

**Groundwater of the lower Shag Valley, North
Otago: Phase 2 investigations**

By I.M. Turnbull & H.L. Fraser

Confidential

Client Report
2005/48

**June
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Prepared for

Waitaki District Council

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COMMERCIAL: IN CONFIDENCE

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EXECUTIVE SUMMARY

The lower Shag Valley contains groundwater in two aquifer systems: shallow unconfined gravels, and a deeper confined aquifer hosted by quartz gravel. The shallow aquifer is recharged by the Shag River and tributaries, and by local rainfall. The shallow gravel aquifer rests on mudstone of low permeability; the same mudstone overlies and confines the quartz gravel aquifer. Both aquifers have been investigated by a drilling programme aimed at upgrading knowledge of the lower Shag Valley groundwater resources.

Previous models of the shallow aquifer system were constrained by a lack of accurate subsurface information, and volumes and flow rate estimates were based on assumed aquifer thickness. The recent drilling suggests the estimates of aquifer thickness were too high, and consequently the estimated aquifer volume has been downgraded from $7.3 \times 10^6 \text{ m}^3$, to $3.9 \times 10^6 \text{ m}^3$.

If the groundwater levels (saturated thicknesses) used are representative of relatively high groundwater level periods, then storage volume during dry summer conditions is revised to $2.2 \times 10^6 \text{ m}^3$. This is based on the maximum groundwater level fluctuation of 1.214 m at Chisholms bore, and assumes Chisholms reflects groundwater fluctuation over the system.

A previously suggested confined aquifer within quartz gravels of the Taratu Formation has been confirmed by one exploratory well, which produced a small artesian flow from below 44 m depth near Munro Road. Two other wells are also likely to be producing water from Taratu Formation gravel. Recharge sources for this aquifer are not known with certainty, but may include rainfall, the Shag River and possibly the Pleasant River. However, tritium dating of water from the exploratory well determined that the water was 150 years old or more, and did not detect any “modern” water. Surface outcrops show significant variation in thickness and rock type within the Taratu Formation, together with previously unsuspected faulting. Aquifer storage capacity of $4000 - 40\,000 \text{ m}^3$ is estimated but recharge rates are unquantified.

The results from the drilling programme lead us to recommend that (a) any further development of the shallow gravel aquifer should be directed at upgrading the existing water supply intake galleries; and that (b) although internally complex, the deeper quartz gravel aquifer should be further explored by additional wells and testing.

1. INTRODUCTION

1.1 Background to drilling programme

The farming regions of the Shag Valley and adjacent downlands in northeast Otago suffer from severe water shortages during droughts. In order to alleviate this situation, in May 2000 the Waitaki District Council (WDC), secured Government funding to investigate alternative sources of ground and surface water for the Shag Valley. As part of that investigation, a report was prepared on the groundwater potential of the lower Shag Valley (Cameron *et al.* 2003). This report was based on existing geological mapping, outcrop and subsurface information, flow gauging, groundwater level monitoring, and rainfall records. It assessed the potential of the various alternative groundwater resources of the area, including a possible deep aquifer under the lower Shag Valley. The report gave some poorly constrained calculations of storage volumes within the shallow Shag Valley aquifer system, which currently supplies most groundwater to the region. There are strict controls on continued or increased exploitation of this shallow aquifer. Cameron *et al.* (2003) also recommended further investigations in order to understand the lower Shag Valley alluvial groundwater system.

In 2004, the WDC obtained additional funding to follow up recommendations from the various investigations conducted during Phase 1. Some of this funding was aimed at implementing recommendations contained in the Cameron *et al.* (2003) report, in particular a drilling programme. This programme was intended to upgrade knowledge of the shallow gravel aquifer, and to test the suggested deeper aquifer within the Taratu Formation. A work plan was designed by the Institute of Geological & Nuclear Sciences (GNS) in consultation with David Stewart of Raineffects Ltd and the WDC (see Appendix 1). Five wells were drilled between 18th and 19th September 2004 (see Appendix 2). After assessment of the drilling results, the work plan was revised in late October (see Appendix 1) to include geological investigations of surface outcrops of the Taratu Formation, which appeared to have more potential as an aquifer than the shallow gravels.

1.2 Scope of this report

This report presents the results of the drilling programme, and the outcome of the surface investigations following drilling. It integrates these results with conclusions from the Cameron *et al.* (2003) report, and makes several recommendations for future work. In this report we make the assumption that readers are familiar with the Cameron *et al.* (2003) report, and consequently we do not repeat detailed information on geology or on surface and subsurface water flows. This report should be read in conjunction with Cameron *et al.* (2003), in particular their figures 1.1. and 2.1. Calculations on flow, and surface and groundwater recharge-discharge relationships, have not been revisited.

1.3 Summary of geology

The geology of the lower Shag Valley is summarised by Forsyth (2001) at a regional scale, and by McMillan (1999) for the area northeast from Palmerston. Cameron *et al.* (2003) synthesised these data sources in their Figures 1.1. and 2.1. The entire lower Shag Valley is underlain by basement schist. The schist is overlain by sedimentary rocks which dip (slope) down to the east from the hills northwest of Palmerston, toward the Shag Point – Horse Range – Kakanui Mountains ridges which define the northeast limit of the Shag Valley. These ridges are uplifted along the complex Waihemo Fault System. Quaternary gravel terraces infill the central part of the lower Shag Valley.

The sedimentary rocks are divided into the Taratu Formation (quartz gravel and sand) which rest on schist, and the overlying Abbotsford Formation. The latter formation is predominantly grey to brown and green siltstone with minor sandstone, and is an impermeable unit which caps, or confines, groundwater within the Taratu Formation. As these sedimentary rocks dip north-eastward, they become steadily deeper in that direction. In many places both in the Shag Valley and beyond, another unit (Wangaloa Formation; see McMillan 1999) lies between the Abbotsford and Taratu Formations. Wangaloa Formation is a shelly sandstone or siltstone; as its hydrogeological properties are similar to Abbotsford Formation, it is treated as part of the Abbotsford for the purposes of this report.

The Shag River has eroded an almost flat surface on the top of the Abbotsford Formation, and this surface lies at quite shallow depths across the lower Shag valley, where it forms a “bottom” to the shallow gravels. These gravels are mapped as Morven and Pagon Road formations, and as modern river-bed gravels. They include beds and layers of loose fine gravel, and host groundwater in a shallow gravel aquifer system. The Morven and Pagon Road units lie at 2-3 and up to 5-7 m above the modern Shag River flood plain, and in outcrop range from fresh to moderately weathered.

Minor faults (Glenpark and Meadowbank) trend northeast across the lower Shag Valley and have implications for depth to basement schist, and for aquifer continuity. A minor fault mapped in Palmerston (Palmerston Fault of McMillan 1999) may have more significance than previously realised.

2. DRILLING PROGRAMME

2.1 Siting parameters

The wells drilled were sited according to some or all of the following parameters (see Appendix 1):

- Within Pagon Road terrace gravels, or on the lower (modern) terrace gravels. The older gravels (Smilie Formation and Morven Formation) were downgraded as potential aquifers;

- Within reaches where the Shag River is known to recharge the aquifer, rather than *vice versa*;
- Near existing and utilised wells, so pump testing could be undertaken should the investigation bores intercept significant groundwater;
- Up-valley from possible salt-water contamination;
- In areas where adverse affects on existing wells will be minimised;
- One drillhole would be sited to test the potential of the deep Taratu gravels.

Holes SV001, 002, 003 and 005 were sited above the shallow gravel aquifer(s), with SV004 also testing the Taratu Formation (see Fig. 1.1, Appendix 1). All holes except SV002 were planned to drill through terrace gravels mapped as the Pagon Road Formation of McMillan (1999). SV002 was sited on what has been mapped as the older, higher Morven Formation terrace, but had the additional aim of testing for locally derived fan gravel or alluvium on the southern flank of the lower Shag Valley. Any significant thickness of such alluvium would result in an overall decrease in thickness of the shallow gravel aquifer (unless compensated for by a greater thickness of underlying gravel over mudstone).

2.2 Drilling conditions

Drilling was undertaken between 18th and 19th September by Washington Drilling Ltd, using a CP 650-EX percussion rig. The driller was Steve Pilcher. Ground conditions were wet, and weather conditions varied from sun to snow, hail and strong wind. Holes were logged on-site by H.L. Fraser, and cuttings sampled at 1 m intervals. Cuttings were later examined under binocular microscope. Down-hole water levels were measured with a piezometer. Based on Otago Regional Council data, water levels in the Shag River over the period 16th to 20th September were low but normal for this time of year, declining from 490 l/s to 470l/s (D.L. Stewart, pers. comm. 14-6-2005).

Holes SV001, 002, 003 and 005 were plugged and abandoned. Hole SV004 at Munro Road had an artesian flow; this was controlled by capped and tapped casing inserted into mudstone to a depth of 6 m. A pressure gauge was also installed on the well head. This well could be further developed and tested if required, subject to some constraints (see Section 6.2.1).

2.3 Drilling results

Well logs for the five holes drilled are given in Appendix 2. All holes intersected thin gravel sequences, thinner than predicted from old logs and surface elevations. Holes SV001, west of Chisholms bore, and SV003 north of Palmerston, were sited close to the Shag River and probably penetrated modern alluvium, rather than the mapped Pagon Road Formation. While this suggests some inaccuracies in the geological map, it made no difference in that the main factor controlling groundwater is depth to mudstone basement, not thickness of (dry) gravel on the nearby terrace edge. The mapping errors probably arose because at these locations, the surfaces were interpreted to be degraded Pagon Road terraces, very close to modern flood

plain levels, and the height difference between the two units is only a few metres.

In all holes, drilling was continued through gravels into Abbotsford Formation, to ensure the full gravel sequence was obtained. In most cases, the upper mudstone is brown-weathered, and this may be a reason for over-estimation of gravel thickness in earlier well logs, where fine gravels are also brown in colour and the gravel-mudstone contact could be difficult to pick.

From cuttings and on-site observations, it proved difficult to differentiate Morven from Pagon Road gravels, in spite of the differences in weathering seen in some surface outcrops. Both units consist of fine to medium (0.5 – 2 cm) lithic gravel with a clay to sandy matrix, the clasts being fresh to only weakly weathered. Clasts are predominantly semischist, with minor quartz and volcanic material and rare (but conspicuous) jasper. Little high-grade schist is present. The weathering seen in Morven outcrops may be superficial, rather than pervasive, and consequently Morven Formation gravel may be a better aquifer than previously inferred. This has been taken into account during revised aquifer volume calculations.

Hole SV002, north of SH1, intersected 2 m of loess and topsoil above brown-grey sandy to muddy fine gravel. There was no evidence of locally-derived silty alluvial fan sediments derived from Puketapu to the south, implying that the full gravel sequence extends over most of the terrace mapped as Morven Formation.

Hole SV005, at Blacks Road, intersected 4 m of clay and silt, above 1 m of fine gravel. This thick clay-rich sequence may represent an old Shag River channel filled with loess and locally-derived alluvium; the channel has removed the predicted 5-10 m of gravel.

Well SV004 penetrated only 2 m of probable Pagon Road Formation gravel before intersecting Abbotsford Formation mudstone. This continued to a depth of ca. 43 m and consists of varying brown to green mudstone and siltstone. The green colour is due to the mineral glauconite (common within Abbotsford Formation). No evidence was seen of a shelly unit which is sometimes present at the base of the Abbotsford Formation (Wangaloa Formation; McMillan 1999), although given the nature of the cuttings sampled this is not surprising. Silty granular loose grey quartz-schist sand (Taratu Formation) extends from 43 m to ca. 55 m; the upper contact with Abbotsford appears to be quite sharp (within the limits of resolution of the cuttings).

The basal contact of the Taratu Formation cannot be located accurately, but is inferred to be at ca. 57 m. Cuttings from below this depth include rounded quartz grains (representing Taratu Formation) but these are probably from down-hole contamination. Schist fragments in cuttings from around 50 m are mostly weathered, but further down they are silvery-grey and probably from fresh schist. The hole terminated in fresh schist at 72 m; a change in drilling conditions into harder rock occurred at 63 m, perhaps reflecting the change from weathered to fresh schist. The uncertainty over the basal contact is due to (a) the basal Taratu probably

including schist clasts (seen in surface outcrops); and (b) the upper few metres of schist being weathered and soft with residual quartz fragments. The fresh schist cuttings from the bottom of the hole are quartz-rich with abundant micaceous fragments and are typical of schist from the areas south of the Shag Valley (cf. Forsyth 2001).

3. SURFACE INVESTIGATIONS OF TARATU FORMATION

The results of the drilling phase were assessed and formed the subject of a draft report circulated in October 2004. From this assessment, it was decided that the most productive use of remaining funding was to investigate the surface outcrops of Taratu Formation, adjacent to the Shag Valley, as this would give useful data on potential Taratu aquifer thickness and properties should further exploration and possible exploitation be planned (see Appendix 1).

3.1 Taratu Formation surface distribution

The surface investigations show that the extent of the Taratu Formation as previously mapped (P.J. Glassey, unpublished 1:50 000 geological map I43; and McMillan 1999) was reasonably accurate at that scale. Taratu Formation caps the ridges west of the Shag Valley between Glenpark, Meadowbank and Taieri Peak Road, with basement schist exposed in the valleys. The formation is overlain by a thinner veneer of Abbotsford Formation on some ridges, and dips 4-5° to the NE. It averages 20-30m thick in this area. The formation is crossed by local streams where they emerge onto the extensive flats of the Glenpark-Meadowbank stretch of the Shag River.

Taratu Formation is also exposed in the sides of the Pleasant River valley along Stenhouse Road, where it is thicker (up to 50m), rests on an uneven surface over schist (with local relief of up to 20 m), and dips at 3-4°E. It is overlain by a much thicker sequence of Abbotsford Formation east of Taieri Peak Road. The formation is close to river level in some few places, and lies beneath the river south of Smylers Peak.

3.2 Taratu Formation lithologies

In the Pleasant River valley, Taratu Formation is typically a massive to thickly bedded breccia-conglomerate with schist fragments up to boulder size (average 10 cm) and quartz pebbles up to 5 cm. These rocks are strongly cemented with limonite (iron oxide) and clay, and form prominent bluffs along the valley walls. The breccia becomes finer upward, into fine well sorted sandy gravel, variably limonite-cemented. It is overlain, around Smylers Peak, by massive to centimetre-bedded glauconitic sandstone interpreted to be basal Abbotsford Formation. North of Taieri Peak Road, Taratu Formation is predominantly quartz sandstone, granular in places, partly limonite-cemented, and lacking the cemented coarse basal schist-quartz conglomerate. It is overlain by glauconitic sandstone, with rare fossil fragments, of basal Abbotsford Formation. Well logs suggest the presence of quartz-schist gravel at depth (east of a postulated NW-trending fault). The thicker sequence near and south of the Pleasant River implies the presence of a “paleovalley” infilled with coarser sediments

in this area; the side of the valley lies roughly beneath Taieri Peak Road. (Note that this is not an “underground river” full of groundwater).

The limonite cementation (and consequent degradation of aquifer porosity and permeability) is due to precipitation of iron oxides from through-flowing groundwater. It can be accentuated in near-surface outcrops where water evaporates. The much stronger cementation of the formation along the Pleasant River may also be influenced by the coarser grain size and initial higher permeability of the quartz-schist gravels. Cementation has not been apparent in Taratu Formation intercepted in wells.

3.3 Faulting and subsurface distribution of Taratu Formation

Structure contours on the base of the Taratu Formation confirm the NNE dip, north of Taieri Peak Road; and suggest the presence of a previously unsuspected NW-trending fault, parallel to SH85 along the west side of the Glenpark-Meadowbank flats. This fault may be exposed in an outcrop near the end of McElwee Road, and is responsible for dropping the base of the Taratu Formation to ca. 55m depth in drillhole SV004 at Munro Road, 20-30 m deeper than surface outcrops indicate. Whether this fault is a continuation of the Palmerston Fault mapped by McMillan (1999) is uncertain. The throw on that fault is unknown and there are no records of why it was mapped, nor is there any present-day outcrop.

The presence of the Glenpark Fault has been confirmed. North of Taieri Peak it lies just east of where it was previously mapped, but the NE trend and down-to-the-east throw are as mapped. Total offset near Glenpark is in the order of 200m, possibly decreasing to 100 m at Taieri Peak Road.

The structure contours on Taratu Formation in Pleasant River are difficult to constrain because of relief on the schist surface, but appear to confirm the E to ESE dip measured in overlying Abbotsford Formation. The Meadowbank Fault crossing the Pleasant River remains as an inferred fault, but the location and throw are poorly known. It must lie SE of Hughes Road, as schist outcrops near that road are too high to be part of the Pleasant River block. Structure contours support a SE-down throw of up to 50 m on the Meadowbank Fault, north of the Pleasant River (note that this is opposite to the throw further SW: cf. Forsyth 2001). The well(s) drilled on Cleave’s property (ORC record No. I43/0039) indicate that this point is probably on the SE side of the Meadowbank Fault, but the depth to Taratu Formation is also consistent with it being on the NW side; the implication is that throw on the Meadowbank Fault decreases to the NE.

4. REVISION OF HYDROGEOLOGY

4.1 Taratu Formation

The Taratu Formation forms a widespread but patchy blanket over much of eastern Otago (Forsyth 2001), and is an important aquifer in North Otago where it is named the Papakaio

Formation. It consists of quartz and quartz-schist gravel and sand (conglomerate and sandstone), and (in places) coal seams and carbonaceous mudstone; it is also locally cemented by limonite or silica. The groundwater potential of the Taratu Formation beneath the Shag Valley was one of the targets of the current investigation. Surface and subsurface investigations confirm Cameron *et al.*'s (2003) suggestion that the Taratu Formation extends beneath the lower Shag Valley. It has a thickness of between 20 m and 50 m, thinning northward from the Pleasant River where the paleovalley is inferred (see above). Although the formation is tightly cemented in some surface exposures at Shag Point and in the Pleasant River catchment, there is still potential for useful volumes of groundwater to occur within fractures in cemented gravels. The degree of cementation decreases north from the Pleasant River.

Drillhole SV004, south of Munro Road, was sited to (a) check on the thickness of the shallow gravel aquifer and (b) to intercept the Taratu Formation at a depth of ca. 50 m, in order to reduce the amount of unproductive overlying mudstone that had to be penetrated. As described above, approximately 12 m of water-bearing fine quartz gravel and possible quartz-schist gravel were intersected by SV004, confirming the existence of this artesian aquifer.

Cleave's well (I43/0039) was drilled in 2003 southwest of Meadowbank at GR I43/296237 to a depth of 72 m. It intercept groundwater in Taratu Formation quartz-schist gravel and sand beneath Abbotsford Formation (see Appendix 3). An old well near Sutherland Road (I43/0022) penetrated to 37 m and is reported to be artesian and the water "very hard" (Irricon 1995); there is no well log. Based on this tenuous information and the results from SV004, the Sutherland Road well also apparently bottomed in Taratu Formation, rather than in surficial gravels.

A third well northeast of the Shag River valley near Craig Road also intercepted at least 20 m of Taratu Formation below 45 m, with good flows of groundwater from coarse quartz sand and gravel (see Appendix 3). The well is intermittently used for irrigation, when a down-hole pump is inserted. This well lies NW of the Glenpark Fault, and given the likely throw on that fault, hydrogeological connection with the Taratu Formation SE of the Glenpark Fault cannot be assumed.

4.2 Taratu water quality

The Taratu Formation is likely to be fully saturated beneath the lower Shag Valley, and have an artesian or sub-artesian pressure head, as the aquifer is confined from the surface by the low-permeability Abbotsford Formation. The available groundwater storage volume of the aquifer in the 20 km² lower Shag Valley area is difficult to estimate. The thickness (based on surface outcrop and two wells) is probably less than the 35 m estimated by Cameron *et al.* (2003), but the confined aquifer storage coefficient may well be higher than 10^{-5} to 10^{-4} , given the loose nature of the gravel intercepted in SV004 and in the well on Craig Road.

The water from well SV004 initially had a high silt load which would have been rather abrasive on pumping equipment. This was probably due to the relatively fine-grained nature of the Taratu at this location, and to the schist debris within it. Where the formation consists of clean coarse quartz gravel, this does not appear to be a problem, although injudicious well development may cause collapsing in loose sands. The SV004 water cleared after a few days.

From comparison with the Papakaio Formation near Oamaru (ORC 2002), water from the Taratu Formation may be aggressive (low pH) and have high iron, manganese chloride, sodium, magnesium and sulphate concentrations. High iron and manganese concentrations are common in confined aquifers with relatively long groundwater residence times, and are also likely where limonite cementation is developed, such as in the Pleasant River region. High iron and sulphate contents could also be predicted from surface exposures at Shag Point, where quartz gravel is in places cemented with pyrite (Fe_2S). There is some potential for contamination of the aquifer from surface activities, as the aquifer recharge zones are only partly protected by the overlying low-permeability Abbotsford Formation. This mudstone may also protect the Taratu Formation aquifer from saltwater contamination, in the parts that are well below sea level.

4.3 Taratu aquifer geometry

The Taratu Formation aquifer is cut off to the northwest by the Glenpark Fault, and dips beneath Abbotsford Formation between the Glenpark and Meadowbank faults. Structure contours on the base of the formation between these two faults show a gentle NE dip, and also imply a NW-trending fault, downthrown by some 20-30 m on the NE side, along the foot of the slopes west of the Meadowbank – Glenpark flats. The Meadowbank Fault offsets the Taratu Formation north of the Pleasant River, but throw probably decreases to the NE and the Taratu aquifer is inferred to be continuous across this fault beneath the Shag River. The influence of the Palmerston Fault is unknown. Based on the dip of the overlying Abbotsford Formation in surface outcrops, the Taratu aquifer may be more than 500 m below sea level at the SH1 bridge over the Shag River.

An alternative inference which could be drawn from the results of the groundwater dating (see Section 4.8, below) is that Taratu Formation surface outcrops in the hills are separated from other parts of the formation beneath Munro Road, possibly by faulting, and that much of the aquifer may be broken into discrete blocks not necessarily in hydraulic continuity.

The recent drilling was not designed to investigate the ORC (2002) suggestion that the Taratu Formation is in hydraulic connection with the Shag Valley Quaternary gravel aquifer north of the Shag River estuary, where the Taratu Formation is in contact with Quaternary sediments. Springs along the Waihemo Fault System near Walsh Road (R. Philip, *pers. comm.* 2004) also suggest some potential for groundwater in this area. Groundwater has been reported from the Taratu Formation in the Shag Point colliery, but at considerable depths; the extent of the aquifer(s) at Shag Point is unknown and they are likely to be interrupted by coal seams and numerous faults (Mutch *et al.* 1986). We believe the complexity of deformation along the

Waihemo Fault System makes any exploration of hydraulic connections and aquifers within the fault system somewhat difficult and probably expensive at this stage.

4.4 Quaternary gravels

The Quaternary gravels provide the most accessible groundwater source in the lower Shag Valley, and they are currently used for local water supply. Groundwater occurs in unconfined aquifers (mainly gravels) within the Morven and Pagon Road Formations and the modern river gravels. For general discussion, these units are all treated as a single aquifer system. The aquifer rests on an eroded Abbotsford Formation surface; the recent drilling suggests this surface is not as deep as previously thought and the overall aquifer thickness is probably nearer 10 m than the 15 m previously estimated.

Drillhole SV002 penetrated Morven Formation gravel which was cleaner and less clay-rich than surface exposures indicated. On this basis, we tentatively suggest Morven Formation gravels may have better aquifer potential than previously inferred. Intersections of Pagon Road gravels provided little new data, beyond a downward revision of probable average thickness.

4.5 Groundwater levels

Although drilling was undertaken during and after a period of wet weather, Shag River levels were normal and falling (see Section 2.2, above).

The groundwater level in SV002, the only shallow hole to strike significant water, was at 4 m, with a saturated thickness of 3 m. Development and pump testing would be required to confirm the usefulness and viability of this well; in the mean time it has been plugged.

Water was intersected at 44 m in SV004, and this level rose until the well was discharging freely onto the surface after a few hours.

4.6 Revised groundwater storage volumes

4.6.1 Shallow gravel aquifer

The volume of the lower Shag Valley gravel aquifer, between Glenpark and the SH1 bridge, was estimated by Cameron et al. (2003), based on the inferred thickness of sediment from the groundwater table down to the base of the aquifer. The volume of water contained in the aquifer was estimated using ArcView 3D Analyst extension ® software, which enables calculation of volume between two surfaces. The surfaces used were the groundwater surface (based on 14 October 1997 piezometric map data) and the base of the gravel aquifer as estimated from geological bore logs and cross sections. Aquifer unit thicknesses of 5 m (modern gravels), 10 m (Pagon Rd Formation), and 13 m (Morven Formation) were used in that volume calculation.

The recent drilling suggests the estimates of aquifer thickness were too high, and that the modern river gravels and Pagon Road Formation are thinner than previously estimated. Note that although formation thicknesses have reduced by more than half, the estimated saturated thickness of each formation has not been reduced by a similar amount. The revised saturated gravel thicknesses are:

Morven Formation	=	3.25m
Pagon Road Formation	=	3.25m
Modern river gravels	=	1.28m

Using the same storage coefficient of 0.1, the estimated aquifer volume has been downgraded from $7.3 \times 10^6 \text{ m}^3$, to $3.9 \times 10^6 \text{ m}^3$ (mean $3.1 \times 10^6 \text{ m}^3$).

If the groundwater levels (saturated thicknesses) used are representative of relatively high groundwater level periods, then storage volume during dry summer conditions is estimated at $2.2 \times 10^6 \text{ m}^3$. This is based on the maximum groundwater level fluctuation of 1.214 m at Chisholms bore, and assumes that the variation in groundwater level at this bore is representative of the aquifer.

4.6.2 Taratu Formation aquifer

Cameron *et al.* (2003) estimated potential storage of 7000 to 70 000 m^3 in the Taratu Formation beneath the lower Shag valley, assuming a storage coefficient of 10^{-5} to 10^{-4} and a thickness of 35 m. It is assumed that the aquifer is fully saturated, although in the Craig Road area the upper part of the formation was dry. Based on data from recent drilling and surface investigations, the average thickness of the aquifer is probably only 20 m, and the estimated volume should be reduced to 4000-40 000 m^3 . However there is considerable thickness variation (<10 up to 50 m), and the storage coefficient in places is reduced by the limonite cement, so these estimates are very approximate. Pump testing, to determine transmissivity, data on recharge rates (from dating), and much better control on subsurface thickness, is required to refine the estimates.

4.7 Groundwater recharge-discharge

The potential sources of groundwater recharge in the shallow gravel aquifer were given by Cameron *et al.* (2003) as:

1. Shag River flow loss to groundwater;
2. Infiltration of local rainfall;
3. Groundwater outflow from surrounding hill country;
4. Flow loss from Shag River tributaries to groundwater.

The Taratu Formation confined aquifer is likely to be recharged from the following sources:

1. Rainfall infiltration on the southwest side of the Shag Valley north from Palmerston, where Taratu Formation is exposed on ridge tops, and only partly capped by impermeable Abbotsford Formation. Some of this infiltration escapes from surface outcrops on ridge sides into streams, but may be recaptured in stream beds;
2. Flow loss from NE-flowing streams between Glenpark and Meadowbank, where they cross Taratu Formation at the foot of the hill slopes. Some of this flow loss may be into younger gravels, but near-surface Taratu gravels may also be recharged;
3. Possibly from the Shag River immediately downstream of the Glenpark Fault and the schist barrier at Craig Road (although no outcrop has been found to confirm this);
4. Possibly from fracture aquifer(s) within the schist (this would depend on hydraulic head differences between Taratu Formation and schist);
5. From the Pleasant River south of Palmerston, south of Smylers Peak.

The latter possibility enhances the potential for recharge of the Taratu aquifer under the Shag Valley. There is some groundwater loss due to seepage from Taratu Formation outcrops upstream from this recharge point, but infiltration from the Pleasant River should far exceed such losses. The effect of the Meadowbank Fault on aquifer continuity near Meadowbank is inferred to be minimal, based on existing data.

Hydraulic connections with groundwater systems along the Waihemo Fault and from Taratu Formation along Craig Road (see above) are speculative.

4.8 Groundwater dating

Groundwater can be dated by measuring its tritium and CFC/SF₆ contents. Tritium levels in groundwater systems are used to measure groundwater residence times over the timescale 0-70 years, and CFC/SF₆ dating is best for groundwater less than 30 year old. Long residence time indicates little flow-through, and thus the groundwater could easily be “mined” and extraction must be carefully monitored to ensure sustainability. If the residence time is very short, this indicates recharge from surface and rain water, and possible groundwater extraction rates then become much more dependent on local rainfall – like the shallow aquifer.

A tritium sample from well SV004 (Fraser Ross well on Munro Rd) yielded an age of 150 years or more. Based on this age, the CFC/SF₆ technique was not considered useful. No other suitable samples were able to be collected.

Sample	Depth (m)	Our No.	Tritium (TU ¹)	Age ² (years)
Fraser Ross well	72	TOT 76	0.032 ± 0.020	150 or more

¹Tritium concentration expressed as tritium units (TU), where 1 TU signifies a tritium/hydrogen ratio of 1×10^{-18} .

²Estimated average age (i.e. mean residence time) of the groundwater is based on the tritium concentration assuming an exponential piston flow mixing model with mixing fraction of 70% (E70%M).

The report on this sample from Dr Mike Stewart, GNS, Lower Hutt, states:

“The mean residence time of the water underground is estimated to be 150 years or more, based on an exponential piston flow mixing (EPM) model with 70% mixing (see Stewart & Morgenstern (2001), for an explanation of the EPM model). This model is chosen because of the hydrogeological situation of the well (which draws on an aquifer of quartz gravel/schist at 52 to 72 m depth, below a 15 m [*sic*]¹ confining layer of mudstone). The tritium concentration lies within twice the measurement error of zero, hence we consider that the sample does not contain tritium and the age could therefore be older than 150 years. At present, no modern recharge (i.e. water containing tritium) is observed.”

The Taratu aquifer beneath Munro Road thus contains old water, although the tritium technique cannot determine exactly how old. We also cannot tell whether this sample is representative of the whole aquifer. The water in this sample apparently dates from around the time of European settlement in the area, or possibly from long before this date. As no modern recharge was detected, we conclude that the water in this part of the aquifer is very slow-moving.

5. CONCLUSIONS

1. Having a geologist on the drilling rig to monitor cuttings enabled better control on depths to target lithologies than may have been the case with many previous wells;
2. Some old well logs may have over-estimated depths to Abbotsford Formation mudstone, and consequently previous estimates of aquifer volume were too large;
3. The Quaternary gravel aquifer system is thinner than previously estimated, with smaller storage volume;
4. The Morven Formation gravels are less weathered than previously thought, enhancing their reservoir potential somewhat;
5. The Quaternary aquifer has a revised estimated median storage volume of ca. 3.9×10^6 m³. The storage volume is estimated to drop to 2.2×10^6 m³ in drought conditions;
6. The Taratu Formation quartz gravel hosts a confined aquifer which lies at relatively shallow depths (about 50 m) between the Glenpark and Meadowbank faults.
7. Taratu aquifer volume estimates range from 4000-40 000 m³; further drilling is necessary to confirm the extent and continuity of the aquifer;

¹ The actual figure is closer to 50 m.

8. The Taratu aquifer at Munro Road contains water ≥ 150 years old and no modern recharge was detected. It is not known how accurately this sample represents the aquifer;
9. Taratu groundwater may have an “aggressive” chemistry similar to the Papakaio aquifer in North Otago, especially in high iron. Geochemical analysis is required to confirm this assumption;
10. Large-scale extraction of groundwater from the Taratu aquifer, in the absence of proven recharge, could deplete the resource;
11. The possibilities for sustainable use of the aquifer are at present unknown but are unlikely to extend to large-scale irrigation.

6. RECOMMENDATIONS

Several recommendations are made as a result of this investigation.

6.1 Shallow aquifer

Based on the results of recent drilling, it appears that the shallow aquifer system in the lower Shag Valley has less potential than previously thought.

1. Further drilling into this aquifer is not likely to find large volumes of groundwater, especially in view of the constraints on allocation.
2. If further exploitation of the shallow aquifer is planned, the most productive investment would be in extending and upgrading the existing water traps.

6.1.1 Upgrading existing extraction system

The total through-flow of the Shag River and its accompanying shallow aquifer is not all being intercepted by the present abstraction systems (Cameron *et al.* 2003), with possible through-flow of 58 l/s and abstraction of only 16.7 l/s (dependant on inflow rate further upstream). Increasing the efficiency of the interception system will obviously result in additional abstraction capacity. As the groundwater is flowing through a shallow (10 m \pm) aquifer resting on an impermeable Abbotsford Formation basement, possible improvements would be a row of shallow bores across most of the valley; or a deep trench up to several hundred metres long, infilled with coarse very permeable gravel and a pick-up system at the bottom of the trench. However, we emphasise that these systems would need to be designed and implemented by suitably qualified groundwater and hydraulic engineers.

6.2 Taratu Formation

The Taratu Formation is a relatively unexploited aquifer, with probably only one or two producing wells within it. Based on existing knowledge, this aquifer has significant potential to extend groundwater resources within the lower Shag Valley. There is limited potential to develop well SV004, drilled during this programme. However, based on limited data, the water in the aquifer is old and slow-moving, with no modern recharge detected. Furthermore, it is almost certainly not a single aquifer, but is broken by faults into blocks which may not be hydraulically connected. The Taratu aquifer is still very poorly constrained and there is not enough information on which to base the sustainable management of the resource. We recommend the following actions prior to any development and water allocation:

1. Using new surface and subsurface information obtained during this investigation, design and implement additional drilling into the Taratu Formation in order to refine its depth, thickness and aquifer properties. At least two of the holes should be set up for pump testing.
2. Revise estimates of Taratu Formation aquifer volume and properties from the results of this drilling programme.
3. Take water chemistry samples of Taratu Formation water to confirm the quality of the resource, after flushing bores for some days to remove possible drilling fluid contamination.

i.	Test for pH	xi.	Potassium
ii.	Boron	xii.	Silica
iii.	Bromide	xiii.	Sodium
iv.	Arsenic	xiv.	Sulfate
v.	Calcium	xv.	Nitrate-nitrogen
vi.	Chloride	xvi.	Nitrite-nitrogen
vii.	Conductivity	xvii.	TKN
viii.	Fluoride	xviii.	Ammonia or ammonium
ix.	Iron (total and dissolved)	xix.	Phosphorus
x.	Manganese	xx.	E. coli

4. Obtain further tritium samples from wells in different parts of the aquifer, to refine groundwater residence and recharge properties.
5. Should modern water be found by tritium dating, install groundwater level recorders on the pump-tested bores to see if they respond to Shag River and/or rainfall events.

6.2.1 Well development

Although Well SV002 intercepted some groundwater in the shallow aquifer, upgrading the extraction system is a higher priority than developing SV002. Of the other wells drilled during this programme, only SV004 on Munro Rd has any potential for development.

Possible silting and pump erosion problems, the lack of data on groundwater chemistry, and the age of the water in this well lead us not to recommend its immediate development.

Due to the possibility of the Taratu aquifer at this site being limited and thus vulnerable to depletion, we recommend the following should SV004 be developed:

1. A second well be drilled nearby to enable pump testing;
2. Casing and screening of both wells, to prevent ingress of sediment;
3. Chemical analysis of groundwater, as recommended under 3). above;
4. Dating of water samples at intervals to check for any influx of new water;
5. GPS survey prior to pumping to check for possible ground subsidence following “mining” of groundwater.

7. ACKNOWLEDGEMENTS

The authors thank Shag Valley landowners for permission to drill on their land and investigate surface outcrops, and Mr R. Philip for assistance in organising access and for introductions. Discussions with Mr D. Stewart of Raineffects Ltd were an integral part of developing and implementing the programme. Washington Drilling Ltd and especially S. Pilcher are thanked for their contribution to these investigations. P.J. Forsyth and P.J. Glassey (GNS Dunedin) are thanked for their contributions to the mapping, to geological discussions, and for reviewing this report. Mr T. Heller (previously Otago Regional Council) provided a commentary on the work programme and unearthed well logs. The aquifer volume calculations were upgraded by Mr Stewart Cameron of GNS (Wairakei). Comments on the text from S. Cameron (GNS Wairakei), R. Philip and D. Stewart have been incorporated in this report. Report processing and assembly was by B. Elliot and E. Lang, Landcare Research, Dunedin.

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APPENDIX 1: WORK PLANS FOR PHASE 2 GROUNDWATER INVESTIGATIONS

Shag Water Resources – Groundwater Investigations Phase 2 Study Brief

1 Introduction

The Shag River Catchment Water Supplies Sub-Committee is undertaking feasibility studies for supplementing water supplies for the area. In Phase 1 of the study, Raineffects Limited, GNS (Cameron *et al.* 2003) and David Hamilton & Associates Ltd completed scoping studies on surface water and groundwater resources, irrigation opportunities, and water storage possibilities. Results of the groundwater investigations showed that further investigation of the groundwater potential to supplement existing public water supplies was warranted, but that available groundwater resources were probably insufficient for any significant irrigation use.

MAF have approved a Sustainable Farming Fund grant towards further investigations into ground and surface water supplies. However, available funding is such that a reassessment of the Shag Valley aquifer volume and properties, one of the recommendations arising from Phase 1 (Cameron *et al.* 2003), is not feasible. Instead, a groundwater exploration programme will be implemented aimed at providing new information on the groundwater of the Shag Valley but which may also, if sufficient quantities of water are found, provide new wells(s) which could be used for supplementing existing public water supplies.

The Waitaki District Council is the lead agency with Mr Philip Bell, Assets Group Manager, the Project Manager. The first point of contact between parties will be David Stewart of Raineffects Limited.

1.1 Shag Valley Aquifer Potential

Based on calculations presented by Cameron *et al.* (2003), there appears to be more groundwater available in the Shag Valley aquifer than is currently extracted. The amount of groundwater which could be extracted from the aquifer depends on several factors which are not fully quantified. These include:

- 1) Storage capacity of the aquifer. The estimated potential aquifer storage ($7.3 \times 10^6 \text{ m}^3$) is based on limited information as to the thickness, lateral extent and storage coefficient of the gravels.
- 2) Recharge and flow rates. Low flows in the Shag River, manifested as reduction or total loss of surface water flows, equate to reductions in monitored groundwater levels (e.g. Chisholm's bore). Estimates of flow rates vary considerably.
- 3) Distance from the Shag River. Bores close to the river are more affected by Shag River flow rates as they are within modern gravels, rather than in lower porosity and older terrace gravels.

Current extraction rates of ca. 16.7 l/s are estimated to be lower than the natural discharge rate, and the groundwater “take” is estimated at 1% of total storage volume during drought conditions. Groundwater that has not been intercepted is therefore passing through the aquifer, and the aim of this phase of the investigation is to explore the remaining potential

groundwater resource.

1.2 Uncertainties and Risk

It must be emphasised that the figures given by Cameron *et al.* (2003) are poorly constrained due to a lack of data. In particular, the aquifer volume, flow rates within it, and recharge rates may be considerably in error. As a consequence *the volume of groundwater in the Shag Valley aquifer that could be exploited, in addition to that already taken, may be less than presently believed* (see above). To refine these figures requires a much more extensive investigation than can be afforded under the current budget, although such refinement is a requirement for sustainable management of the aquifer.

The decision to undertake a limited drilling programme with the aim of increasing current groundwater extraction is risky. Drillholes are being sited based on inadequate knowledge, and *it must be accepted that some holes may be dry*. However, any wells will provide new data and improve knowledge of the aquifer.

2 Work Plan

2.1 General

At least four investigation holes will be drilled. The number depends on the depths of the first four. If the aquifer base is intersected at shallow depths, more holes may be possible. It is anticipated (Cameron *et al.* 2003, Appendix 2) that these holes will be around 20m in depth. The wells will be drilled, cased as necessary, and logged on site, with depth to “basement” mudstone closely monitored so unnecessary drilling is avoided. Groundwater levels will be monitored by piezometer.

2.2 Drilling Target Selection

Sites for the drillholes will be chosen on the following grounds:

- Within Pagon Road terrace gravels, or on the lower (modern) terrace gravels. The older (Morven) gravels are discounted as they tend to be clay-rich, of smaller extent, and remote from Shag River recharge.
- Within reaches where the Shag River is known to recharge the aquifer, rather than *vice versa*; this should ensure that in periods of low flow there is still at least some water flowing into the aquifer.
- Near existing and utilised wells, so that pump testing can be undertaken as part of well development should the investigation bores intercept groundwater.
- Up-valley from possible salt-water contamination. At least one bore near Bushey Park is known to have intercepted salt water, but the depth, nature and location of the interface between the Shag Valley aquifer and seawater is unknown beyond that.
- In areas where adverse affects on existing wells will be minimised. If a new well upstream from existing wells extracts large volumes of groundwater, flows in downstream wells may be reduced.

- Ideally, one drillhole would be sited to test the potential of the deep Taratu gravels in addition to the shallow aquifer.

2.3 Specific Well Sites

Final locations will be chosen in consultation and agreement with David Stewart of Raineffects Limited. Agreements with landowners on locations of proposed drilling sites need to be in place before any drilling is undertaken. These agreements are to be arranged by David Stewart of Raineffects Limited between the WDC and the landowner.

2.4 Drilling Operations

GNS will provide a site geologist to oversee drilling operations. The site geologist will report by Email or in person to David Stewart of Raineffects Limited once drilling of each hole is completed. Drilling depths will be no greater than 20m unless otherwise agreed between GNS and David Stewart of Raineffects Limited. GNS will reinstate the drill site to as close as possible to its original condition following drilling. Note that should ground conditions be unsuitable for rig access, there will be some delay in the timetable given in Section 5, below.

2.5 Pump Testing

Should the investigation wells intercept significant groundwater, pump tests should be run prior to further development. As this result is uncertain, the costs of pump testing are not included in this proposal and should form part of any future well development programme.

2.6 Interpretation

The existing estimate of the volume of the Shag Valley aquifer as given by Cameron *et al.* (2003), will be revised based on new data obtained from the drilling programme. The revised figure will assist in constraining possible extraction rates should the new wells be developed. Further refinement of the aquifer model, as recommended in the Cameron *et al.* (2003) report, is beyond the scope of the budget and this proposal.

2.7 Future Use of Newly Drilled Investigation Bores

It is expected that some (if not all) of the newly drilled investigation bores may be used to supplement existing water supply if yields are sufficient and consistent. Costs for conversion of newly drilled investigation bores into wells suitable for water supply are not covered by this project.

If the newly drilled well(s) are suitable for water supply, then the Waitaki District Council (WDC) will need to pay the additional costs of casing, screen, consultation, etc. GNS and WDC will agree on the extra cost of completion of water supply wells.

The WDC will need to decide on the future use of the investigation bores, and casing removal, promptly on completion of each well. Any costs incurred as part of WDC decision on the future use of the investigation bores, e.g. drillers standby costs and consultation, are not part of this contract.

It may be that if the WDC do not want the well for its own purposes, it could be offered to the local landowner. If the local landowner wants the well, then that landowner will have to pay the cost for casing, screen, etc. GNS and the landowner will agree on the extra cost of

completion of water supply wells.

2.8 Reporting.

Monthly progress reports will be prepared by GNS and forwarded by EMAIL to David Stewart of Raineffects Limited by the 5th of the following month. David Stewart will in turn provide a progress report to WDC by 10th of that month.

A final report will be prepared initially in draft form for discussion and comment by WDC representatives and in final form incorporating changes agreed between WDC representatives and GNS. This report will contain:

- The results of this investigation including geological information collected as part of this project, in the form of interpreted well logs
- Refinement of the aquifer volume calculations from new information.
- Recommendations as to which (if any) of the investigation drillholes should be developed as production wells

3 Costs

\$35,000 incl. GST

GNS will submit monthly invoices as progress payments from June 2004.

4 Terms and Conditions

The work will be done under the attached Terms and Conditions, modified from GNS'S Standard Terms and Conditions with respect to use of data and results, following previous arrangements with WDC.

5 Timetable

30 June 2004 identify agreed drill hole locations

30 July 2004 drilling completed

31 August 2004 interpretation of results completed

13 September 2004 first draft of report completed and sent to WDC representatives

20 September 2004 WDC representatives comments received by GNS

15 October 2004 final report complete

6 Outputs

- Brief Emailed monthly reports.
- Well logs
- A final report as detailed under Section 2.8 of this contract

7 Otago Regional Council Drilling and Water Use Consents

David Stewart of Raineffects Limited will be responsible for obtaining drilling consents, and any other ORC consents relevant to the project. GNS will provide him with all information relevant to drilling consents such as drilling locations etc.

8 Drilling Contracts

GNS will be responsible for organising the drilling contract and for signing off the driller's invoice to WDC. The driller will invoice WDC directly in order to reduce costs, but the accounts are to be approved by GNS and David Stewart before payments are made.

9 Communication

GNS's prime point of contact in this project is David Stewart of Raineffects Limited. David Stewart is responsible for liaising with the ORC, Waitaki District Council, local farmers, media, and community groups. David Stewart is also responsible for providing a monthly update of progress to WDC for updating local Councillors.

Dated:

Dated:

Signed:

Signed:

Waitaki District Council

Institute of Geological and Nuclear Sciences

Shag Water Resources – Groundwater Investigations Phase 2

GNS revised work plan for November – December 2004

The drilling phase of this programme is complete (see GNS Report for end September 2004), a draft report prepared, and invoices for drilling and GNS work to date submitted. In order to extract the maximum information on Shag Valley aquifer potential from the remaining budget (\$9500 incl GST), GNS has revised the original work plan following discussions with David Stewart and Rod Phillip.

GNS is of the opinion that further drilling into the shallow Shag Valley gravel aquifer would not be useful. The Taratu Formation quartz gravel aquifer is seen as having the most potential in the lower Shag Valley, although water quality may be an issue should the water be needed for domestic supply. Further exploratory well(s) into the deeper Taratu Formation should be targeted at the deeper parts of the aquifer and there are insufficient funds available for such drilling. The most useful and affordable information on the Taratu aquifer can be obtained by surface examination of Taratu outcrops west of Palmerston, and by dating the water from wells tapping the Taratu aquifer.

Existing surface geological information was adequate for locating and testing the Taratu aquifer, but as this information was obtained in the course of regional geological mapping, it is inadequate for detailed volume and internal aquifer characterisation. Detailed surface mapping will enable GNS to constrain the properties of the Taratu Formation aquifer (e.g. presence and degree of cementation, grain size variation, thickness, structure, throw on faults etc.). Dating of Taratu Formation water (using tritium) will provide information on groundwater residence time, and thus on recharge. Additional methods (e.g. geochemistry and dating CFC content of Taratu Formation groundwater) would be useful but are unaffordable on the present budget.

The revised programme proposed is:

- Late October, sampling of groundwater from wells at Craig Road and Munro Rd; field examination of outcrops in Pleasant River and west of Palmerston (three days).
- Early November, structure contouring of Taratu aquifer, and revision of draft report based on surface mapping
- Mid November, submission of revised report.
- Mid December, submission of final report after review and comments

Tritium dating of water samples currently takes a minimum of three months from sampling, and GNS proposes to submit a second smaller report on the implications of the dating results when they come to hand, in March next year. This delay is unfortunate but unavoidable.

I M Turnbull
26.10.04

APPENDIX 2: WELL LOGS FROM PHASE 2 DRILLING, LOWER SHAG VALLEY

Shag Valley Ground Water Investigation							
Location:	Shag bend		Grid reference:	2333251/5523606	Map Sheet:	J43	
Contractor:	Washingtons		Driller:	Steve Pilcher	Drill Rig:	CP-650 EX	
Date Started:	18-Sep-04		Date Complete:	18-Sep-04	End of Hole:	7.5 m	
Geologist:	H.Fraser		Water depth:	dry	Weather:	Snow	
Drill Hole ID:	SV001						
Metres	Sample No.	Sketch	Unit Name	Colour	Moisture	% Clasts	% Clay
0	J43/001		Top soil	Brown	Dry	30	70
1	J43/002		Modern gravel	Brown	Moist	80	20
2	J43/003		Modern gravel	Brown	Moist	90	10
3	J43/004		Modern gravel	Brown	Moist	90	10
4	J43/005		Modern gravel	Brown	Moist	90	10
5	J43/006		Modern gravel	Brown	Moist	90	10
6	J43/007		Modern gravel	Brown	Moist	90	10
8	J43/008		Ab. mudstone	Green	Dry	0	100

Shag Valley Ground Water Investigation							
Location:	Puketapu		Grid reference:	2333251/5523606	Map Sheet:	J43	
Contractor:	Washingtons		Driller:	Steve Pilcher	Drill Rig:	CP-650 EX	
Date Started:	18-Sep-04		Date Completed:	18-Sep-04	End of Hole:	9 m	
Geologist:	H.Fraser		Water depth:	5 m	Weather:	Snow/Hail	
Drill Hole ID SV002							
Metres	Sample No.	Sketch	Unit Name	Colour	Moisture	% Clasts	% Clay
0	J43/009		Loess	Brown	Moist	0	100
1	J43/009		Loess	Brown	Moist	0	100
2	J43/010		Morven Fmn	Brown	Moist	80	20
3	J43/011		Morven Fmn	Brown	Moist	80	20
4	J43/012		Morven Fmn	Brown	Moist	80	20
5	J43/013		Morven Fmn	Brown	Saturated	80	20
6	J43/014		Morven Fmn	Brown	Saturated	80	20
7	J43/015		Morven Fmn	Brown	Saturated	80	20
8	J43/016		Morven Fmn	Brown	Saturated	50	50
9	J43/017		Ab. mudstone	Brown/Green	Moist	0	100

Shag Valley Ground Water Investigation							
Location:	Old Railway		Grid reference:	2330928/5523742		Map Sheet:	J43
Contractor:	Washingtons		Driller:	Steve Pilcher		Drill Rig:	CP-650 EX
Date Started:	18-Sep-04		Date Complete:	18-Sep-04		End of Hole:	5 m
Geologist:	H.Fraser		Water depth:	3 m		Weather:	Snow/Hail
Drill Hole ID:	SV003						
Metres	Sample No.	Sketch	Unit Name	Colour	Moisture	% Clasts	% Clay
0	J43/018		Loess Topsoil	Brown	Moist		100
1	J43/018		Loess	Brown	Moist		100
2	J43/019		Loess	Brown	Moist		100
3	J43/020		Gravel	Brown	Wet	70	10
4	J43/021		Ab. mudstone	Brown/Green	Moist		100

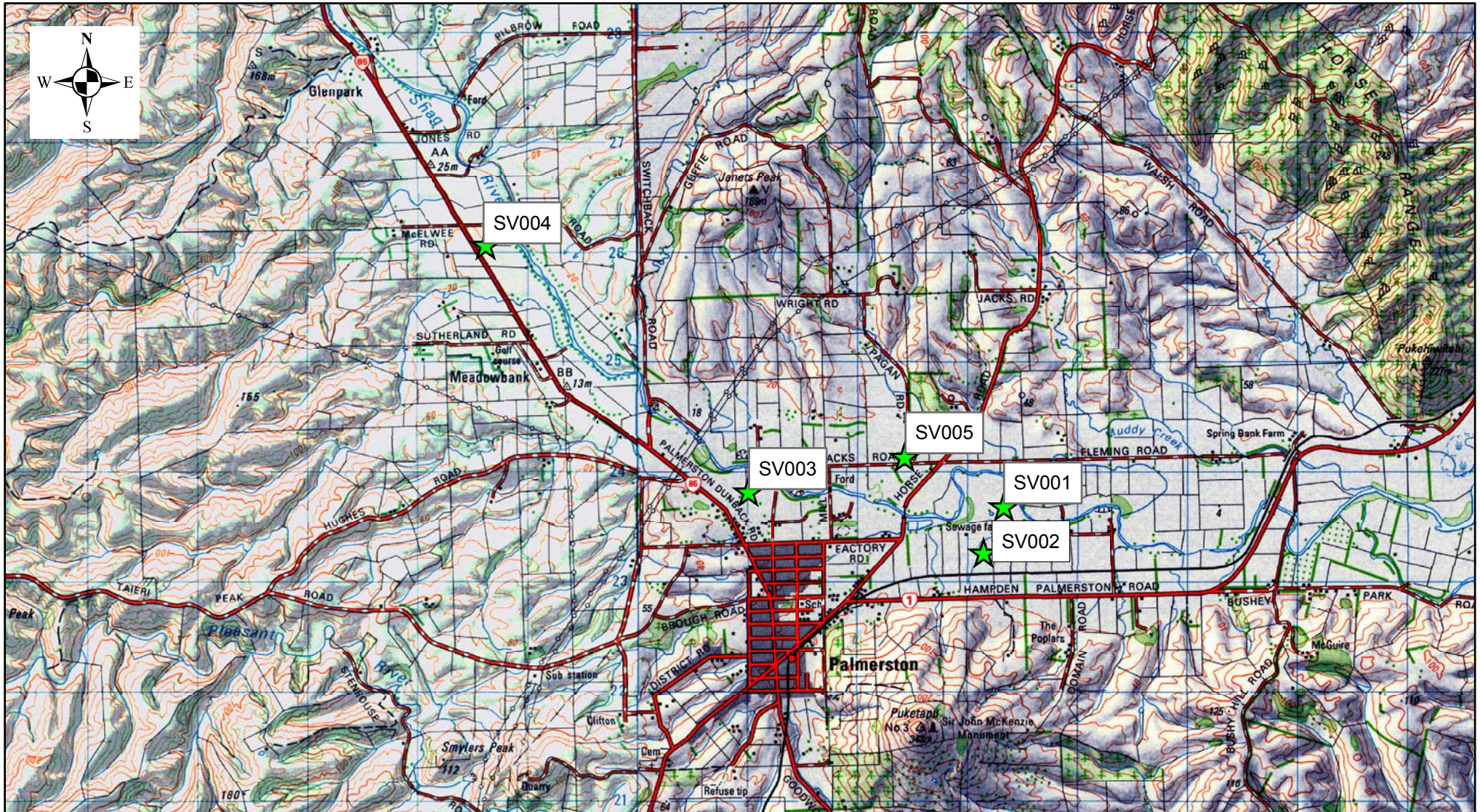
Shag Valley Ground Water Investigation

Location:	Munro Road		Grid reference:	2328537/5526058		Map Sheet:	I43
Contractor:	Washingtons		Driller: Steve Pilcher			Drill Rig: CP-650 EX	
Date Started:	18-Sep-04		Date Completed:	19-Sep-04		End of Hole: 72 m	
Geologist:	H.Fraser		Water depth: 44 m		Weather:	Snow/Rain/Windy	
Drill Hole ID:	SV004						
Metres							
0	Sample No.	Sketch	Unit Name	Colour	Moisture	% Clasts	% Clay
1	J43/022		Modern gravels	Brown	Wet	90	10
2	J43/023		Modern gravels	Brown	Wet	70	30
3	J43/024		Ab. mudstone	Dark Green	Wet	40	60
4	I43/001		Ab. mudstone	Dark Green	Dry	20	80
5	I43/002		Ab. mudstone	Grey Green	Dry	0	100
6	I43/003		Ab. mudstone	Grey Green	Dry	0	100
7	I43/004		Ab. mudstone	Grey Green	Dry	0	100
8	I43/005		Ab. mudstone	Grey Green	Dry	0	100
9	I43/006		Ab. mudstone	Green	Dry	0	100
10	I43/007		Ab. mudstone	Brown	Dry	0	100
11	I43/008		Ab. mudstone	Brown Green	Dry	0	100
12	I43/009		Ab. mudstone	Brown Green	Dry	0	100
13	I43/010		Ab. mudstone	Brown Green	Dry	0	100
14	I43/011		Ab. mudstone	Brown Green	Dry	0	100
15	I43/012		Ab. mudstone	Green	Dry	0	100
16	I43/013		Ab. mudstone	Green	Dry	0	100
17	I43/014		Ab. mudstone	Green	Dry	0	100
18	I43/015		Ab. mudstone	Green	Dry	0	100
19	I43/016		Ab. mudstone	Green	Dry	0	100
20	I43/017		Ab. mudstone	Green	Dry	0	100
21	I43/018		Ab. mudstone	Dark Brown	Dry	0	100
22	I43/019		Ab. mudstone	Dark Brown	Dry	0	100
23	I43/020		Ab. mudstone	Green	Dry	0	100
24	I43/021		Ab. mudstone	Green	Dry	0	100
25	I43/022		Ab. mudstone	Green	Dry	0	100
26	I43/023		Ab. mudstone	Green	Dry	0	100
27	I43/024		Ab. mudstone	Green	Dry	0	100
28	I43/025		Ab. mudstone	Green	Dry	0	100
29	I43/026		Ab. mudstone	Green Brown	Dry	0	100
30	I43/027		Ab. mudstone	Brown	Dry	0	100
31	I43/028		Ab. mudstone	Brown	Dry	0	100
32	I43/029		Ab. mudstone	Brown	Dry	0	100
33	I43/030		Ab. mudstone	Brown	Dry	0	100
34	I43/031		Ab. mudstone	Brown	Dry	0	100
35	I43/032		Ab. mudstone	Brown	Dry	0	100
36	I43/033		Ab. mudstone	Brown	Dry	0	100
37	I43/034		Ab. mudstone	Dark Brown	Dry	10	90
38	I43/035		Ab. mudstone	Dark Brown	Dry	80	20
39	I43/036		Ab. mudstone	Grey	Dry	50	50
40	I43/037		Ab. mudstone	Grey	Dry	60	40

Shag Valley Ground Water Investigation

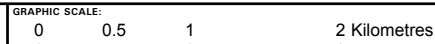
Location:	Munro Road		Grid reference:	2328537/5526058		Map Sheet:	I43
Contractor:	Washingtons		Driller: Steve Pilcher			Drill Rig: CP-650 EX	
Date Started:	18-Sep-04		Date Completed:	19-Sep-04		End of Hole: 72 m	
Geologist:	H.Fraser		Water depth: 44 m		Weather:	Snow/Rain/Windy	
Drill Hole ID:	SV004						
Metres							
41	I43/038		Ab. mudstone	Grey	Dry	70	30
42	I43/039		Ab. mudstone	Grey	Dry	60	40
43	I43/040		Ab. mudstone	Grey	Dry	60	40
44	I43/041		Ab. mudstone	Grey	Dry	60	40
45	I43/042		Taratu	Grey	Wet	80	20
46	I43/043		Taratu	Grey	Wet	100	0
47	I43/044		Taratu	Grey	Wet	100	0
48	I43/045		Taratu	Grey	Wet	100	0
49	I43/046		Taratu	Grey	Wet	100	0
50	I43/047		Taratu	Brown	Wet	100	0
51	I43/048		Taratu	Brown	Wet	100	0
52	I43/049		Taratu	Brown Grey	Wet	100	0
53	I43/050		Taratu	Brown Grey	Wet	100	0
54	I43/051		Taratu	Brown Grey	Saturated	100	0
55	I43/052		Taratu	Brown Grey	Saturated	100	0
56	I43/053		Taratu	Brown Grey	Saturated	100	0
57	I43/054		Taratu	Brown Grey	Saturated	100	0
58	I43/055		Taratu	Brown Grey	Saturated	100	0
59	I43/056		Weathered schist	Grey Brown	Wet	100	0
60	I43/057		Weathered schist	Grey Brown	Wet	100	0
61	I43/058		Weathered schist	Grey Brown	Wet	100	0
62	I43/059		Weathered schist	Grey Brown	Wet	100	0
63	I43/060		Weathered schist	Grey Brown	Wet	100	0
64	I43/061		Schist	Grey	Wet	100	0
65	I43/062		Schist	Grey	Wet	100	0
66	I43/063		Schist	Grey	Wet	100	0
67	I43/064		Schist	Grey	Wet	100	0
68	I43/065		Schist	Grey	Wet	100	0
69	I43/066		Schist	Grey	Wet	100	0
70	I43/067		Schist	Grey	Wet	100	0
71	I43/068		Schist	Grey	Wet	100	0
72	I43/069		Schist	Grey	Wet	100	0
	I43/070		Schist	Grey	Wet	100	

Shag Valley Ground Water Investigation							
Location:	Blacks Road	Grid reference:	2332369/5524071	Map Sheet:	J43		
Contractor:	Washingtons	Driller:	Steve Pilcher	Drill Rig:	CP-650 EX		
Date Start:	19-Sep-04	Date Completed:	19-Sep-04	End of Hole:	8 m		
Geologist:	H.Fraser	Water depth:	5 m	Weather:	Snow/Hail		
Drill Hole I	SV005						
Metres	Sample No.	Sketch	Unit Name	Colour	Moisture	% Clasts	% Clay
0	J43/025		Topsoil	Brown	Moist	0	100
1	J43/025		Loess, silt	Brown	Moist	0	100
2	J43/025		Loess, silt	Brown	Moist	0	100
3	J43/025		Loess, silt	Green	Moist	0	100
4	J43/025		Loess, silt	Green	Moist	0	100
5	J43/026		Gravel	Brown	Wet	80	20
6	J43/027		Ab. mudstone	Green	Moist	0	100
7	J43/027		Ab. mudstone	Green	Moist	0	100



GROUNDWATER OF THE LOWER SHAG VALLEY
NORTH OTAGO: PHASE 2 INVESTIGATIONS

LOCATION PLAN



ORIGINAL SCALE AT A4:
1:50000



FIGURE 1.1

DRAWN:
H.L.F.

DATE:
November 2004

APPENDIX 3: LOGS OF ADDITIONAL WELLS INTO TARATU AQUIFER

Logs of additional wells into Taratu aquifer

Two well logs were provided by Washingtons. A third log (of an earlier hole drilled at Cleave's, in 2003) has yet to be obtained (if it exists).

Well No. I43/0039 (Cleave's) was drilled near Hughes Road east of the Meadowbank Fault. It intersected Abbotsford Formation beneath 10 m of "clay" (possibly weathered Abbotsford mudstone) to a depth of 54.7 m. Beneath this is 17m (+) of what we interpret as Taratu Formation quartz gravel, probably with weathered schist fragments, to a total depth of 72 m. Max Dickson (pers. comm.) reported quartz gravel from this interval. Based on an interpreted collar height of 50 m ASL, the Taratu aquifer is mostly below sea level at this point.

Another well (un-numbered as yet: Clutha Transport, E. Williams) on Craig Road (no specific location) also intercepted groundwater in coarse quartz gravel of the Taratu Formation beneath Abbotsford Formation, from 45 m to a depth of 67.3 m (aquifer thickness 17 m). This well was probably sited on the northwest side of the Glenpark Fault, where Taratu and Abbotsford sediments overlie schist on the upthrown side of the Glenpark Fault. Hydraulic connection with the main Taratu aquifer under the Shag River cannot be assumed.

Pump tests indicate good groundwater flows from Craig Road, but less from Hughes Road.

