. Information on the effects of sediment on receiving waterbodies is included in ECan 2007.

4.3 Dewatering Discharge Quality

4.3.1 Suspended Solids

Dewatering consents require that dewatering water pass through a sediment removal device prior to discharge, with total suspended solids (TSS) in the discharge leaving the site not exceeding 150 g/m^3. Breaches of the TSS limits are generally noted through a visual check of the water being released into the environment. Standard samples can be used for comparison to allow a rough instant field assessment of discharge quality (Figure 7). If required a sample is taken and tested in a laboratory (24 hr to 48 hr turn-around).

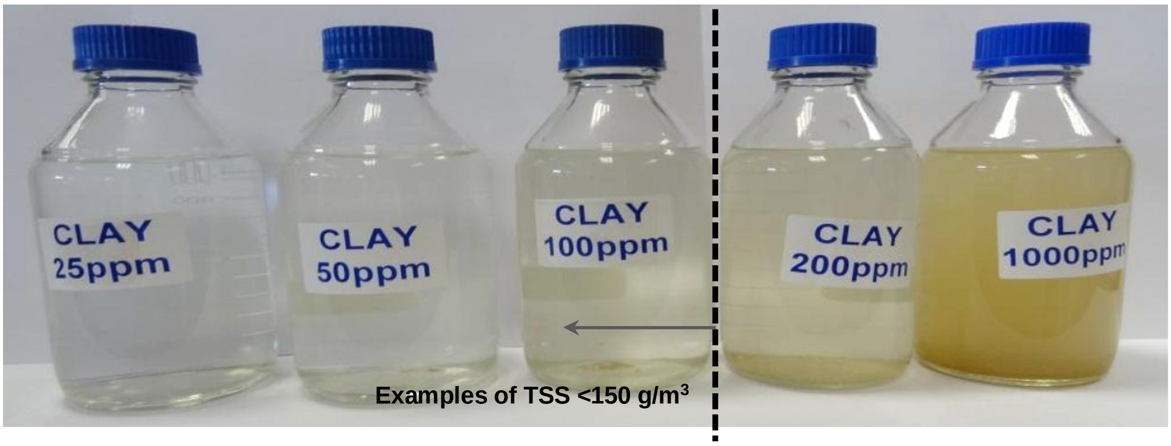


Figure 7 Example Example of comparative samples to visually assess approximate TSS within the discharge. The bottles shown here are 250 ml lab sample bottles.

Because primary sedimentation tanks remove the solids that settle quickly, it is only particles with a long settling time that will be discharged from the primary treatment. Therefore samples of discharge water that meet the consent should be prepared in a laboratory based on the typical particle size expected to be discharged from the primary tanks. These can be compared with samples taken on site to allow approximation of the TSS value of the discharge.

This would allow any compliance breach to be addressed early. The visual testing is low cost and able to be actioned and recorded quickly.

4.3.2 Contaminated Groundwater

Discharge consents may require that contamination risk zones be identified adjacent to the site. Potential for dewatering activities encountering contaminated groundwater can be assessed through review of the Ministry of the Environment Hazardous Activities and Industries List (HAIL).

Soil HAIL zones are areas where current and historic land uses have a relatively high potential to cause soil contamination, and with this groundwater contamination. These land uses are classified using the HAIL classification from A to I.

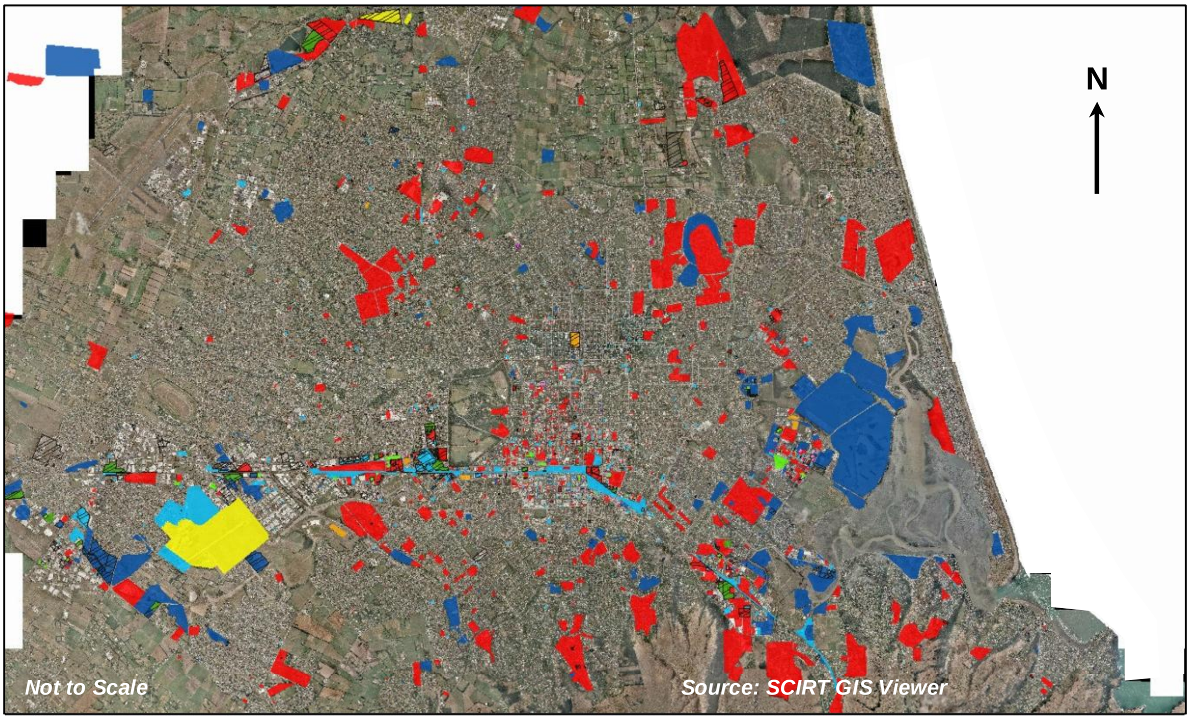


Figure 8 Christchurch Soil HAIL Zones

Groundwater HAIL zones relate to areas that have been identified as having land uses, both current and historic, that have a relatively high potential to cause ground contamination that may lead to contamination of groundwater (Zone 1), or have a medium potential to cause groundwater contamination, or the scale of potential contamination is small (Zone 2).

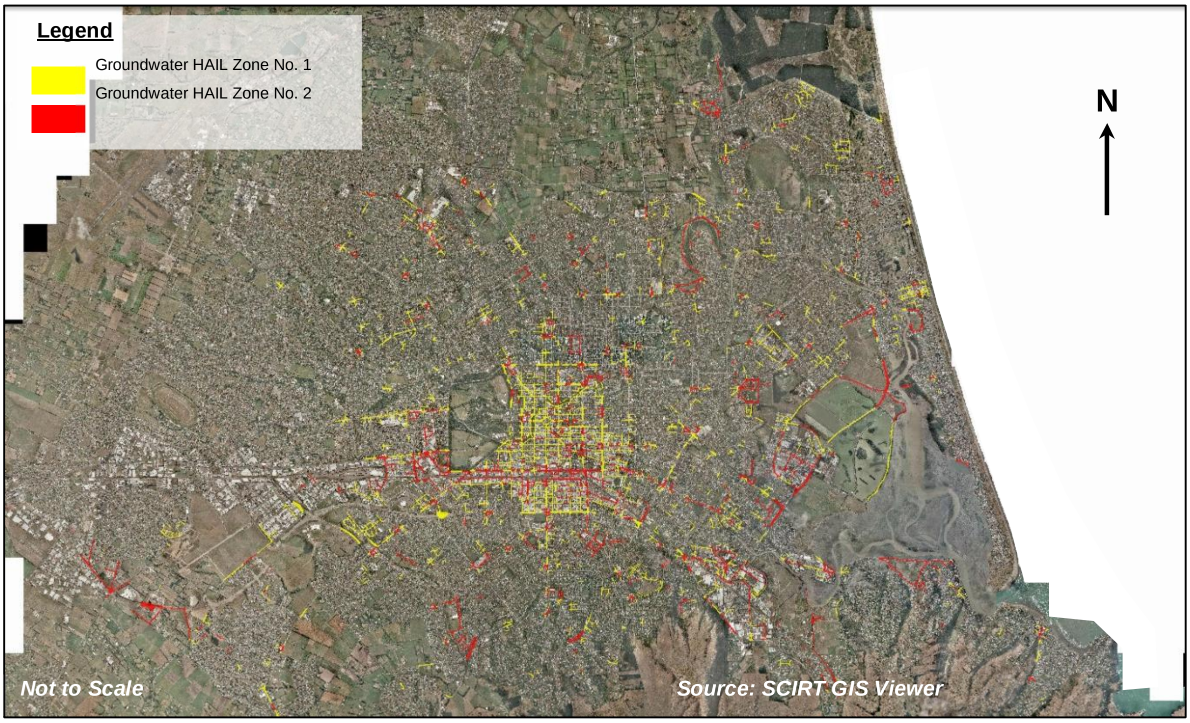


Figure 9 Christchurch Groundwater HAIL Zones

Prior to commencement of the project construction phase the risk of encountering contaminated groundwater must be assessed and if contamination is indicated, further investigation should be carried out in the field (as necessary) to verify levels of contamination and allow appropriate planning for design of the dewatering system.

Dewatering discharge is to be carried out in accordance with the Environmental Management Plan and the Dewatering Procedure Plan. Site specific sampling to determine the nature and concentration of contaminates may be required as outlined in the consent and the Dewatering Procedure Plan. These requirements must be incorporated into the project ITP and monitored during implementation.

4.4 Methods of Discharge Treatment

4.4.1 Sediment Control using Settling Tanks

Settling tanks are the most common method of treatment of discharge water. If possible these should be placed out of the road environment on berms. The tank must be sized appropriately for the quantity of the discharge to ensure that the flow velocity is lowered to promote sedimentation and so that the detention time is sufficient. The required detention time increases rapidly with decreasing particle size such that fine silt removal is challenging and clay removal impossible unless the flow is pre-treated with a flocculent. In all cases a properly constructed filter at the suction inlet will limit sediment extraction from the ground and reduce the loading of a settling tank.

Appendix B covers sizing of settling tanks in greater detail.

The overflow from the tank to the ground should also be controlled through the use of a pipe or hose. This will avoid erosion and overland transport of entrained sediment resulting from the overflow. It will also allow the flow to be directed to the closest channel and then sump or swale.

Regularly monitor the depth of sediment in the tank and the clarity of the water exiting the settling tank, especially during excavation (i.e. 2 hourly as part of the ITP and consent conditions).

Ensure that the settling tank is appropriately fenced to prevent public access.

Advantages

- Good gross settlement traps
- Sediment can be removed with suction trucks
- Allows incorporation of additional discharge water treatments, such as oil separators
- Ability of water to be accessed and used for other purposes (e.g. dust suppression)
- Can be used in conjunction with other methods of sediment capture

Disadvantages

- Not generally large enough to allow settlement times for clay or fine silt particles
- Safety risk of water depth in public environment
- Large item to place in the road environment

4.4.2 Filtering Discharge through Vegetation

Filtering dewatering discharge through vegetation generally comprises the surface application of the discharge onto vegetated land, allowing water to soak through the soil and recharge the groundwater table. In general this requires a large area or an area of heavy/rank grass growth to capture the fines. Swales and coffer dams can also be used to collect the sediment and allow the water to drain away. Remediation of the land following its use in this way is often required, generally comprising re-grassing or aeration to avoid permanent clogging of the soil structure by the deposited fines.

It is important to remember that filtering discharge though vegetation can only be used as a secondary treatment after the discharge has been passed through a sedimentation tank to remove larger particles.

Advantages

- Discharge seeps into ground and not directly into a waterway
- Vegetation provides extended flow paths and captures sediment which is bound by grasses
- Not in road environment

Disadvantages

- Needs grassed flow path
- Constant water flow can compromise grass health
- Pores in ground can become clogged and require remediation
- Some maintenance required if coffer dams in place
- Rain events can mobilise discharged site sediment

4.4.3 Collection with Sediment Control Bag / Flocculent Impregnated Sock

A sediment control bag or flocculent impregnated sock comprises a geotextile bag attached to the pump outlet, filtering the larger sediments from the discharge water. There are a number of types of proprietary treatment devices available ranging from pore size sieving to flocculent impregnated fabric. These systems vary in size, efficiency and cost, but should be investigated and considered where appropriate. These systems can also be used in series with other sediment treatment methods, such as filtering through vegetation.

Advantages

- Small in size
- Good for gross silt contamination contained in a small area
- Easy to dispose of silt

Disadvantages

- Unable to cope with large discharges or high pressure discharges.
- Silt must be disposed of with the bag
- Fines/silt can weep out of the bag
- Connection of pump discharge hose to bag is a common point of failure

Flocculent use is currently under investigation with ECan, as some are eco-toxic if not bound by clay.

4.4.4 Flocculent Settlement Ponds

There are several proprietary solutions for flocculent settlement pond sediment collection. They require a constant monitoring process and also have not been fully accepted or approved by ECan. They are also generally used on large scale sites dealing with sediment run-off from rain events rather than dewatering operations. Small volume and small site systems are being developed and may prove to be of use when tested in the Christchurch environment.

4.4.5 Opportunities for Use of Dewatering Discharge

During work planning, review opportunities to utilise dewatering water on site, reducing municipal water use. The following questions should be asked for each project:

- Can the site water be used for dust suppression on streets?
- Can the site water be used for establishment of planting/ berm areas?

- Can water be used for conditioning materials for optimum water content for compaction, piling requirements?

4.5 Effects of Groundwater Drawdown on Surface Water Bodies

Design of dewatering systems should consider the effects (if any) on surface water bodies of importance. Potential effects will depend on the depth of drawdown relative to the level of the watercourse, the period of drawdown, the rate of dewatering, the distance from the water body, and the permeability of the soil between the site and the watercourse.

Measures which could be implemented on site to limit effects of groundwater drawdown on surface water bodies include:

- Recharge to the surface water body
- Installation of temporary cut-offs to lengthen flow paths (e.g. sheet pile wall, grout curtain, groundwater recharge)
- Modification of dewatering methodology to reduce influence beyond the site

4.6 Avoidance of Ground Settlement

4.6.1 General

Avoidance of adverse ground settlement is important to both limit damage to elements of the project, and to the adjacent infrastructure and private property.

Consideration of the potential for adverse ground settlement associated with dewatering is essential.

Dewatering activities can result in settlement of surrounding ground because:

- Drawdown of groundwater increases effective stress in the soil leading to both elastic (immediate) and consolidation settlement of soils. Settlement magnitude is dependent on the magnitude of groundwater drawdown, the soil profile and material properties at the site.
- High flow velocities through the soil to dewatering wells and/or ineffective filters result in mobilisation and loss of fines, which can lead to local ground settlement
- Instability of excavation sides, due to insufficient reduction of pore water pressures or seepage, compromises stability

Sands and gravels are comparatively permeable and stiff, so the settlements which result from changes in pore water pressure and effective stress occur rapidly during the period of construction and effects on the ground surface are generally small. However, softer and less permeable soils such as clay, silt and organic soils are prone to consolidation; settlements in these materials may take some time to develop and have adverse effects on adjacent property.

4.6.2 Settlement Mitigation

Methods to limit adverse dewatering settlement are:

- Settlement associated with loss of fines can be mitigated through appropriate design of the dewatering system to control flow velocity and provide screens and/or filters matched to the grading of the in-situ soils. Entrainment of fines must be monitored during construction; actions could include analysis of TSS in discharge water and/or monitoring of accumulation of sediment in sedimentation tanks.

- Drawdown-induced ground settlement is mitigated though pre-construction estimation of groundwater drawdown and settlement coefficients to identify risk prior to drawing the groundwater down, and water level monitoring in monitoring boreholes to check that larger drawdowns than anticipated at distance from the excavation are not occurring. Differential settlement is most problematic; this can be reduced by managing the rate of drawdown and understanding where clear changes in soil type occur. Should potentially damaging settlement be indicated, these can be mitigated by installing groundwater cut-offs to stem or restrict groundwater flow and limit drawdown beyond the site.
- Provide sufficient temporary support to excavations to maintain stability, where seeps might otherwise induce progressive collapse of the sides of the excavation.
- During dewatering implement staged drawdowns (where appropriate), and monitor field settlement and water level changes beyond the immediate site, comparing against theoretical settlements and water levels to allow warning of potential dewatering settlement issues.

4.6.3 Theoretical Assessment of Immediate and Consolidation Settlement

The level of detail undertaken in assessment of potential dewatering settlement, should increase with increasing dewatering risk category number (refer Section 2).

Prior to commencing assessment of potential ground settlement associated with dewatering at a site, the knowledge of the following is required:

- sensitivity of adjacent structures to total and differential settlement
- soil profile and material properties at the site (affecting magnitude of total and differential settlement and time for consolidation)
- groundwater conditions at the site and proposed drawdown
- details of the dewatering methodologies being implemented
- temporary works design for the excavation

An approximate estimation of the soil profile can be developed though a desktop review of available geotechnical information. Table 7 provides a range of typical moderately conservative soil parameters compiled from a range of reference texts and previous field experience within Christchurch. The parameters are only appropriate for a first pass sensitivity assessment to identify if dewatering could potentially induce adverse settlements at the project site.

Parameters can be refined though in-situ soil testing such as Standard Penetration Test (SPT), Cone Penetrometer Test (CPT) and shear wave velocity, and published relationships and by laboratory testing.

Where settlement sensitivity assessment identifies problematic total and differential settlements, a review of the appropriateness of the proposed dewatering methodology is required. Geotechnical investigation and laboratory testing may be required to enable refined estimation of potential dewatering settlements at the site.

4.6.4 Settlement Monitoring

Implementation of a settlement monitoring plan is recommended. This is also mandatory for high to very high risk dewatering projects (refer Table 5).

Prior to commencing dewatering perform condition surveys of adjacent properties that could potentially be affected by dewatering considering anticipated effects and specific dewatering design.

The scope of settlement monitoring should be selected considering risks and potential consequence of adverse settlement at the site or on adjacent property. A typical settlement monitoring system would comprise a series settlement markers sited at various distances beyond and at the site, within the zone of influence of groundwater drawdown. Monitoring points should be surveyed to an accuracy of +/-2 mm. Note that the reference benchmark must be located beyond the extent of the anticipated influence of groundwater drawdown. For very high risk projects, incorporation of piezometer standpipes will allow confirmation of the field groundwater drawdown and will enable calibration of field settlement observation with theoretical assessments.

Alert and Action settlement thresholds should be set, selected though theoretical assessment of anticipated settlements and review of sensitivity of adjacent structures and infrastructure. It is prudent to implement staged groundwater drawdown, providing hold points to allow adequate time to enable observation of the delayed settlement response of the ground.

Table 7 Typical soil parameters for first pass assessment of dewatering settlement

Soil Type	Compressibility	Unit Weight (kN/m^3)		Coefficient of Volume Compressibility m_v (m^2/MN)		Modulus of Elasticity of Soil E_s (MPa)		Poisson's ratio, u
		Lower Limit	Upper Limit	Lower Limit	Upper Limit	Lower Limit	Upper Limit	
Medium dense to dense SAND or Sandy GRAVEL	**Negligible** Immediate Settlement	19	22	-	-	100	200	0.30 – 0.40
Medium Dense SAND	**Very Low** Immediate Settlement	18	20	-	-	30	80	0.30 – 0.40
Loose SAND	**Low** Immediate Settlement	17	19	-	-	10	25	0.30 – 0.40
Loose to medium dense fine Silty SAND	**Low** Immediate Settlement Consolidation	17	18	0.05	0.10	5	30	0.30 – 0.35
Firm to stiff Sandy SILT	**Moderate** Consolidation	16	17	0.10	0.25	-	-	0.30 – 0.35
Soft to firm alluvial SILT	**High** Consolidation	16	17	0.25	0.80	-	-	0.30 – 0.35
Highly organic alluvial CLAY, SILT and PEAT	**Very High** Consolidation	13	16	0.30	>1.5	-	-	0.30 – 0.40

Material parameters compiled from a range of reference texts [Bowles (1996), Carter and Bentley (1991)] and previous field experience within Christchurch.

5 References

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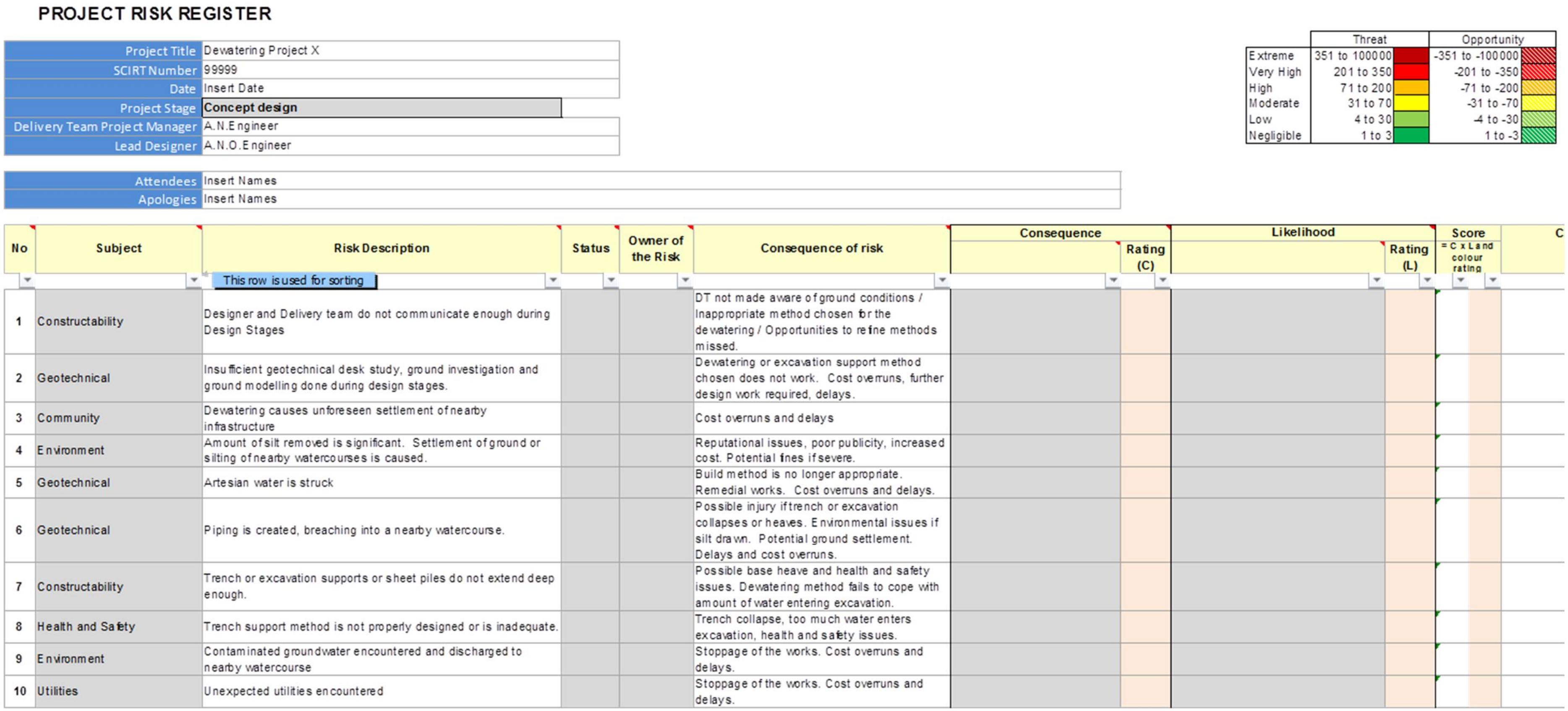
Recommended Dewatering Guidelines for further Reference

1. Construction Industry Research and Information Association (CIRIA) 2000: C515, “Groundwater Control – design and practice”. ISBN 0 86017 515 4
2. US Department of Defence, UFC 3-220-05, Dewatering and Groundwater Control, 16 January 2004 [http://www.wbdg.org/ccb/DOD/UFC/ufc_3_220_05.pdf]

Appendices

A

Appendix A Non-exhaustive List of Risks for Projects Involving Dewatering - Example



PROJECT RISK REGISTER

Project Title	Dewatering Project X
SCIRT Number	99999
Date	Insert Date
Project Stage	**Concept design**
Delivery Team Project Manager	A.N.Engineer
Lead Designer	A.N.O.Engineer

	Threat		Opportunity	
Extreme	351 to 100000	🟥	-351 to -100000	▨
Very High	201 to 350	🟥	-201 to -350	▨
High	71 to 200	🟧	-71 to -200	▨
Moderate	31 to 70	🟨	-31 to -70	▨
Low	4 to 30	🟩	-4 to -30	▨
Negligible	1 to 3	🟩	1 to -3	▨

Attendees	Insert Names
Apologies	Insert Names

No	Subject	Risk Description	Status	Owner of the Risk	Consequence of risk	Consequence		Likelihood		Score		C
							Rating (C)		Rating (L)	= C x L and colour rating		
		This row is used for sorting										
1	Constructability	Designer and Delivery team do not communicate enough during Design Stages			DT not made aware of ground conditions / Inappropriate method chosen for the dewatering / Opportunities to refine methods missed.							
2	Geotechnical	Insufficient geotechnical desk study, ground investigation and ground modelling done during design stages.			Dewatering or excavation support method chosen does not work. Cost overruns, further design work required, delays.							
3	Community	Dewatering causes unforeseen settlement of nearby infrastructure			Cost overruns and delays							
4	Environment	Amount of silt removed is significant. Settlement of ground or silting of nearby watercourses is caused.			Reputational issues, poor publicity, increased cost. Potential fines if severe.							
5	Geotechnical	Artesian water is struck			Build method is no longer appropriate. Remedial works. Cost overruns and delays.							
6	Geotechnical	Piping is created, breaching into a nearby watercourse.			Possible injury if trench or excavation collapses or heaves. Environmental issues if silt drawn. Potential ground settlement. Delays and cost overruns.							
7	Constructability	Trench or excavation supports or sheet piles do not extend deep enough.			Possible base heave and health and safety issues. Dewatering method fails to cope with amount of water entering excavation.							
8	Health and Safety	Trench support method is not properly designed or is inadequate.			Trench collapse, too much water enters excavation, health and safety issues.							
9	Environment	Contaminated groundwater encountered and discharged to nearby watercourse			Stoppage of the works. Cost overruns and delays.							
10	Utilities	Unexpected utilities encountered			Stoppage of the works. Cost overruns and delays.							

B

Appendix B Settling Tank Sizing

Purpose of Settling

- To remove coarse suspended sediment before discharge of flow to the environment at concentrations below consented levels.

Principle of Settling

- Suspended solids present in water having a specific gravity greater than that of water tend to settle down by gravity as soon as the flow turbulence is largely eliminated.
- The chamber in which the settling takes place is called a settling tank.
- The average time that the water is detained in the settling tank is called the detention period.

Particle Settling

Efficient particle trapping is dependent on maintaining a very low horizontal flow velocity with emphasis on suppression of turbulence at the tank inlet and outlet, and provision of adequate settling and solids collection zones.

Settling Tank Design

- Settling tanks used for construction site dewatering flows must be sized for continuous flow operation with a very low velocity largely free of turbulence.
- Settling tanks are usually long and rectangular in plan with a length ranging from 3 to 5 times their width.

A settling tank can be divided into four different functional zones as shown in Figure 10:

- Inlet zone: region in which the flow is uniformly distributed over the cross section such that the flow through the settling zone follows a horizontal path
- Settling zone: settling occurs under calm conditions; minimum depth of 1 m
- Collection zone: for the collection of solids below the settling zone
- Outlet zone: outflow is collected and discharged via an outlet weir

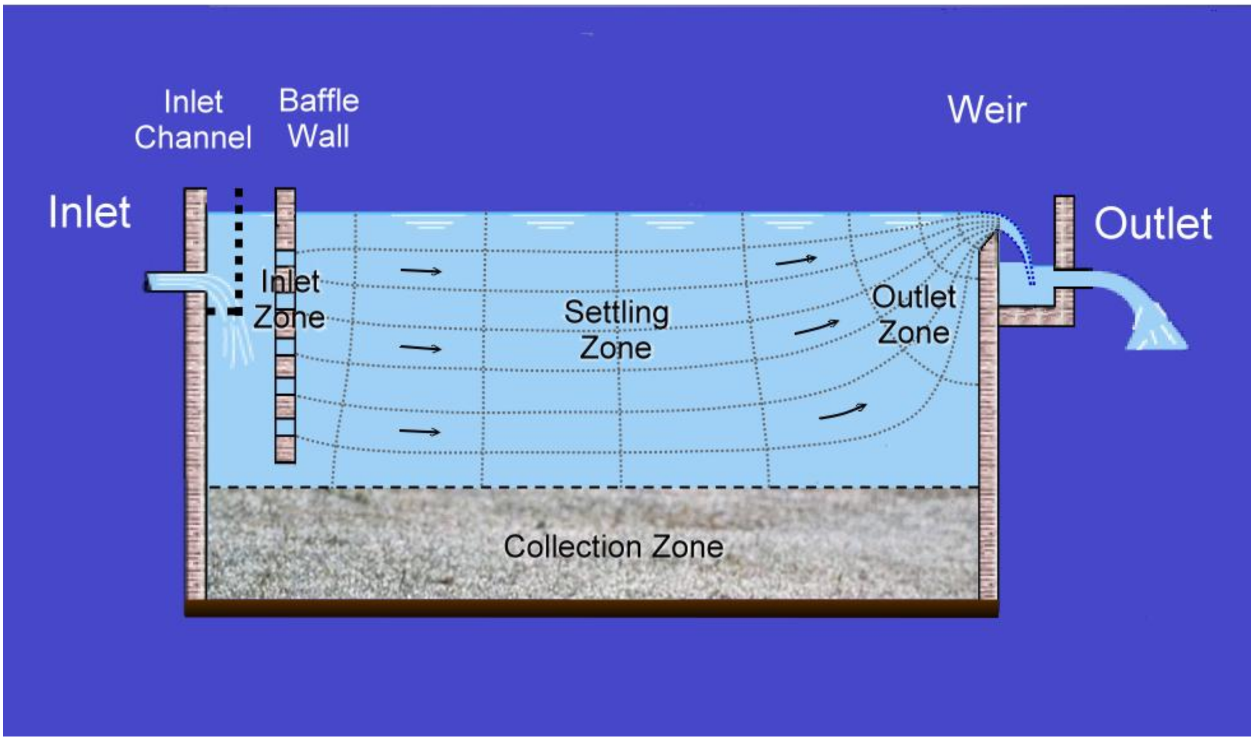


Figure 10 Settling Tank Schematic

Inlet and Outlet Devices

Inlet Devices: Inlets should be designed to distribute the flow equally vertically and horizontally so that velocity in the settling zone is uniform and free of turbulence. This will require a lateral flow distribution device followed by a baffle wall.

Outlet Devices: An outlet weir should be included across the full width of the tank to maintain low velocities through to near the tank end. Concentrated outlets direct to a discharge pipe result in excessive velocities near the outlet and these velocities can extend backward into the settling zone, causing particles to be drawn into the outlet.

Settling Operation

Particles falling through the settling basin have two components of velocity:

1. Vertical settling velocity: $v_s = (\rho_p - \rho_w)gd^2/18\mu$ (Stokes Law)

   Where: ρ_p is the particle effective density (refer to Table 1)

   ρ_w is the density of water = 999 kg/m^3 at 15 °C

   d is the particle effective diameter (m)

   μ is the viscosity of water = 0.00114 kg/(m.s) for water at 15 °C

2. Horizontal flow velocity: $v_h = Q/A_x$

   Where: Q is flow rate (m^3/s)

   A_x is the tank settling zone cross section area (m^2) (= width x depth)

For the detention period in the tank settling zone (t_0) to be sufficient for a particle to settle out before the arriving at the end of the tank then it must be equal to (or greater than) the settling time. That is:

t_0 = Settling Volume/Flow Rate = $L.W.Z_0/Q$ (sec) (detention period) where: Q = Flow Rate (m^3/s)

L = Settling Zone Length (m)

Z_0 = Settling Zone Depth (m)

W = Tank Width (m)

and $t_0 = Z_0/v_s$ sec (Settling time)

then $v_s = Z_0/t_o = Q/LW = Q/A_S$ m/s (vertical settling velocity)

and $A_s = Q/v_s$ m^2

where $A_s = L.W$ = the settling zone plan area (m^2)

Thus, the depth of the basin (Z_o) is not a factor in determining the size of particle that can be removed completely in the settling zone. The determining factor is the quantity Q/A_s, which corresponds to the terminal setting velocity of the particle that is 100% removed.

Some finer particles will also be removed in the proportion of the settling velocity of those particles to the tank design settling velocity, but where the tank horizontal velocity exceeds about 4 times the particle settling velocity then most of those fine particles will be siphoned up by the rising velocity in the outlet zone.

Monitoring

A well-constructed dewatering system should not discharge sediment beyond the initial set up development period but the sediment tank should still be checked regularly to ensure that accumulated sediment has not intruded into the settlement zone and cleaned out immediately if that has happened.

The monitoring for particles drawn into the outlet can be with a Silt bag fitted over the outlet discharge pipe.

Design Summary

3.	**Settling zone plan area (A_s):**	Flow rate / Particle Vertical Settling Velocity = Q/v_s
4.	**Tank shape:**	Length/Width (L/W) = 3:1 to 5:1
5.	**Settling Zone Depth:**	1.0 m to 1.5 m
6.	**Collection Zone Depth:**	At least 50% of Settling Zone Depth = 0.5 m to 0.75 m
7.	**Inlet Zone Length:**	0.5 m
8.	**Outlet Zone Length:**	0.5 m

Example tank sizing for various particle sizes and flow rates are shown in below in Table 9 and example tank sizing calculations follow.

Table 8 Particle Diameter and Settling Velocity

Particle Type	Diameter (d) (mm)	Settling Velocity (v_s) (mm/s)	Effective Density (ρ_p) (kg/m^3)
Coarse Sand	1.00	150	2580
	0.80	120	2560
	0.60	85	2550
	0.40	53	2530
	0.30	36	2500
Fine Sand	0.20	20	2460
	0.15	13	2430
	0.10	6.1	2380
	0.08	4.0	2350
Coarse Silt	0.06	2.2	2300
	0.04	0.93	2220
	0.02	0.21	2070
Medium Silt	0.015	0.11	2000
	0.010	0.043	1900
	0.005	8.4x10-3	1700
Very Fine Silt	0.002	8.2x10-4	1430

Note that effective density reduces with size due to increasingly non-spherical shape and the ragged nature of finer particles. This contributes to very fine particles having extremely low settling velocities that make them difficult to settle out.

Table 9 Required Settling Zone Plan Areas and Velocities for a Settling Zone Depth of 1 m

Target particle type ->	**Medium Silt**	**Coarse Silt**	**Fine Sand**	**Medium Fine Sand**
Particle Size to Trap ->	0.015 mm	0.060 mm	0.100 mm	0.150 mm
Settling Velocity (vs) ->	0.011 mm/s	2.2 mm/s	6.1 mm/s	13 mm/s
Required Detention Time ->	25 hours	7.6 minutes	2.7 minutes	1.3 minutes
Flow Rate (L/s)	**Required settling zone plan area & horizontal flow velocity**			
10	900 m^2 + 0.6 mm/s	4.5 m^2 + 8 mm/s	1.6 m^2 + 13 mm/s	0.8 m^2 + 20 mm/s
15	1400 m^2 + 0.7 mm/s	7 m^2 + 10 mm/s	2.5 m^2 + 17 mm/s	1.2 m^2 + 24 mm/s
20	1800 m^2 + 0.8 mm/s	9 m^2 + 11 mm/s	3.3 m^2 + 19 mm/s	1.5 m^2 + 28 mm/s
30	2700 m^2 + 1.0 mm/s	14 m^2 + 14 mm/s	4.9 m^2 + 23 mm/s	2.3 m^2 + 34 mm/s
40	3600 m^2 + 1.1 mm/s	18 m^2 + 16 mm/s	6.6 m^2 + 27 mm/s	3.1 m^2 + 39 mm/s
50	4500 m^2 + 1.3 mm/s	23 m^2 + 18 mm/s	8.2 m^2 + 30 mm/s	3.8 m^2 + 44 mm/s

Example Tank Sizing Calculations

Example 1:

Aim to remove all sediment larger than fine sand (0.100mm) with a peak flow rate of 20 L/s.

Minimum Settling zone plan area (A_s) = Q/v_s = (20/1000)/(6.1/1000) = 3.3 m^2
Tank L/W = 3 => Tank Width (W) = Sqrt(A_s/(L/W)) = Sqrt(3.3/3) = 1.05 m
Required Settling Zone Length (L) = 3W = 3.1 m

Adopt Settling Zone Depth (Z_0) = 1.0 m
Settling Volume = L.Z_0.W = 3.1*1.0*1.05 = 3.3 m^3
Detention time: t_0 = Settling Volume/Q = 3.3/0.020 = 164 sec = 2.7 minutes

Check settling time: t_0 = Z_0/v_s = 1.0 / (6.1/1000) = 164 sec = Detention time; Okay

In addition add 0.5 m to the tank length for the Inlet Zone and a further 0.5 m for the Outlet Zone.
Also allow for a sediment Collection Zone depth of 50% of the Settling zone depth = 1.0 * 0.5 = 0.5 m

Tank Design Summary:
Length = Inlet Zone + Settling Zone + Outlet Zone = 0.5 + 3.1 + 0.5 = 4.1 m
Width = 1.05 m
Depth = Settling Zone Depth + Collection Zone depth
= 1.0 + 0.5
= 1.5 m

Example 2:

Aim to remove all sediment larger than coarse silt (0.060 mm) with a peak flow rate of 20 L/s.

Minimum Settling zone plan area (A_s) = Q/v_s = (20/1000)/(2.2/1000) = 9.1 m^2
Tank L/W = 3 => Tank Width (W) = Sqrt(A_s/(L/W)) = Sqrt(A_s/3) = 1.74 m
Required Settling Zone Length (L) = 3W = 5.2 m

Adopt Settling Zone Depth (Z_0) = 1.0 m
Settling Volume = L.Z_0.W = 5.2*1.0*1.74 = 9.1 m^3
Detention time: t_0 = Settling Volume/Q = 9.1/0.020 = 455 sec = 7.6 minutes

Check settling time: t_0 = Z_0/v_s = 1.0 / (2.2/1000) = 455 sec = Detention time; Okay

In addition add 0.5m to the tank length for the Inlet Zone and a further 0.5 m for the Outlet Zone.
Also allow for a sediment Collection Zone depth of 50% of the Settling zone depth = 1.0 * 0.5 = 0.5 m

Tank Design Summary:
Length = Inlet Zone + Settling Zone + Outlet Zone = 0.5 + 5.2 + 0.5 = 6.2 m
Width = 1.74 m
Depth = Settling Zone Depth + Collection Zone depth
= 1.0 + 0.5 = 1.5 m

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