NORTHEASTERN BRITISH COLUMBIA DISPOSAL WELL STUDIES

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INTRODUCTION

Water is a vital commodity and certain to become more important as demand grows and the number of clean sources shrinks. British Columbia has an abundance of clean fresh water not only in its plentiful rivers and lakes but also in its groundwater. Both types of valuable fresh water are susceptible to contamination from waters produced as a result of hydrocarbon production.

Water that is produced incidental to oil and gas production is typically re-injected into isolated formations using dedicated water-disposal wells. Sometimes this is done only to avoid contaminating the surface with oily and brackish water; often it serves the dual purpose of waste removal and pressure maintenance of depleting hydrocarbon reservoirs. If done correctly, subsurface water disposal can avoid contaminating either surface water or groundwater. An understanding of the practice is necessary to ensure proper procedures are followed to mitigate leakages uphole into potable reservoirs.

As a first step in understanding the practice of waste-water disposal in the subsurface of BC, a set of studies of representative disposal wells is being prepared. A sample study for one well (BRC HTR Beau Beg D-25-G/94-G-1) has been presented here to show the proposed style and level of content. Any comments or suggestions from readers will be taken into account while working on the additional well studies. The more comprehensive report will include studies of disposal wells from different pools and formations throughout northeastern BC. This information should provide insights into which formations are most useful for the practice and which formations have the greatest limitations. Also to be provided is a brief summary of the technical aspects of water disposal and an overview of the current practice within BC.

Included for each individual well study will be a brief geological description, a history of the well, potential disposal volumes, and engineering and geological parameters needed for volumetric calculations or reservoir modelling. A well-plan showing the construction details of the well bore and a log showing the injection zone will also be included whenever possible. More or less detail and features will be included in the future, depending on input from readers.

The well files for this location contain a wide range of information, and that is partly why it was selected for study. BRC HTR Beau Beg is typical for water disposal wells in BC because it was not drilled specifically for that purpose. It began as a Halfway Formation gas well and was later converted to Baldonnel Formation water disposal when production became uneconomic due to a high water cut.

All information for the disposal well studies will be taken from publicly available well files.

SAMPLE WATER DISPOSAL WELL STUDY: BRC HTR BEAU BEG

Location:	200 / D-25-G/94-G-1 / 02
Pool:	Baldonnel (as designated by the British Columbia Oil and Gas Commission)
Formation:	Baldonnel Formation
Formation Age:	Triassic
Rig Release:	February 28, 2000
Status (October 2007):	Water Disposal

Development Details

This well was drilled for potential gas production in both the Halfway and Baldonnel Formations. After a period of production from the Halfway Formation between 2001 and 2002, the well was suspended due to a high water cut. The Baldonnel Formation was never produced because testing showed it to be wet with only small volumes of sour gas. The original well operator, Canadian Hunter Exploration Ltd., applied to convert the well to water disposal in the Baldonnel Formation, and permission was granted by British Columbia's Oil and Gas Commission on July 30, 2001. This was followed by injectivity testing that confirmed its suitability.

During testing, water was injected at rates of up to 190 m3 per day with a pressure of 13 996 kPa. Pressure dropped off satisfactorily after pumping stopped, demonstrating the presence of an aquifer-supported constant-pressure boundary. Water disposal began in 2002 and has continued at least until the date of the latest records of 2007.

Figure 1 shows the original well completion scheme for this well, which is typical for this region. Surface casing was set to a depth of 255 m, presumably below the depth of the lowest potable aquifer. Production casing was set to total depth. A plug was set to isolate the Halfway Formation from the Baldonnel Formation, and a sleeve was included within the tubing to allow the flexibility of dual- or

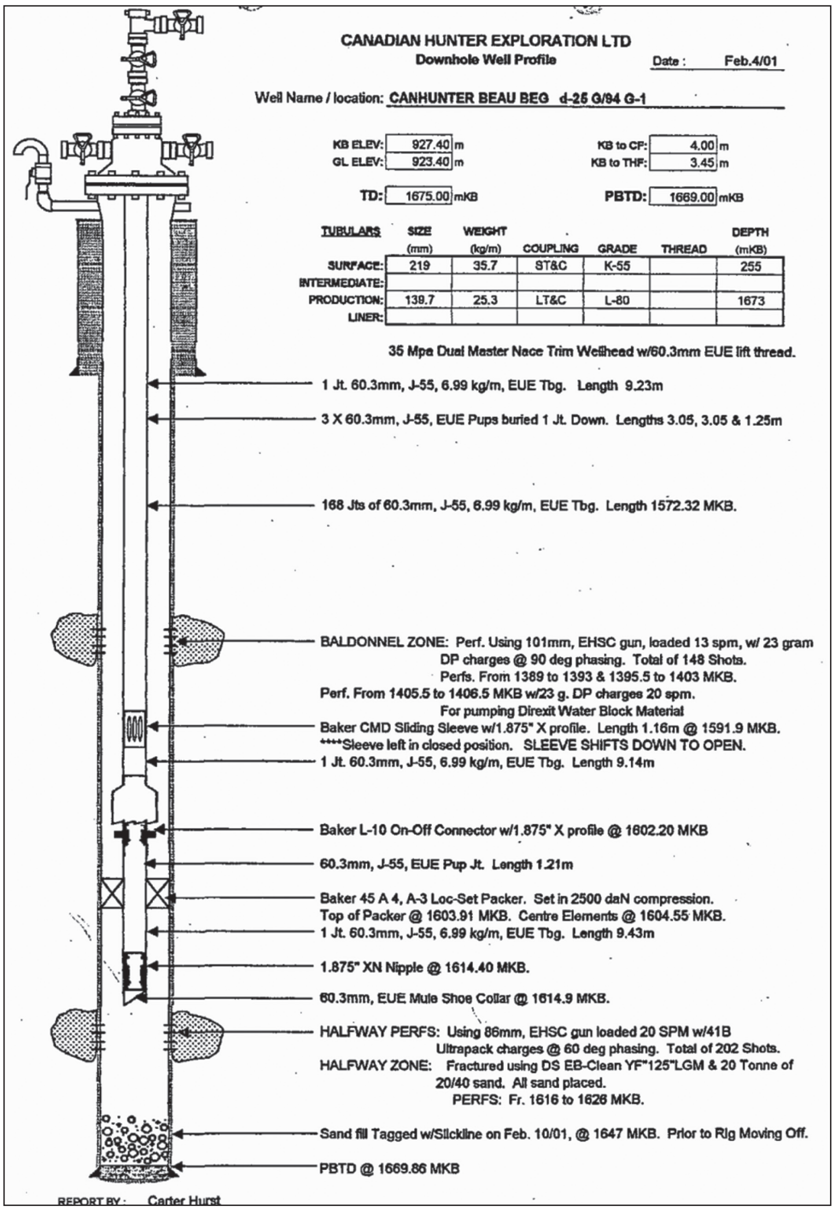

Figure 1: Well Completion Plan for d-25-G/94-G-1. This is taken from the wellfile for this location. The Halfway and Baldonnel Formations were both perforated, but the Halfway was sealed off by a plug and a sleeve was left in the closed position.

single-zone production. Figure 2 shows the revised completion scheme designed to isolate the Halfway from the Baldonnel. Separate tubing strings allowed dual Halfway Formation gas production and Baldonnel water disposal until the gas production was suspended.

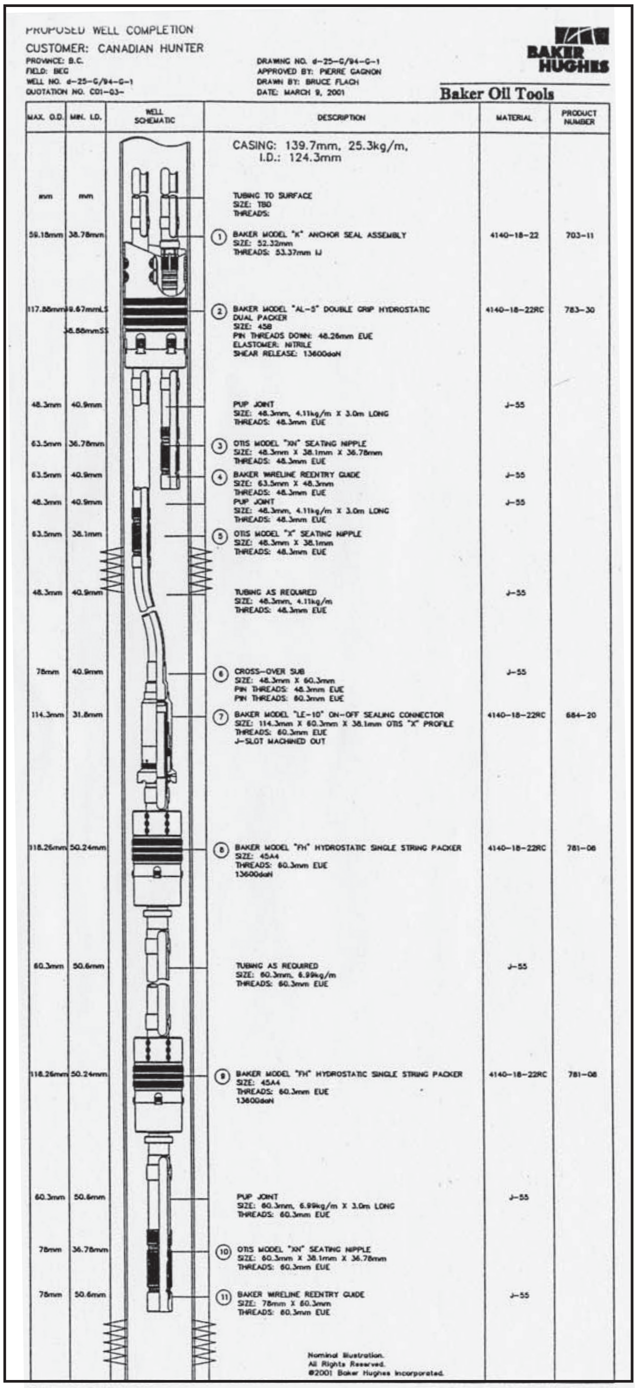

Figure 2: Revised Well Completion Plan d-25-G/94-G-1. This setup allows for isolation of the Halfway Formation from the Baldonnel Formation so that production and disposal could occur concurrently. Halfway gas production was suspended in 2002.

Geology

Hydrodynamic flow mapping (confidential consultant report) shows a general aquifer flow direction conforming to the regional dip of southwest to northeast. Trapping is also generally to the northeast, where relatively porous facies pinch out or are eroded. Post-Triassic exposure eroded the Triassic surface very unevenly and created considerable subsurface relief. Trapping is therefore determined not just by facies, but also by amount of erosion and regional dip. If only the stratigraphically lowest portions of the Baldonnel Formation remain uneroded, the chances for economic gas accumulations are less because the better porosity is generally in the upper units. At this location, the Pardonet Formation is missing, which suggests that at least some of the Baldonnel has been eroded. Normally the Pardonet provides sealing, but in this case the overlying trap is provided by the Nordegg Formation.

Figure 3 is a map of the structural elevations of the Baldonnel Formation, which are characterized by long linear northwest trends of ridges and valleys interrupted by what appear to be erosional re-entrants. The tops of Baldonnel in the linear gas fields just to the west of location d-25-G (near centre of Figure 3) follow trends at generally higher structural elevations on a relatively raised ridge. Location d-25-G appears to be in a trough or possibly an erosional re-entrant. Location c-35-G is producing gas from the Baldonnel and is located on a structurally higher spur that projects into the trough. Completions within the Baldonnel in this region are usually near the top of the formation, where porosity tends to be higher and water saturations lower.

Reservoir porosity for the Baldonnel averages 10% to 12%; in this case the facies is relatively non-porous with pinpoint porosity of between 3% and 8% (Figure 4). In places the facies appears to be tight. The wellfile sample log describes the Baldonnel as a finely crystalline, argillaceous dolomite. Originally it was deposited as an argillaceous mudstone under stable, shallow-shelf environmental conditions; later it was uniformly dolomitized.

The density log response shows that the completed interval has variable reservoir quality. At best, reservoir parameters yield a water saturation calculation of 30%; other parts of the completed interval clearly are tight or wet. No core was cut across the reservoir interval, but based on local knowledge, permeability is likely poor except where enhanced by fracturing. Long-term disposal into this zone will probably be limited by the poor to fair porosity and low permeability.

Figure 5 shows water-disposal data up to November 2007. The curves suggest that volumes of disposal water have remained fairly constant except for annual monthly dips. However, hours on pump have been rising steadily. Wellhead pressures (Table 1) have been reported since only 2006 and do not show a clear trend of increase or decrease.

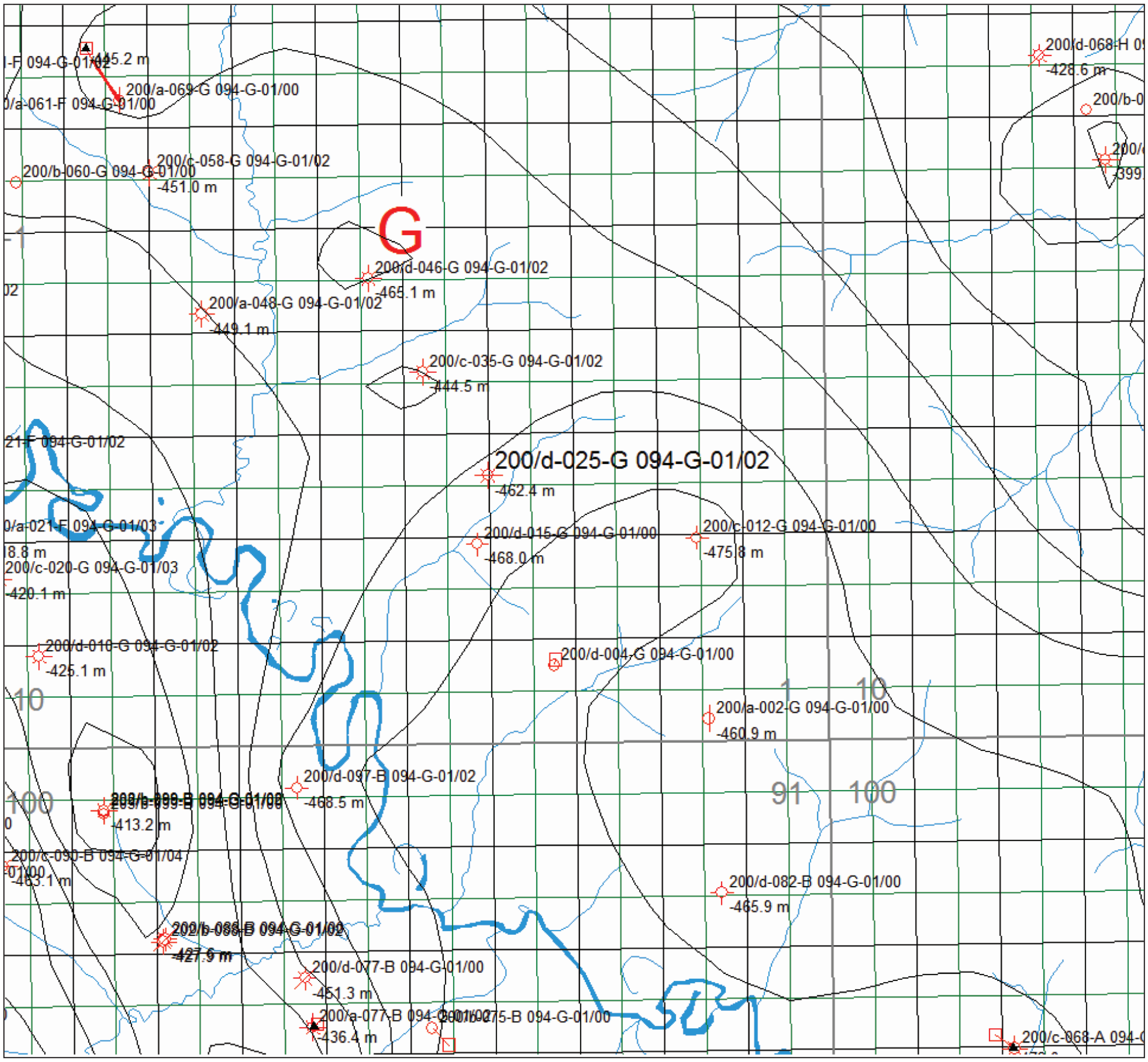

Figure 3: Structural Elevation of the Baldonnel Formation. Contour interval is 10 m. Structural elevations are shown below the well locations. Location d-25-G is shown to be in an intermediate structural position: it is between the elevation of the gas producers to the northwest (e.g., c-35-G) and the wet wells to the southeast (e.g., c-12-G). Although the scale of this illustration is not regional, it is possible to note the linear northwest-southeast trend of drilling and production.

Maximum wellhead pressures appear to be well below the estimated fracture pressure of roughly 25 000 kPa.

Figure 6 shows a cement bond log over the Baldonnel Formation and surrounding zones. A generally good bond between casing and borehole is indicated, although some weaker signals are present over the Nordegg Formation. The bond might be less complete here, likely due to the possibility of sloughing in this shale formation. Overlying bonds appear to be strong, so any leaks between the Baldonnel Formation and annulus would likely not get past the Nordegg Formation shales.

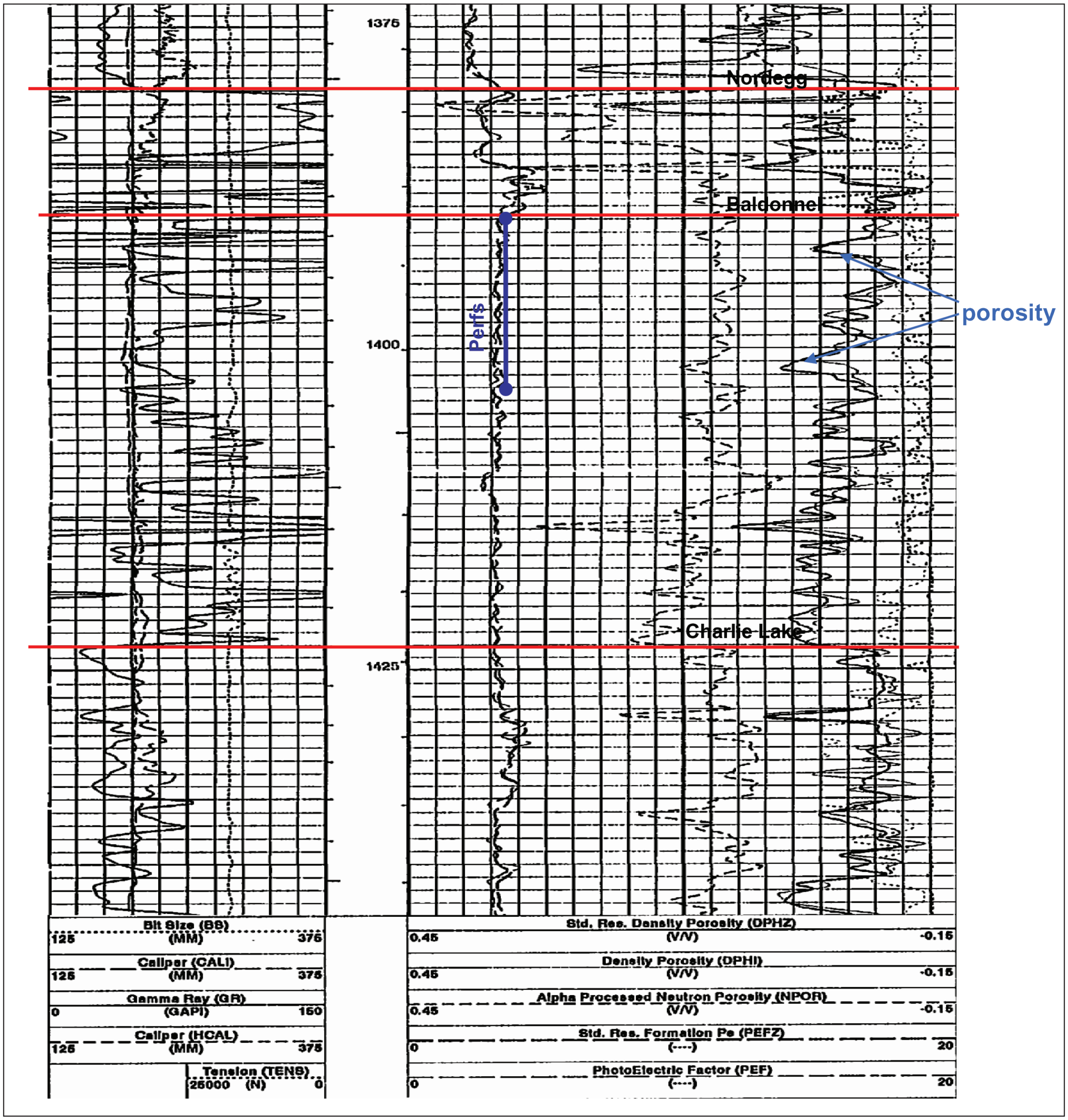

Figure 4: Neutron-Density Log d-25-G/94-G-1. Porosity is scaled in sandstone units, so through the perforation interval porosity peaks at roughly 8% when converted to limestone. Much of the interval is tight. The Pardonet Formation is missing, so the Nordegg Formation shale is acting as the seal.

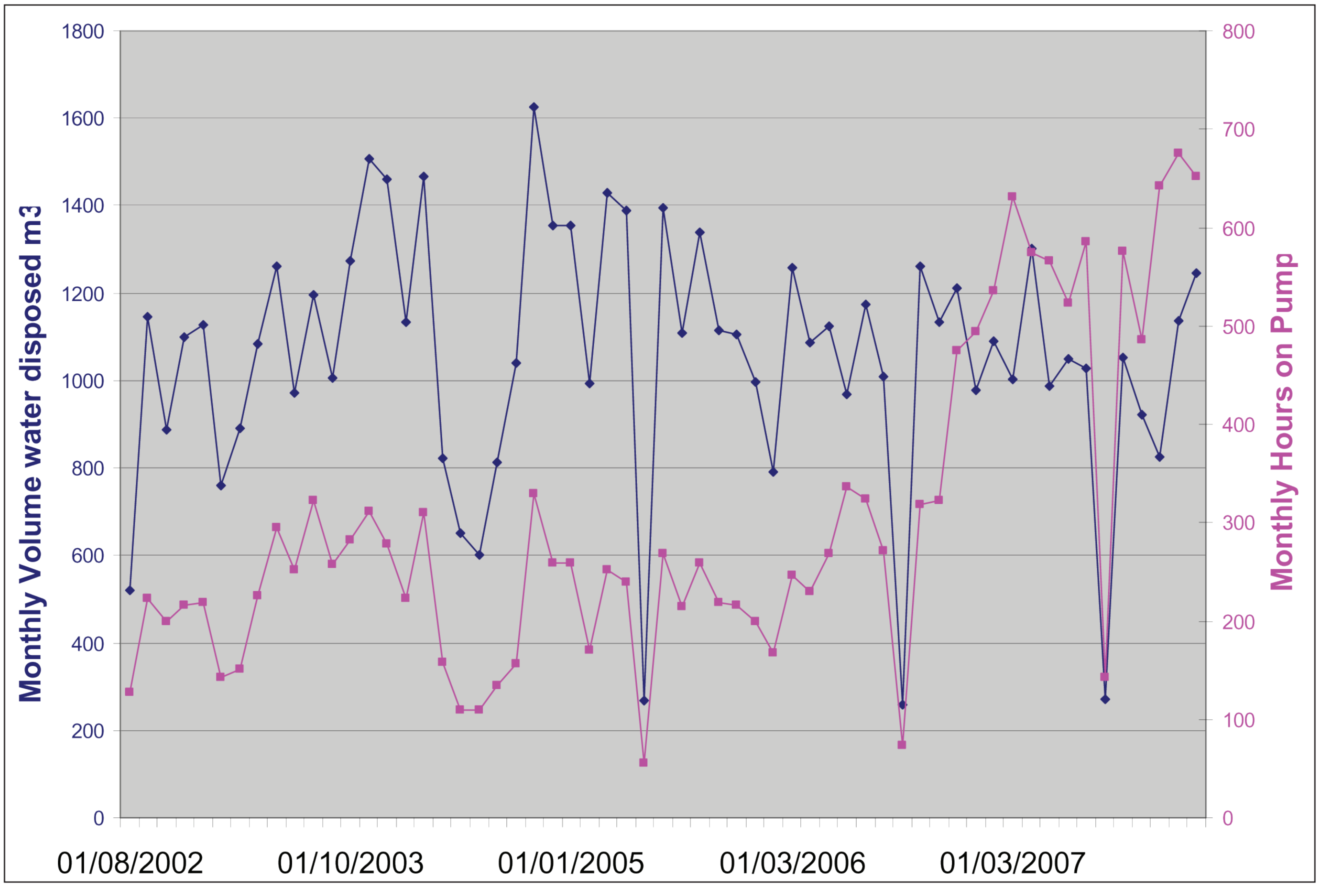

Figure 5: Water Disposal Plot for d-25-G/94-G-1. As volumes seem to be decreasing slightly, monthly hours on pump appear to be increasing. Data has been taken from the IRIS database of the Oil and Gas Commission of British Columbia.

Drilling, Formation Evaluation, And Completion Practices

Casing:	255 m @ 219 mm 1673 m @ 140 mm
Log Suite:	Sonic, Compensated Neutron, Induction, Gamma Ray, Cement Bond, Temperature
Completion:	Perfs 1389–1393 m, 1395.5–1403 m
Stimulation:	acid wash

Reservoir Data

Depth:	1389 m KB
Lithology:	Dolomite
Trapping:	Stratigraphic/Structural
Net porosity:	7 metres
Porosity:	7%
Water Saturation:	30% (optimal)
Initial Pressure:	11 473 kPa
Reservoir Temperature:	70 ºC

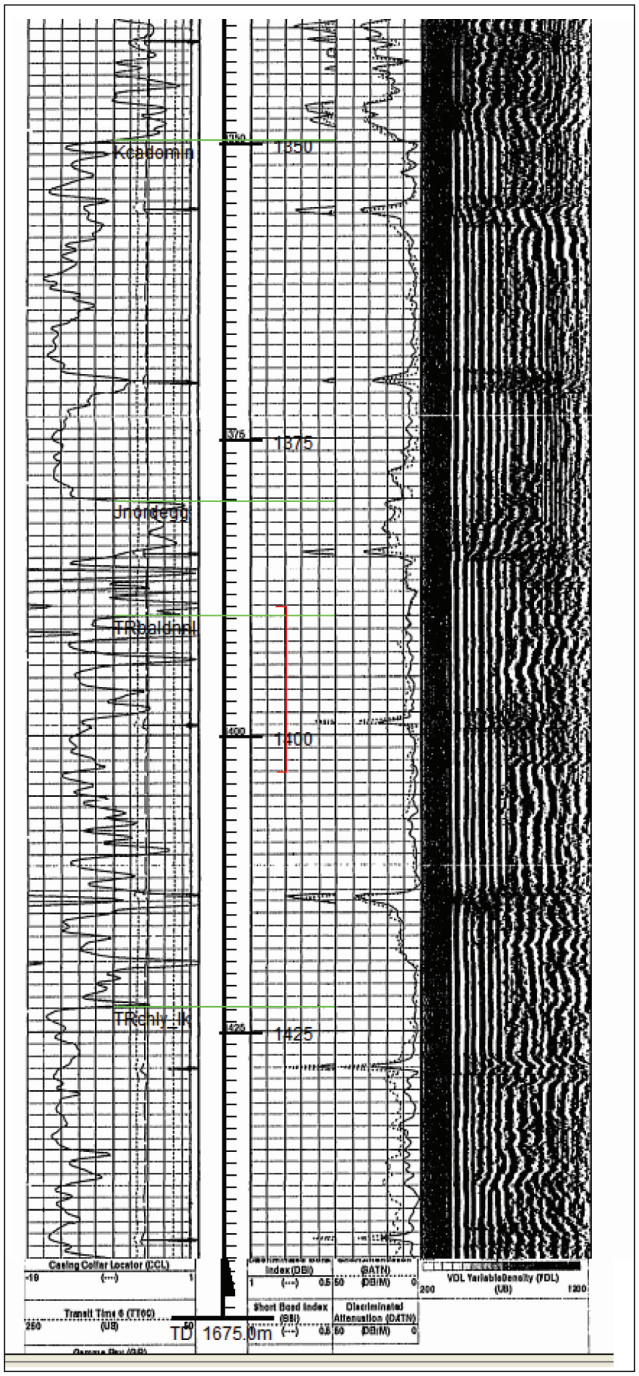

Figure 6: Cement Bond Log d-25-G/94-G-1. Generally strong amplitudes indicate good cement bond and low likelihood of leaks behind casing. Some weakness of bond is suggested by weaker returns at around 1380 m in the Nordegg Formation. Overlying bonds appear to be good, so leaks would likely not go far up-hole.

TABLE 1. MONTHS ON PUMP VS. WELL HEAD PRESSURE (KPA) D-25-G/94-G-1.*

Months on Pump	Well Head Pressure (kPa)
01/07/2006	6900
01/08/2006	5150
01/09/2006	3000
01/10/2006	6900
01/11/2006	3500
01/12/2006	4600
01/01/2007	2900
01/02/2007	4200
01/03/2007	6000
01/04/2007	8400
01/05/2007	4500
01/06/2007	8500
01/07/2007	8100
01/08/2007	5000
01/09/2007	5300
01/10/2007	7900
01/11/2007	4500
01/12/2007	5600
01/01/2008	7200

**This data is from the IRIS database of the Oil and Gas Commission. Values began to be reported in 2006. Few wells in British Columbia have complete records for wellhead pressure. When graphed, the values do not yet show a clear trend of increase or decrease. If a rule-of-thumb fracture gradient of 18 kPa/m is applied (approximately 25 000 kPa at 1400 m), the maximum wellhead pressure so far has been well below the limit.*