Review of regulation of deep well injection under the Resource Management Act

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EXECUTIVE SUMMARY

The Taranaki Regional Council (TRC) requested that the Institute of Geological and Nuclear Sciences (GNS Science) review issues involved with regulation of deep well injection (DWI) under the Resource Management Act of 1991 (RMA) of fluids produced in association with oil and gas exploration and production in that region. These fluids mainly comprise saline produced water that has been brought to the surface with the hydrocarbons. As a part of this review, the TRC indicated a particular interest in review of overseas regulatory environments to ensure that the TRC program is consistent with international best practice.

This report was prepared in response to the TRC's request in 2012. It includes brief reviews of the requirements under the federal underground injection control (UIC) program in the United States (US) run by the US Environmental Protection Agency (USEPA) and programs run by agencies in two provinces of Canada (i.e., Alberta and British Columbia). With regard to the USEPA program, information on concerns related to program implementation are also discussed. However, there is only limited information available assessing USEPA implementation of the UIC program and none was found with regard to the two Canadian provinces. What was found regarding the experience under the USEPA's UIC program indicates substantial problems have been encountered and that, in some cases, these have, resulted in contamination of underground sources of drinking water (USDW).

A brief presentation of historical guidelines which have been available within the TRC and consent conditions representative of those under consideration by TRC for recent DWI applications is presented next. These cover many of the most important provisions found in USEPA and Canadian programs. However, there is room for slight improvement to strengthen the ability of the TRC regulatory program to protect groundwater resources.

The New Zealand Department of Labour promulgated regulations in 1999 covering well-drilling which address several important well integrity issues and are applicable to DWI. However, the Department of Labour programme is focussed on worker health and safety and the tone of these regulations is passive (i.e., self-regulation). Self-regulation in the absence of a vigorous regulatory programme is unlikely to result in optimum outcomes for the public interest. These regulations are currently under review for upgrading to international best practice.

The final section of the report presents conclusions and recommendations for improvements to strengthen existing provisions of both the TRC regulatory program and the Department of Labour 1999 regulations. Well integrity is critical to health and safety, environmental protection, and proper development of petroleum hydrocarbon resources. There is a need for an active regulatory programme with comprehensive requirements and interagency coordination to ensure that nothing important falls between the cracks.

The following improvements to the TRC regulatory program for DWI are recommended:

1. Adopt a provision similar to those in USEPA and Canadian requirements to protect potentially useable groundwater that has TDS levels in excess of 1,000 mg/L (i.e., 4,000 mg/L as in Canada or possibly 10,000 mg/L as in the US).

2. Adopt the concept of designating an Area of Review (AoR) when assessing applications for proposed injection wells. This would make current TRC practice

explicit and quantitative. The AoR is an “area surrounding the injection well that may be affected by the injection activity” and can be defined by a fixed radius or mathematical modelling. USEPA regulations provide for provision of information “extending one mile beyond the property boundaries of the source” while Canadian requirements specify a 1.6 km radius from the bottom-hole location of the injection well.

The following improvements to the Department of Labour 1999 regulations are recommended for consideration in the ongoing review and revision process:

1. Require submittal of comprehensive site and injection well information including in the “Injection Operation Management Plan” the types of information required in the following plans required by the USEPA with plan submittal approval in advance:
   (a) Proposed formation testing program plan.
   (b) Proposed operation plan. Note existing TRC consent conditions. This plan should specify that the maximum operation pressure be less than 90 percent of formation fracture pressure or less than the pressure at which hydraulic isolation was demonstrated.
   (c) Proposed contingency plans.
   (d) Proposed well maintenance plan.
   (e) Monitoring and reporting plan.
   (f) Plugging and abandonment plan.

2. Require initial and routine continuing mechanical integrity testing throughout the operational life of the injection well to include a combination of logging methods, pressure testing, and continual monitoring of well pressures. Pressure testing should include annual packer isolation tests.

3. Require provision of a performance bond or equivalent to guarantee resources sufficient to plug and abandon the well at the end of its service life.

4. Conduct routine site inspections of approved injection wells during construction and testing as well as during normal operation.

1.0 INTRODUCTION

Fluids produced in association with oil and gas production in the Taranaki Region must be appropriately disposed of in accordance with the Resource Management Act of 1991 (RMA). Deep well injection (DWI) is one method being used for this purpose.

DWI has historically been used by several petroleum companies in the Taranaki Region to dispose of fluids from petroleum production operations and at least one consent application to do so has been submitted during the first part of 2012. These fluids mainly comprise saline produced water that has been brought to the surface with the hydrocarbons. This report has been prepared in response to a request from the Taranaki Regional Council (TRC) that the Institute of Geological and Nuclear Sciences (GNS Science) review the issue of regulation of DWI under the RMA for fluids produced in association with oil and gas exploration and production. The TRC indicated a particular interest in review of overseas regulatory environments to ensure that that the TRC program is consistent with international best practice (McLay, 2012).

This report first presents information about programs for the regulation of DWI in North America (i.e., Canada and the US). The existing program for regulation of DWI in the TRC is then reviewed. Finally, recommendations regarding possible improvements for the TRC program are presented.

2.0 NORTH AMERICAN REGULATORY PROGRAMS

It is beyond the scope of this report to perform a thorough review of how DWI is regulated throughout the world and there do not appear to be any other reports or studies available in the worldwide literature of that kind. However, it is informative to look briefly at the regulation of DWI in parts of the US and Canada. The US has a very large program covering DWI of many kinds as well as for the disposal of fluids related to oil and gas production. Canada also has substantial oil and gas production and similar concerns with regard to DWI. In both the US and Canada, the relevant regulatory programs involve state or provincial government agencies. However, in the US there is an overarching federal system. In this section of the report, after first looking at USEPA regulations, those of two Canadian provinces are reviewed.

2.1 USEPA Regulations

Oil and gas production in the United States of America (US) is a massive industry with a long history. Oil and gas production in the US commenced over a hundred years ago during the late-1800s and it has been estimated that there are approximately 3.8 million oil and gas wells in the contiguous 48 states alone (Otton and Mercier, 2012). DWI commenced during the 1930s as a part of this industry when “oil producers first began disposing of the brine produced in conjunction with crude oil back into the same formation from which it had been extracted” (McCurdy, 2011). Reportedly, “documented cases of groundwater contamination” from this practice “began to surface” in the 1960s (McCurdy, 2011). Although some US states began regulating injection of oil field brines as early as the 1950s, these were generally regulations under the purview of state oil and gas commissions or departments of natural resources and were oriented toward facilitating development of petroleum hydrocarbon reservoirs rather than environmental protection.

In response to the evident problems, Congress realized that federal intervention was necessary and, when the Safe Drinking Water Act (SDWA) was amended in 1974, gave the U.S. Environmental Protection Agency (USEPA) the authority to regulate underground injection of wastes in order to protect underground sources of drinking water (USDW). USDW were defined under the SDWA as having less than 10,000 mg/L total dissolved solids (TDS). Given the large numbers of injection wells already in operation and the problems that were becoming evident with regard to them which had spurred this legislation, the USEPA was behind from the start and had to run to try and catch up. However, the development of national regulatory programs of this type is not an easy or rapid process and it was not until 1980 that relevant regulations were developed by the USEPA for its new underground injection control (UIC) programme under the SDWA. This programme established classes of injection wells, with Class II wells being designated as those for injecting fluids associated with oil and gas production. The most prominent such fluids are "brines taken from a producing formation" (McCurdy, 2011). It was estimated by the late-1980s that there were about 160,000 Class II wells in the US at that time. The current estimate is in the range of 144,000 to 151,000 (Hembra, et al., 1989; McCurdy, 2011; UIC Program, 2012a, UIC Program, 2012b). Prior to the adoption of new regulations to protect surface water quality in the late-1960s, produced waters were typically disposed of by release into surface streams. Today, approximately 95% of produced waters in the US are disposed of via underground injection at an estimated volumetric flow rate on the order of 10 million m^3/day (Otton and Mercier, 2012).

2.1.1 Regulatory Scheme

USEPA regulations are the minimum foundation for the regulation of DWI in the US. Given the size of the US and the various industrial operations that occur there and utilize DWI for the disposal of waste fluids, including a large oil and gas industry, the nature of the US program is worth considering. In the US federal system, such programs typically have overarching federal requirements that states must comply with and DWI is no exception. States that accept "primacy" develop their own programs that must be at least as stringent as USEPA regulations require. Thirty-three of the 50 US states have taken this option. In the others, USEPA either shares implementation of the federal program with states or directly implements it without state involvement (UIC Program, 2012b).

USEPA regulations for Class II wells are found at Part 146 of Title 40 of the Code of Federal Regulations (40 CFR 146). They provide requirements for well construction, operations (including monitoring and reporting), and information that must be submitted. The following is a summary of pertinent provisions:

1. Construction requirements (Section 146.22)

   (a) "All new Class II wells shall be sited in such a fashion that they inject into a formation which is separated from any USDW by a confining zone that is free of known open faults or fractures within the area of review."

   (b) "All Class II injection wells shall be cased and cemented to prevent movement of fluids into or between USDW. The casing and cement used… shall be designed for the life expectancy of the well" taking depth to the bottom of all USDW, depth to the injection zone, and average and maximum injection pressures into account. In addition, information on formation fluids, lithology of the injection and confining

zones, external and internal pressures and axial loading, hole size, size and grade of casing strings, and class of cement may be considered.

(f) "Appropriate logs and tests shall be conducted during the drilling and construction of new Class II wells" and a "report interpreting the results… of those logs and tests" prepared and submitted. "At a minimum, these logs and tests shall include:

(1) "Deviation checks;"

(2) "Such other logs and tests as may be needed" with the following "considered:"

(a) "Electric and caliper logs before casing is installed;"

(b) "Cement bond, temperature, or density logs after the casing is set and cemented;"

(c) "Electric porosity and gamma ray logs before the casing is installed;"

(d) "Fracture finder logs."

(g) "At a minimum, the following information concerning the injection formation shall be determined or calculated:"

(1) "Fluid pressure;"

(2) "Estimated fracture pressure;"

(3) "Physical and chemical characteristics of the injection zone."

2. Operating, monitoring, and reporting requirements (Section 146.23)

(a) "Operating requirements shall, at a minimum, specify that:

(1) Injection pressure "shall not exceed a maximum… calculated so as to assure that the pressure during injection does not initiate new fractures or propagate existing" ones in the "confining zone adjacent to the USDWs" or "cause the movement of injection or formation fluids into an USDW."

(2) "Injection between the outermost casing protecting USDW and the well bore shall be prohibited."

(b) Minimum monitoring requirements are:

(1) "Monitoring of the nature of injected fluids… sufficient "to Yield" representative data of their characteristics;

(2) "Observation of injection pressure, flow rate, and cumulative volume at least"

(i) "Weekly for produced fluid disposal operations;"

(ii) "Monthly for enhanced recovery operations;"

(iii) "Daily during the injection of liquid hydrocarbons and injection for withdrawal of stored hydrocarbons;"

(iv) "Daily during the injection phase of cyclic steam operations."

(v) "At reasonable intervals no greater than 30 days."

(3) "A demonstration of mechanical integrity… a least once every five years during the life of the injection well;"

(4) "Maintenance of the results of all monitoring until the next permit review;"

(5) "Hydrocarbon storage and enhanced recovery may be monitored on a field or project bases rather than on an individual well basis."

(c) Reporting requirements. "Reporting… shall at a minimum include" an annual report "summarizing the results of (required) monitoring" with "monthly records of injected fluids, and any major changes in characteristics or sources of injected fluids." For hydrocarbon storage and enhanced recovery projects, reporting may be "on a field or project basis rather than an individual well basis."

3. Information that must be submitted for Class II wells (Section 146.24)

(a) Prior to issuance of a permit for an existing well to operate or the construction of a new well:

(1) Information required in 40 CFR 144.31 and 144.41(g). In addition to various administrative matters required in order to obtain a permit for an underground injection well, there are the following substantive requirements:

(i) "A topographic map… extending one mile beyond the property boundaries of the source depicting" relevant aspects of the facility including wells, springs, and other surface water bodies, and drinking water wells listed in public records or otherwise known to the applicant within a quarter mile of the facility property boundary."

(ii) "A plugging and abandonment plan that meets the requirements of Section 146.10. Section 146.10 provides that plugging and abandoning of Class II wells must be accomplished with cement "in a manner which will not allow the movement of fluids either into or between USDW" by one of three specifically listed methods or an alternative approved method providing "a comparable level of protection."

(2) Maps showing the injection well and the project area with the number and name of all existing producing, injection, and abandoned wells as well as dry holes and water wells.

(3) "Tabulations of wells" and proposed operating data to include all known wells "within the area of review" (AoR). The AoR is that "area surrounding the injection well that may be affected by the injection activity" which may be determined by a "fixed radius" or via mathematical modelling (UIC Program, 2012b). Information on mathematical equations that may be used for such modelling is presented in Section 146.6. Tabulated data "shall include" information on the type of well, it's construction, date drilled, location, depth, record of plugging (if abandoned) and "any additional information" required by regulators.

(4) Operating data to include:

(i) Average and maximum daily flow rates and volumes of fluids injected.

(ii) Average and maximum injection pressure,

(iii) "Source and an appropriate analysis of the chemical and physical characteristics of the injection fluid."

(iv) Geologic data on the injection and confining zones and "all USDC which may be affected by the injection."

(v) Schematics or "other appropriate drawings of the… construction details of the (injection) well."

(vi) Assurance "through a performance bond or other appropriate means" that the applicant has "the resources necessary to close plug or abandon the well.

4. Information that may be submitted for Class II wells (Section 146.24)

   (a) A "proposed formation testing program to obtain the information required by Section 146.22(g)."

   (b) "Proposed stimulation program."

   (c) "Proposed injection procedure."

   (d) "Proposed contingency plans… to cope with well failures so as to prevent migration of contaminating fluids into an USDW."

   (e) "Plans for meeting monitoring requirements of Section 146.23(b)."

5. Information considered prior to granting well operation approval (Section 146.24)

   (a) "All available logging and testing program data."

   (b) "A demonstration of mechanical integrity pursuant to Section 146.8." Section 146.8 defines the term "mechanical integrity" (i.e., "no significant leak" from the any portion of the well and "no significant fluid movement into an USDW through vertical channels adjacent to the injection well bore."

   (c) "Anticipated maximum (operational) pressure and flow rate."

   (d) "Corrosiveness of injected fluids and formation fluids."

   (e) "Lithology of injection and confining zones."

   (f) "Type and grade of cement."

Various forms used by USEPA in its UIC program are available via the internet. These forms are listed in Table 1.

2.1.2 Assessment of USEPA Regulatory Program

There appears to be little publicly available information evaluating the USEPA's DWI regulatory program with regard to Class II wells. Results of a literature search to retrieve such information were minimal. Only three reports bearing on the issue were retrieved from the general literature: (1) a U.S. General Accounting Office (USGAO) report specific to the occurrence of contamination from injected oil and gas wastes (Hembra, et al., 1989); (2) a law review paper about DWI in general (Herbert, 1996); and (3) a recent report prepared by Pro Publica, a non-profit investigative journalism organization in the US (Lustgarten, 2012a and 2012b). Information presented in these is summarized as follows:

Table 1: USEPA UIC Program Forms[1]

Form #7520-	Form Name
1	Part I: Permit review and issuance/wells in the area of review
2A	Part II: Compliance evaluation
2B	Part II: Compliance evaluation - significant noncompliance
3	Part III: Inspections - Mechanical integrity testing
4	Part IV: Quarterly exceptions list
5	Part V: Summary of UIC grant utilization
6	Permit application
7	Application to transfer permit
8	Injection well monitoring report
9	Completion form for injection wells
10	Completion form for brine disposal, hydrocarbon storage, or enhanced recovery
11	Annual disposal/injection well monitoring report
12	Well rework record
14	Plugging and abandonment plan
16	Inventory of injection wells
17	Pre-closure notification form

[1.] UIC Program (2012c).

1. Hembra, et al. (1989) -

   This USGAO report was written a relatively short time after the USEPA established its UIC program in 1980. As background information in their report, Hembra et al. (1989) noted that:

   > Brines from Class II wells can enter drinking water supplies directly, through cracks and leaks in the well casing, or indirectly through nearby wells, such as those once used for oil and gas production, that have ceased operating. If these abandoned wells are not properly plugged – that is sealed off – and have cracked casings, they can serve as pathways for injected brines to enter drinking water. Because groundwater moves very slowly, any contaminants that enter it will remain concentrated for long periods of time, and cleanup, if it is technically feasible, can be prohibitively costly.

   Hembra, et al. (1989) estimated that when they wrote their report there were about 160,000 Class II injection wells located in 31 US states. Hembra, et al. (1989) did not have complete information and qualified the results of their assessment by saying "the full extent of (contamination of drinking water supplies by Class II injection wells) is unknown." However, they found that the USEPA was "aware of 23 cases nationwide in which drinking water was contaminated by Class II wells." Of these 23 cases, "most resulted from cracks in the injection wells or from injection directly into drinking water" and, "for the most part," discovery of the contamination occurred "as a

result of required pressure testing and file reviews." However, in more than a third of the cases the contamination resulted when "injected brines travelled up… improperly… abandoned wells in the vicinity of the injection wells and entered drinking water through cracks in these old wells." For the most part, the contamination was not discovered "until water supplies became too salty to drink or crops were ruined." This is a potentially serious problem because there are "approximately 1.2 million abandoned oil and gas wells in the US, of which 200,000 may not be properly plugged" and the number of improperly plugged wells was believed to be increasing as a result of economic conditions at the time (Hembra, et al., 1989).

Additionally, Hembra, et al. (1989) found that some aspects of program implementation were simply not occurring. For example: review of well files in four states found that the files of 41 percent of the wells "contained no evidence that pressure tests had ever been performed, even though these tests are required before start-up and every 5 years thereafter" and in three of the four states reviewed "internal controls were not in place to ensure that all necessary documentation was on file." A major recommendation made by Hembra, et al. (1989) was that "area of review requirements" be applied to all Class II wells (both existing and new at the time of program adoption). USEPA had initially proposed that requirement in 1976, but in response to objections from industry that it would be too expensive to implement had not adopted it for existing wells (Hembra, et al., 1989).

2. Herbert (1996) –

   This law review paper looked primarily at the regulation of DWI of hazardous wastes (i.e., Class I injection wells). However, there are two pertinent take home points from his paper:

   1. Like Hembra, et al. (1989) found with regard to Class II wells, Herbert (1996) concluded that "The full extent to which injected hazardous wastes has contaminated drinking water is unknown." He went on to say that "While there are very few documented cases of contaminated drinking water in the US, experience has shown that there are inherent risks in poorly conceived deep-well projects" and he gave two specific examples of were DWI resulted in contaminated drinking water supplies: (1) in injection well owned by Tenneco Oil Company in Louisiana in 1975; and (2) an injection well owned by Velsicol Chemical Corporation in Texas. In both of these cases, the wells were "constructed without packers and tubing, with injection occurring directly through the casing." In addition to these two documented cases, Herbert (1996) noted "one additional case of suspected (drinking water) contamination" and eight of nondrinking water contamination. All of these cases "involved well malfunctions that (resulted) in contamination around the well-bore, where it is… easy to detect." It would be "far more difficult to detect" subsurface contamination that "did not produce effects on the surface" and, in fact, a reliable method of doing so "has not been (devised)."
   2. Federal regulation of DWI was slow in coming after the USEPA was directed by Congress through the SDWA of 1974 to do it. In the 1980s, some members of Congress described the USEPA's performance in this area as "underwhelming" and, as noted above, many deficiencies were apparent whenever someone looked.

3. Lustgarten (2012a and 2012b) –

   Lustgarten's review of the use of injection wells for disposal of wastes in the US provides quantitative information on problems that have developed with injection wells and the compliance rate. Lustgarten notes that "review of well records, case histories, and government summaries… (from) more than 220,000 well inspections (194,000 for Class 2 wells) found that structural failures inside injection wells are routine" and that "from late 2007 to late 2010" there was "one well integrity violation… issued for every six deep injection wells examined – more than 17,000 violations nationally." Furthermore, "more than 7,000 wells showed signs that their walls were leaking" and the "records also show wells are frequently operated in violation of safety regulations and under conditions that greatly increase the risk of fluid leakage and the threat of water contamination.

   Lustgarten includes statements from a number of geologists working for such federal agencies as the U.S. Department of Energy (USDOE) and USEPA and from academia. These statements provide considerable reason to be concerned. He notes that USEPA regulations require that Class II injection wells be drilled deep below drinking water aquifers (i.e., USDW) and be "walled with multiple layers of steel tubing and cement and regularly monitored for cracks." These requirements and the geology involved are assumed to be protective of water quality. For example, "officials say" that injected wastes will be "contained by layer after layer of impermeable rock" and that, therefore, "The laws of physics and fluid dynamics should ensure that the waste can't spread far and is diluted as it goes." One scientist at the University of Texas is quoted as saying such layering 'is a very strong phenomenon and it's on our side," but another more cautious USDOE scientist is quoted as saying "I do think the risks are low, but it has never been adequately demonstrated… Every statement is based on a collection of experts that offer you their opinions. Then you do a scientific analysis of their opinions and get some probability out of it. This is a wonderful way to go when you don't have any evidence one way or another… But it really doesn't mean anything scientifically."

   Lustgarten goes on to say that "the hard data that does exist comes from well inspections" and presents additional data from those inspections as well as specific examples. Based on his review of well records over the three year period of 2007-2010, he concluded that "when an injection well fails, it is most often because of holes or cracks in the well structure itself." Reportedly, a large number of problems were detected during the mechanical integrity testing required annually for Class I and every five years for Class II wells. He reports that during 2010 there were 7,500 violations nationally as a result of such testing "with more than 2,300 wells failing" and "In Texas, one violation was issued for every three Class II wells examined" that year. One specific example noted was with regard to a Class II well in Louisiana in September 2009. In that case, "oil and gas waste" was "discovered… in a roadside ditch." The fluid was traced to "a crack in the casing of a nearby injection well." When the rest of the well was tested, another hole was found 600 feet underground "and just a few hundred feet away from an aquifer that is the sole source of drinking water for that part of the state."

Among the other violations noted by Lustgarten were violations of requirements for maximum allowed pressure in continued injection of wastes after "the target rock zone could no longer handle the volume being pushed into it. Reportedly, in the former case, there were 1,100 documented violations of such pressure limitations in the well records reviewed since 2008. An incident occurred near the drinking water supply well field for the municipality of Chico, Texas was cited as an example of the latter.

2.2 Canadian Regulations

Of Canada's 10 provinces and three territories, Alberta is by far the major producer of oil and gas and British Columbia is second place in terms of natural gas (Plourde, 2010). Provisions of these two provinces regarding DWI for fluids from oil and gas production are briefly reviewed in this section of the report.

2.2.1 Regulatory Scheme

2.2.1.1 Alberta

The Energy Resources Conservation Board (ERCB) of Alberta regulates the energy industry in that province including oil and gas production. DWI is not allowed into "useable groundwater." Useable groundwater is defined as having a TDS concentration of 4,000 mg/L or less. This depth is also referred to as the "Base of Groundwater Protection" (BGWP) (Parks, 2005). Although precise and up-to-date numbers do not appear to be readily available, the number of wells and the volumes of fluids being injected in Alberta are substantial. At the end of 2003, it is was estimated that there were 1,846 wells "capable of injection" of which 1,338 were operational (Parks, 2005) while the volume of produced water being disposed of by injection in the 2008 time frame was estimated as being approximately 720,000 m^3/day (Shyba, 2008).

With regard to injection and disposal wells, the current ERCB directive (Directive 051) is unchanged from the guide produced by its predecessor agency in 1994 (Alberta Energy and Utilities Board, 1994). The philosophy of deepwell injection and requirements specified are as follows:

1. Philosophy –
    a. Deepwell injection in Alberta is considered "a safe and viable disposal option where wells are properly constructed, operated, and monitored."
    b. Waste minimization "shall be implemented prior to… the deepwell disposal option."
    c. "Regulatory activities will focus on issues related to:"
        (1) "Wellbore integrity to ensure initial and ongoing containment."
        (2) "Formation suitability to ensure initial and ongoing confinement."
        (3) "Suitability of the waste stream for deepwell disposal" considering "the nature of the fluid, the integrity of the well, and alternative waste management options."
        (4) "Reporting and manifesting of disposed wastes."

d. “It is the responsibility of the waste generator to ensure that each waste stream has been properly identified, characterized, and is handled, treated, and disposed of in an acceptable manner.”

2. General criteria –
   a. pH between 4.5 and 12.5 units.
   b. “Does not meet surface water discharge criteria (treatment and return to the surface or watershed is the preferred waste management option).”
   c. “Has a non-halogenated organic fraction of less than 10% by mass (100,000 mg/kg),” so that incineration or recycling is not “economically feasible” unless it is an untreatable sand or crude oil/water emulsion or it is antifreeze or dehydration fluid containing greater than 60% water by mass.
   d. “Has one or more halogenated organic compounds in a total combined concentration less than 1,000 mg/kg.”
   e. “Has a polychlorinated biphenyl (PCB) concentration of less than 50 mg/kg.”

3. Well Classifications –
   a. Ib – “Wells used for the disposal of produced water, specific common oilfield waste streams, and waste streams meeting specific criteria.” Listed waste streams include “spent workover or stimulation fluids (after neutralization and/or processing to recover hydrocarbons).” General criteria specified are:
      (1) pH between 6.0 and 9.0 (to “avoid significant corrosion and possible wellbore integrity problems”).
      (2) Flash point greater than 61 °C, unless an “untreatable sand or crude oil/water emulsion” or “antifreeze or dehydration fluid.”
      (3) Has heavy metal concentrations at or below –
         (a) 20 mg/kg for mercury.
         (b) 100 mg/kg for beryllium, cadmium, silver, and uranium.
         (c) 200 mg/kg for selenium and thallium.
         (d) 500 mg/kg for arsenic, chromium, lead, and nickel.
   b. II – “Wells used for the injection or disposal of produced water (brine) or brine equivalent fluids.”

4. Approval for injection/disposal – The “location and purpose” of the well must be approved and information submitted in support of an application for approval to inject or dispose of certain fluids. “The primary purpose of this information is to ensure wellbore integrity during injection or disposal operations.”

5. Cementing and casing requirements – “The well completion must provide for hydraulic isolation of the injection zone as well as isolation of useable groundwaters from aquifer cross-flow of the injection fluid” and all potential hydrocarbon-bearing zones, in addition to the injection or disposal zone, shall be isolated by cement.” All new class Ib and II wells “shall ensure useable water-bearing zones are isolated with

surface casing cemented to surface from a minimum of 25 m below the lowest useable groundwater zone."

6. Logging requirements –

   a. Cement top location – For all classes of wells, "If the production casing is not cemented to surface, or cement returns to surface are not obtained and maintained during setting, then a cement top locating log shall be run."

   b. Hydraulic isolation – For Class Ib and II wells, a temperature survey and one of the following ("alternate techniques must receive prior ERCB approval" and wellhead injection pressures "may be limited to the pressure at which the hydraulic isolation logging was conducted"):

      (1) Radioactive tracer log.

      (2) Oxygen activation log.

      (3) Cement integrity log.

   c. Casing integrity – A "full length casing inspection log is recommended" for all classes of wells and "shall be run on any existing well being converted to injection or disposal service."

   Waivers to logging requirements will be considered "under certain circumstances," but must be supported by submission of additional information related to casing integrity or hydraulic isolation. Waivers of hydraulic isolation logging "will not normally be granted for… Class 1b wells."

7. Other tests and submission requirements –

   a. Initial pressure tests – An initial pressure test of the casing or tubing/casing annulus to a minimum pressure of 7,000 kPa for 15 minutes shall be conducted prior to commencement of injection or disposal operations… consideration will be given to reduced pressures where a packer is set in tension and may become unseated at the required pressure."

   b. Monitoring programs - For Class Ib and II wells, monitoring "shall include" an "annual packer isolation test to a minimum surface pressure of 1,400 kPa for 15 minutes."

   c. A completed "Well Summary for Injection or Disposal" form and "Wellbore Completion Schematic" (copies provided in Appendix A) "shall be submitted as a part of any application."

   d. Area of review – "An area of review is required for all waste disposal wells… within which offsetting wells must be investigated for hydraulic isolation of the disposal zone is required." For Class Ib wells, the area of review is "1.6 km radius from the bottom-hole location of the subject well." The ERCB "may require a greater or lesser area of review, based on reservoir modelling." Applicants "are expected to consult with ERCB staff on the reservoir modelling technique planned to be used." Modelling "should be implemented for all" Class Ib wells with "the degree of sophistication of the model" reflecting "the sensitivity of both the geological setting and the injected fluid."

8. Operating parameters – Wellhead pressure for Class Ib and II wells – Wellhead pressures will be limited to the lesser of:
    a. "90 per cent of the formation fracture pressure."
    b. "The pressure at which the hydraulic isolation logging was conducted."

Additional information in the appendices of Directive 051 includes logging guidelines, injectivity test procedures details on filling out well summary and well schematic forms, and a table of maximum allowable wellhead injection pressures (Alberta Energy and Utilities Board, 1994).

2.2.1.2 British Columbia

DWI associated with oil and gas production in British Columbia is regulated by the British Columbia Oil & Gas Commission (BCO&GC). The BCO&GC has an established procedure for authorizing DWI of wastes and two sets of guidelines pertinent to them. The guidelines are:

1. Water source, injection and disposal service wells (BCO&GC, 2012a):
    a. General for water injection wells –
        (1) Water injection wells are initially discussed in terms of waterflooding to enhance petroleum hydrocarbon recovery; however, injection wells used for disposal are also discussed in this section of the guidelines without differentiation. It is stated that "injection pressure must not exceed the formation fracture pressure, and recommended practice is to not exceed 90 per cent of this value." It is also stated that "any changes to injection fluid density, usually due to salinity, must be accounted for."
        (2) Monitoring and reporting – "For each month during which water is injected into the well, the form BC-S18" statement "must be filed, reporting total injection hours, volume and average wellhead pressure" (copy of form BC-S18 provided in Appendix A).
        (3) Casing and cementing requirements – For existing wells, "all potentially hydrocarbon-bearing zones, in addition to the injection or disposal zone, must be isolated by cement." For new wells –
            (a) "Surface casing is set below the deepest usable water zone and cemented to surface, or
            (b) If surface casing is not set below the deepest usable water zone, the next casing string is cemented to surface, and
            (c) Hydraulic isolation is established between all porous zones."
    b. Logging requirements –
        (1) "If production casing is not cemented to the surface or cement returns to surface are not maintained during setting, a log must be run to locate the cement top." Additionally, "adequate logging" must be conducted "to demonstrate hydraulic isolation of the injection or disposal zone." Reference is made to ERCB Directive 51 for logging guidelines.

(2) “A full length casing inspection log is required for any existing well being converted for injection or disposal service” with “results and interpretation… submitted as part of the application.”

c. Pressure integrity test requirements –

(1) “The casing or casing/tubing annulus must be pressure tested to a minimum pressure of 7,000 kPa for 15 minutes prior to the commencement of injection or disposal operations. A pressure test is considered successful if the pressure does not vary by more than three per cent during the test period.”

(2) “Annual packer isolation tests must be conducted.”

2. Water disposal wells (BCO&GC, 2012a):

a. General –

(1) “Produced saltwater must be disposed into a subsurface formation via an approved disposal service well… (and) is not permitted into an aquifer containing water usable for domestic or agricultural purposes, or a zone that may pose risk of contamination of such a water aquifer.” It is noted that “produced water includes recovered fluids from a well completion or workover operations (including flowback fluids from fracture stimulations).”

(2) The information required “in an application for disposal of produced water” is listed in BCO&GC (2012b).

(3) “Disposal is generally into water saturated formations that do not contain any hydrocarbon potential.” Approval for disposal may be granted “into a producing pool… where it can be demonstrated that disposal will not be detrimental to ultimate pool hydrocarbon recovery.”

(4) “Disposal injection pressure must not exceed the formation fracture pressure, and recommended practice is to not exceed 90 per cent of this value. Any changes to disposal fluid density… must be accounted for.”

(5) “For each month during which water is disposed of into the well” a report must be filed “reporting total injection hours, volume and average wellhead pressure” using form BC-S18.

b. Casing and cementing requirements –

(1) Surface casing for new wells must be set “below the deepest usable water zone and cemented to surface or”

(2) “If the surface casing is not set below the deepest usable water zone, the next casing string is cemented to surface, and”

(3) “Hydraulic isolation is established between all porous zones.”

c. Logging requirements – Same as for water source, injection, and disposal wells above.

d. Pressure integrity test requirement – Same as for water source, injection, and disposal wells above.

e. Pre-approval injectivity testing –

(1) "A well will not be granted approval to operate for disposal until it has been drilled and tested for hydrocarbon potential in the intended formation."

(2) When an injectivity test volume will exceed a total of 500 m^3 a "temporary" approval may be obtained for an injectivity test to obtain "performance information" for submission to the BCO&GC "to complete the application for disposal operation." An injectivity test, "typically step-rate, is a useful method of determining the formation fracture gradient in areas where this information is unknown" and can be used "to demonstrate that water injection/disposal does not exceed the value of the instantaneous shut-in pressure."

The procedure for authorizing deepwell disposal of wastes in British Columbia is outlined on the website of the BC Canada Ministry of Environment (BCCMofE, 2012). It identifies such wells as Class 1b wells, explains the rationale and philosophy of the procedure, and list disposal criteria as follows:

1. Rationale – "The intent… is to harmonize… requirements… in BC with… requirements for the same wastes in Alberta" with specific reference to Alberta Energy and Utilities Board (1994).

2. Philosophy – "Deepwell disposal of oilfield fluids" is considered "a safe and viable option "where wells are properly constructed, operated, and monitored and where the following principles are applied:
   a. Waste minimization is "implemented prior" to deepwell disposal.
   b. Resource conservation is "pursued whenever possible."
   c. Waste fluids are not "diluted solely" to avoid "waste fluid classification."
   d. Wells are designed and operated "using sound waste management practices and principles of waste minimization."
   e. "Design, construction and operation" of wells complies with all requirements of the BCO&GC.

3. Disposal criteria –
   a. Listed waste streams are prohibited including lube oils, solvents, and diesel invert drilling fluids.
   b. Waste streams are listed which are "considered appropriate for disposal in Class 1B wells without further sampling and analysis." These include:
      (1) Saline fluids from various oil field operations.
      (2) Neutralized (i.e., pH adjusted to the 6.0 to 9.0 range) "spent work over or stimulation fluids."
   c. Waste streams meeting general criteria including those of the Alberta ERCB noted under item 3.a of Section 2.2.1 above.

2.2.2 Assessment of Canadian Regulatory Programs

No assessment of DWI regulatory programs in Canada was located.

3.0 TRC PROGRAM

With the exception of Rule 51 of its Fresh Water Plan, TRC does not have regulations that specifically address DWI, but regulates it under the general provisions of the RMA. Rule 51 provides that DWI is a discretionary activity for which a resource consent from TRC will be required (TRC, 2007 and TRC, 2012a). However, TRC has historically had relevant guidelines. They were found within a staff paper prepared in 2005 on the disposal of contaminants by DWI and a set of guidelines for the disposal of drilling wastes (TRC, 2005a and 2005b, respectively). Four pages of the latter guidelines applied directly to DWI. Pertinent aspects of these guidelines are briefly discussed in Section 3.1 of this report to provide historical context.

The current TRC position on requirements for DWI are indicated in the terms of conditions prepared for consents in response to recent applications for DWI. These are summarized in Section 3.2 of this report.

3.1 Historical TRC Regulatory Position

TRC staff prepared a paper on the disposal of contaminants by DWI in Taranaki in 2005 (TRC, 2005a). This paper indicated that all fluids being disposed of by DWI in the Taranaki region at the time were related to petroleum hydrocarbon operations and included mainly saline produced water, and "specified system additives (e.g., biocides, anti-scaling, and anti-corrosion agents), wellsite contaminated stormwater, and water-based drilling muds. The paper contained a discussion of TRC information requirements for applicants seeking consent for DWI and made considerable reference to USEPA requirements, particularly those applicable to Class I or hazardous waste disposal wells in the US. This was intended to ensure that TRC requirements were more stringent than those in the US for Class II wells applicable for injection of fluids associated with oil and gas production (see Section 2.1 above).

TRC guidelines for DWI identified the types of wastes then being disposed of via DWI in the region (including saline produced water with hydrocarbon residues, hydrocarbon contaminated stormwater, and water-based drilling muds), the information required to be provided by applicants seeking consents (including a well engineering completion report showing pressure test results), the data used to determine the "fresh water-salt water interface," results showing that the water chemistry of the disposal zone was "compatible with that of the fluids to be disposed of," the maximum volume of materials to be disposed of over the lifetime of the well and the "modelled radius of influence of the contaminant plume" expected, a description of how injection and annular pressures would be monitored, and a written procedure identifying the conditions that would trigger concern about the integrity of the disposal well or injection zone and the action to be taken when triggered), and typical resource consent conditions (TRC, 2005b).

3.2 Recently Proposed TRC Consent Conditions

TRC staff recently processed an application by Greymouth Petroleum Ltd. (Riley, 2012) for a consent to cover DWI of produced water, well drilling fluids, well workover fluids (e.g., hydraulic fracturing return fluids), and contaminated stormwater, at their Turangi-A well site. Pertinent findings from that review included the following (TRC, 2012b):

1. The proposed activity would be injection of fluids via a dedicated injection well yet to be drilled.

2. Hydrocarbon exploration, production, and processing are common activities within the area surrounding the well site.

3. There are two private water supply wells in the TRC wells database within 1 km of the well site. Their depths are 2.5 and 26 m and they are used for domestic and agricultural purposes.

4. The information supplied by the applicant was "sufficient… for an informed decision to be made" under the RMA.

5. The application is a "discretionary activity" under Rule 51 of the Regional Fresh Water Plan (RFWP) for Taranaki.

6. Because the TRC was satisfied that "the potential adverse environmental effects of the proposed activity will not be more than minor," the application was processed without notification.

7. Under the RMA, "the discharge of contaminants to land requires resource consent" and "the main resource management issue… is the potential for the discharge… to affect potable groundwater water resources above the receiving formation and immediately below the ground (water table) at the site where the injection is made."

8. The injection target is the Mt. Messenger Formation sands at a depth of approximately 1,050 m true vertical depth (TVD). The sands are likely to have a vertical interval of 15-30 m at the target site and a porosity range of 19-23%. These sands "typically exist in 'lobes' rather than a continuous 'blanket' and… the intercepted lobe will have an extent of approximately 1 km^2."

   "The Mt. Messenger Formation reservoir pressure is over 1,400 psi above hydrostatic pressure, indicating that the" overlying formation "is impermeable."

   The Urenui Formation overlies the Mt. Messenger Formation and it is comprised of "impermeable siltstones and mudstones and forms an extensive aquitard."

9. The saline/freshwater "transition was found to be 214 m TVD at a site 4 km to the southeast of the Turangi-A well site (however how this transition was classified was not stated). It has been reported that resistitivity logs in the Turangi-A well site area indicate saline water below 960 m TVD with saline defined as being "above 1,000 ppm."

10. Information provided by the applicant as to injection pressure, confining layer fracture pressure, injection rates and volume, and the chemical composition of waste streams to be injected was accepted as provided and it was judged that the "target formation" had the "capacity to accept the proposed discharge."

11. Based on general information for the region provided by GNS Science, it was concluded that it "is extremely unlikely that the proposed activity will result in any observable increase in seismic activity."

This staff assessment recommended that the application be approved for a period of four years (i.e., until 1 June 2016) with conditions to be reviewed annually and establishment of a compliance monitoring program and subject to the following general and special conditions (TRC, 2012b and c):

1. General condition – "The consent holder shall pay… all the administration, monitoring and supervision costs of this consent."

2. Special conditions –

    a. The consent holder "shall submit an Injection Operation Management Plan" which shall include the operational details of the injection activities and identify the conditions that would trigger concerns about the integrity of the injection well, injection zone or overlying geological formation" and "action(s) to be taken… if trigger conditions are reached."

    b. "Before this consent is exercised the consent holder shall provide" to the TRC (this information can be included in the above plan) the following information:

        (1) "A final well completion log for the injection well" with design and construction details.

        (2) "Well cementing details, cement bond log and results of annular pressure testing which demonstrates well integrity."

        (3) "Details of on-going well integrity monitoring, well maintenance procedures and safe operating limits for the well."

        (4) "A detailed geological log of the well."

        (5) "Details and results of the Formation Integrity Testing."

        (6) "Results of an electrical resistivity survey clearly showing the confirmed depth of freshwater."

        (7) "A full chemical analysis of the receiving formation-water."

    c. "The injection pressure at the wellhead shall not exceed 23.6 bar (342 psi). If exceeded, the injection operation shall be ceased immediately and the Chief Executive of the TRC informed immediately."

    d. "The rate of injection shall not exceed 14.3 m^3/hr."

    e. "The volume of fluid injected shall not exceed 300 m^3/day."

    f. "The injection of fluids shall be confined to the Mt. Messenger Formation, deeper than 1,050 m TVD."

    g. "The consent holder shall at all times adopt the best practicable option… to prevent or minimize any actual or likely adverse effect on the environment… ensuring that the injection material is contained within the injection zone."

    h. "Only" produced water, well drilling fluids, well workover fluids (including hydraulic fracturing return fluids), and contaminated stormwater "may be discharged."

    i. The consent holder "shall keep daily records" of the injection pressure, maximum and average rate of injection, and volume of fluid injected and shall provide these records monthly to the TRC.

j. For each discharge, the following information shall be recorded and provided to the TRC upon request (this analysis "is not necessary if a sample of the same type of fluid… has been taken and analysed within the previous 6 months"):

   (1) pH.

   (2) Suspended solids concentration.

   (3) Temperature.

   (4) Salinity.

   (5) Chloride concentration.

   (6) Total hydrocarbon concentration.

k. The consent holder "shall ensure that the exercise of this consent does not result in contaminants reaching any usable fresh water… Usable fresh groundwater is defined as any groundwater having a TDS concentration of less than 1,000 mg/L."

l. The consent holder "shall undertake a programme of sampling and testing that monitors the effects of the exercise of this consent on fresh water resources… The Monitoring Programme shall be certified by the Chief Executive, TRC, before this consent is exercised, and shall include:"

   (1) "The location of the sampling sites."

   (2) "Well/bore construction details."

   (3) "Sampling frequency."

m. "All water samples… shall be taken in accordance with recognized field procedures and analysed for:"

   (1) pH.

   (2) Conductivity.

   (3) TDS.

   (4) Major ions (Ca, Mg, K, Na, total alkalinity, bromide, chloride, nitrate-nitrogen, and sulphate).

   (5) Trace metals (Ba, Cu, Fe, Mn, Ni, and Zn).

   (6) Total petroleum hydrocarbons;

   (7) Dissolved methane and ethane gas.

   (8) Methanol.

   (9) Glycols.

   (10) Benzene, toluene, ethylbenzene, and xylenes.

   (11) Carbon-13 composition of any dissolved methane gas discovered.

n. All sampling and analysis shall be undertaken in accordance with a sampling and analysis plan approved by TRC prior to the first sample being taken. "This plan shall specify the use of standard protocols recognized to constitute good professional practice including quality control and assurance and an International Accreditation New Zealand (IANZ) accredited laboratory shall be used for all

sample analysis." Results should be provided to the TRC within 30 days of sampling and shall include supporting quality control and assurance information.

o. The consent holder "shall provide to TRC' during May of every year a summary of all data collected and "a report detailing compliance with consent conditions." The consent holder "shall also provide and assess data which illustrates the on-going integrity and isolation of the wellbore, well performance, and condition" and "an updated injection modelling report, illustrating the ability of the receiving formation to continue to accept additional waste fluids and estimating its remaining storage capacity."

p. The consent holder shall notify TRC in writing "at least 5 days prior to the first exercise of this consent.'

q. TRC "may serve notice of its intention to review, amend, delete or add to the conditions of this resource consent by giving notice of review during the month of June each year" to ensure "that the conditions are adequate to deal with any adverse effects on the environment arising from the exercise of this resource consent, which were either not foreseen… or which it was not appropriate to deal with at the time" the application was considered.

4.0 DEPARTMENT OF LABOUR 1999 REGULATIONS

Although intended for health and safety purposes rather than operational effectiveness in utilization of the petroleum hydrocarbon resource or environmental protection, regulations promulgated by the Department of Labour (now part of the Ministry of Business, Innovation & Employment or MBI&E) in 1999 included provisions at Part 2 under "well-drilling operations" related to well integrity in the drilling and installation of wells for petroleum exploration and extraction (Department of Labour, 1999). These regulations are applicable to wells used for DWI. They are tacit recognition of the obvious, that well integrity is related to the health and safety of personnel. It is equally clear that well integrity, including DWI, is critical to good environmental management under the RMA.

In general, the tone of these Department of Labour regulations is passive, encouraging employers to "take all practicable steps to ensure" that petroleum operations are "designed, constructed, operated, and maintained, and suspended or abandoned… in accordance with generally accepted and appropriate industry practice." In essence, this approach calls for self-regulation. A number of studies have been published on industry self-regulation making both positive and negative points about self-regulation (e.g., Gunningham, 2011; King and Lennox, 2000; King and Toffel, 2007; Lennox, 2006; Short and Toffel, 2010). However, as concluded in a study of US industrial facilities subject to the Clean Air Act during the 1993-2003 decade, "organisations are more likely to follow through on their commitments to self-regulate when they are subject to heavy regulatory surveillance" and, although "self-regulation can be a useful tool for leveraging the normative motivations of regulated organisations… it cannot replace traditional deterrence-based enforcement" (Short and Toffel, 2010). Similar conclusions have recently been reported with regard to self-regulation in workplace health and safety in New Zealand. As noted by Gunningham (2011), although we must take seriously the potential for self-regulation in industrial life… self-regulation is very rarely successful as a 'stand alone' mechanism of social control" and where it has been

"most effective" there has been "an underpinning of government regulation, or third party oversight, or more commonly both."

It is also noteworthy with respect to the Department of Labour 1999 regulations, that they do not cover all important aspects of well integrity that are addressed, for example in North American DWI regulatory programs. For example, there are no requirements for mechanical integrity testing or submittal and review of plans such as an "Injection Operation Management Plan."

The 1999 Department of Labour regulations have recently been reviewed and are being revised at this time. There were "multiple drivers" for undertaking this process. They include an expected expansion in petroleum exploration and production in New Zealand, high-profile major accidents both in New Zealand (e.g., the Pike River Mine disaster in 2010) and elsewhere in the world (e.g., the Deepwater Horizon blowout in the Gulf of Mexico which also occurred in 2010), a review in 2010 that "recommended strengthening New Zealand's safety case regime," and the societal expectation "that petroleum exploration and extraction activities will be regulated by a robust regime in which… the risk of a major accident" is minimised through operators maintaining safety and regulators that "provide assurance that this is being done" (MBI&E, 2012 and Finlayson, 2012). In view of these factors, it was felt that "New Zealand's regulatory standards in hazardous industries were not up to world standard," and that improvement was necessary to "bring the petroleum exploration and extraction sector into line with practice in the United Kingdom and Australia (Finlayson, 2012).

5.0 CONCLUSIONS AND RECOMMENDATIONS

As stated in it, the purpose of the RMA is "to promote the sustainable management of natural and physical resources" while "avoiding, remedying, or mitigating any adverse effects of activities on the environment" and the RMA gives Regional Councils considerable flexibility with regard to achieving this purpose.

There a number of common points in the North American programs for DWI discussed herein. As a whole, these would appear to be consistent with what best practice in the field is at this time. They may be summarized as follows:

1. Administrative requirements to submit an application and obtain a permit for an injection well discharge. The specific information to be provided is delineated and, in some cases, forms are provided by the agencies to the applicant. Information commonly required including –
   (a) Details on any modelling done to define the AoR and maps showing the injection well, production wells, abandoned wells, dry holes, and water supply wells.
   (b) Well construction data.
   (c) Geologic data including information on freshwater aquifers, confining layers, and the injection formation (in the latter case to include fluid pressure), estimated fracture pressure, and physical and chemical characteristics.
   (d) Logging and testing program results.

(e) Demonstration of mechanical integrity (to be demonstrated initially and at defined intervals during normal operation such as five year intervals for the USEPA).

(f) Injections are to be below USDW (10,000 mg/L TDS) for the USEPA or useable water (4,000 mg/L TDS) for the Canadian provinces.

2. Well construction requirements including –

   (a) Casing (with a requirement that surface casing be set below the deepest usable water zone).

   (a) Cementing (including cementing to the surface).

   (b) Well logging.

   (c) Pressure testing (initial test at minimum of 7,000 kPa for 15 minutes and annual packer isolation test at minimum of 1,400 kPa for 15 minutes).

3. General and specific criteria for types of wastes and waste quality.

4. Monitoring and reporting requirements during well operational life including –

   (a) Characterization of the nature of the injected fluids and any substantial changes in same.

   (b) Observed injection pressure, flow rate, and cumulative volume injected weekly for produced fluid disposal, monthly for enhanced recovery operations, daily during injection of liquid hydrocarbons, and at reasonable intervals no greater than 30 days.

   (c) Annual report including monthly records of injected fluids.

5. Plans to be submitted:

   (a) Proposed formation testing program plan.

   (b) Proposed operation (i.e., injection) plan including maximum injection pressure to be used and proposed injection procedures. Operation pressure be less than 90 percent of formation fracture pressure or less than pressure at which hydraulic isolation was demonstrated.

   (c) Proposed contingency plans in the event of malfunctions or well failure.

   (d) Proposed well maintenance plan (to include stimulation provisions).

   (d) Monitoring and reporting plan.

   (e) Plugging and abandonment plan.

6. Provision of a performance bond or equivalent to guarantee resources sufficient to plug or abandon the well at the end of its service life.

Much of the information, including monitoring data, must be submitted on agency forms.

Regulatory requirements in North America emphasise well integrity. Well integrity is critical to various aspects of DWI including worker health and safety, environmental management, and efficient development of New Zealand's petroleum hydrocarbon resources. An active regulatory programme with interagency cooperation and comprehensive requirements is

necessary to protect the public interest. While there have been few well integrity incidents in this country it is considered self-regulation needs to be upgraded to a more active and comprehensive regulatory regime to manage the risks going forward, particularly with the likely increased activity level in the sector..

Most of the regulatory requirements of agencies in North America pertinent to the DWI discharge are already incorporated in proposed TRC consent conditions. Some well integrity requirements are also addressed by the TRC (see Section 3.2 above). This is important because, as noted in Section 4, Department of Labour 1999 regulations are focussed on health and safety issues, including well integrity but do not explicitly address environmental management. However, there are two areas where TRC consent conditions could be slightly strengthened to provide better protection for groundwater resources. The following recommendations are made with that objective in mind:

1. TRC protect at least presently "useable groundwater" by adopting the approach of the Canadian provinces with a criterion of 4,000 mg/L TDS and consider expanding that protection to the 10,000 mg/L criterion used in the US. This level (i.e., 10,000 mg/L TDS) has relevance with regard to application of available desalinization technology (URS Australia, 2002).

   Water with much higher levels of TDS is useable for such purposes as human consumption or agricultural irrigation and such quality water is used in New Zealand as well as other countries. Although there is a guideline value of 1,000 mg/L for drinking water in New Zealand, it is a non-mandatory esthetic rather than health based criterion (DWSNZ-2005, 2008). With regard to agricultural irrigation, only crops that are sensitive to salinity would require water with TDS levels less than 1,000 mg/L. Criteria for crops that are only moderately tolerant would be much higher. Australia and New Zealand Environment and Conservation Council (ANZECC) guidelines provide water quality criteria showing the high end of the range for this case to be 4,500 uS/cm conductivity (ANZECC, 2000). Using a standard factor to estimate, this could be equivalent to 2,500 mg/L TDS or more. Water with much greater levels of salinity could be used to irrigate salt tolerant crops.

   Whether current estimates indicate that existing surface water and shallow fresh groundwater resources will be sufficient for anticipated future water use in the Taranaki Region or not, consideration should be given to protecting deeper sources of groundwater having TDS concentrations exceeding 1,000 mg/L so that they will remain useable if needed in the future.

2. TRC adopt the concept of designating an AoR for assessment in the case of proposed injection wells and require that applicants provide comprehensive information about current site conditions and proposed injection well plans. Delineation of a suitably sized AoR for assessment is a sound concept that provides for appropriate assessment of potential impacts from a proposed injection well. This would make current TRC practice to require a monitoring programme explicit and quantitative with respect to the area involved.

As noted in Section 4, it is also clear that the Department of Labour's 1999 regulations need to be strengthened to bring them up to world standard. It would be appropriate, as part of the currently ongoing review and revision process, to ensure that the principles of the following

provisions of DWI regulatory programs in North America are considered in that review for transfer to New Zealand's requirements:

1. Require submittal of comprehensive site and injection well information to include various necessary plans. Special condition number 1 of TRC (2012b and c) specifies the current TRC requirement for submittal of an "Injection Operation Management Plan" including well operational details, identifying "trigger concerns" about well integrity, and "action(s) to be taken… if trigger conditions are reached." The necessary content of this plan should be specified and broadened to at least match that contained in the following plans required by USEPA:

   (a) Proposed formation testing program plan.

   (b) Proposed operation (i.e., injection) plan including maximum injection pressure to be used and proposed injection procedures with operation pressure less than 90 percent of formation fracture pressure or less than pressure at which hydraulic isolation was demonstrated.

   (c) Proposed contingency plans in the event of malfunctions or well failure.

   (d) Proposed well maintenance plan (to include stimulation provisions).

   (d) Monitoring and reporting plan.

   (e) Plugging and abandonment plan.

2. Require initial and routine continuing mechanical integrity testing throughout the operation life of the injection well to include application of a combination of logging methods, pressure testing, and continual monitoring of well pressures. Pressure testing should include annual packer isolation tests.

3. Require provision of a performance bond or equivalent to guarantee resources sufficient to plug or abandon the well at the end of its service life.

4. Conduct routine site inspections of approved injection wells during construction and testing as well as during normal operation.

6.0 REFERENCES CITED

Alberta Energy and Utilities Board. 1994. Injection and disposal wells – well classifications, completions, logging, and testing requirements. Directive 051, ERCB, Calgary, 35 pages.

ANZECC. 2000. Australian and New Zealand guidelines for fresh and marine water quality, Vol. 1. Canberra.

BCO&GC. 2012a. Water source, injection and disposal service wells. Victoria, BC, Canada, 7 pages. Accessed July at: http://www.bcogc.ca/document.aspx?documentID=1113.

BCO&GC. 2012b. Guideline for approval to dispose of produced water. Victoria, BC, Canada, 1 page. Accessed July at: http://www.bcogc.ca/document.aspx?documentID=642&type=.html.

BCCMofE. 2012. Procedure for authorizing deepwell disposal of wastes. Victoria, BC, Canada, 8 pages. Accessed July at http://www.env.gov.bc.ca/epd/industrial/oil_gas/deepwell_wastes.htm.

DWSNZ-2005. 2008. Drinking-water standards for New Zealand 2005 (Revised 2008). Ministry of Health, Wellington, 163 pages.

Department of Labour. 1999. Health and Safety in Employment (Petroleum Exploration and Extraction) Regulations 1999. Order in Council dated 11 October 1999 reprinted 26 September 2006). Accessed January 2013 at http://www.dol.govt.nz/consultation/petroleum-regulations/qas.asp.

Finlayson, C. 2012. Health and safety a priority in oil and gas production. Minister. Accessed January 2013 at http://beehive.govt.nz/release/health-and-safety-priority-oil-and-gas-production.

Gunningham, N. 2011. Investigation of industry self-regulation in workplace health and safety in New Zealand. Report commissioned under the Workplace Health and Safety Strategy for NZ to 2015 under the National Action Agenda 2010-2013. Gunningham & Associates Pty Ltd, Wellington, 33 pages.

Hembra, R.L., et al. 1989. Drinking water: Safeguards are not preventing contamination from injected oil and gas wastes. Report GAO/RCED-89-97, USGAO, Washington, DC, 47 pages.

Herbert, E.A. 1996. The regulation of deep well injection: changing environment beneath the surface. Pace Environmental Law Review, Vol. 14, Issue 1, Fall, pages 169-225.

King, A.A. and M.J. Lennox. 2000. Industry self-regulation without sanctions: the chemical industry's responsible care program. The Academy of Management Journal, Vol. 43, No. 4, pages 698-716.

King, A.A. and M.W. Toffel. 2007. Self-regulatory institutions for solving environmental problems: perspectives and contributions from the management literature. Working Paper 07-089. Accessed January 2013 at http://mba.tuck.dartmouth.edu/pages/faculty/andrew.king/docs/king_toffel.pdf.

Lennox, M.J. 2006. The role of private decentralized institutions in sustaining industry self-regulation. Organization Science, Vol. 17, No. 6, pages 677-690.

Lustgarten, A. 2012a. Injection wells: the hidden risks of pumping waste underground. Four parts: The poison beneath us; An unseen leak, then boom; Polluted water fuels a battle for answers; and Whiff of phenol spells trouble. Pro Publica, New York, NY, USA. 21 June. Accessed July at: http://www.propublica.org/series/injection-wells.

Lustgarten, A. 2012b. Injection wells: the hidden risks of pumping waste underground. The trillion-gallon loophole: Lax rules for drillers that inject pollutants into the earth. Pro Publica, New York, NY, USA. 21 June. Accessed September at http://www.propublica.org/series/injection-wells.

McCurdy, R. 2011. Underground injection wells for produced water disposal. IN: Proceedings of the Technical Workshops for the Hydraulic Fracturing Study: Water Resources Management," J. Veil and M. Mantell, eds., Report EPA 600/R-11/048, Office of Research and Development, U.S. Environmental Protection Agency, Washington, DC, pages 97-102.

McLay, F. 2012. Personal communication. Director, Resource Management, TRC, Stratford.

MBI&E. 2012. Review of the health and safety in employment (petroleum exploration and extraction) regulations 1999. Accessed January 2013 at http://www.dol.govt.nz/consultation/petroleum-regulations/.

Parks, K. 2005. Deep well disposal and aquifer storage and retrieval. Professional Develpoment Days, APEGGA Conference, Calgary, 22 April, 32 pages.

Otton, J.K. and T. Mercier. 2012. Produced water brine and stream salinity. Undated pdf slides produced by US Geological Survey. Accessed July 2012 at http://waater.usgs.gov/orh/nrwww/otton.pdf.

Plourde, A. 2010. Oil and gas in the Canadian Federation. Working Paper #10-001, Buffett Center for International and Comparitive Studies, Department of Economics, University of Alberta, Edmunton, Canada, 23 pages plus tables.

Riley, D. 2012. Consent application and assessment of environmental effects for the discharge of contaminants via deep well injection: Turangi-A wellsite. BTW Company Ltd., New Plymouth, April, 13 pages plus appendices.

Short, J. and M.W. Toffel. 2010. Making self-regulation more than merely symbolic: the critical role of the legal environment. Administrative Science Quarterly, Vol. 55, pages 361-396.

Shyba, G. 2008. Water management in Alberta's oilfields – issues and opportunities. Presented at the annual conference and professional development seminar, Association of Professional Engineers and Geoscientists of Alberta, Edmunton, Alberta, Canada, 17 April.

TRC, 2005a. Disposal of contaminants by deep well injection in Taranaki. Internal memorandum prepared by K. Brown, TRC, Stratford, 10 pages.

TRC. 2005b. Guidelines for the control of disposal of drilling wastes onto and into land. TRC Document #:☺DMA\PCDOCS\FRODO\98943\1, TRC, Stratford, 41 pages. Accessed July at: http://www.trc.govt.nz/assets/Publications/information-sheets-and-newsletters/resource-consent-information-sheets/drilling+waste.pdf.

TRC. 2007. Resource consents procedure document. Document 191119, TRC, Startford, 58 pages.

TRC. 2012a. Regional fresh water plan. TRC, Stratford. Accessed July at: http://www.trc.govt.nz/fresh-water-plan-index.

TRC. 2012b. Memorandum of 26 April (Document 1035947). Scientific Officer, TRC, Stratford, 23 pages.

TRC. 2012c. Discharge permit issued to Greymouth Petroleum Ltd. Document #1040873-v1. TRC, Stratford, 4 May, 5 pages.

UIC Program. 2012a. History of the UIC program – injection well time line. Office of Ground Water and Drinking Water, USEPA, Washington, DC. Accessed in July at http://water.epa.gov/type/groundwater/uis/history.cfm.

UIC Program. 2012b. Underground injection control 101: permitting guidance for hydraulic fracturing using diesel fuels technical webinars. Office of Ground Water and Drinking Water, USEPA, Washington, DC, May 9-16, 42 pages. Accessed July at: http://water.epa.gov/type/groundwater/uic/class2/hydraulicfracturing/upload/uic_101_webinar_presentation.pdf.

UIC Program. 2012c. Reporting forms. Office of Ground Water and Drinking Water, USEPA, Washington, DC. Accessed in July at http://water.epa.gov/type/groundwater/uic/reportingforms.cfm.

URS Australia. 2002. Introduction to desalination technologies in Australia. Summary Report prepared for Agriculture, Fisheries & Forestry – Australia. Turner, ACT, Australia. Accessed July at http://www.environment.gov.au/water/publications/urban/pubs/desalination-summary.pdf.

APPENDIX A

ERCB WELL SUMMARY FOR INJECTION OR DISPOSAL

ERCB INJECTION/DISPOSAL WELLBORE COMPLETION SCHEMATIC

BCO&GC MONTHLY INJECTION/DISPOSAL STATEMENT (FORM BC-S18)

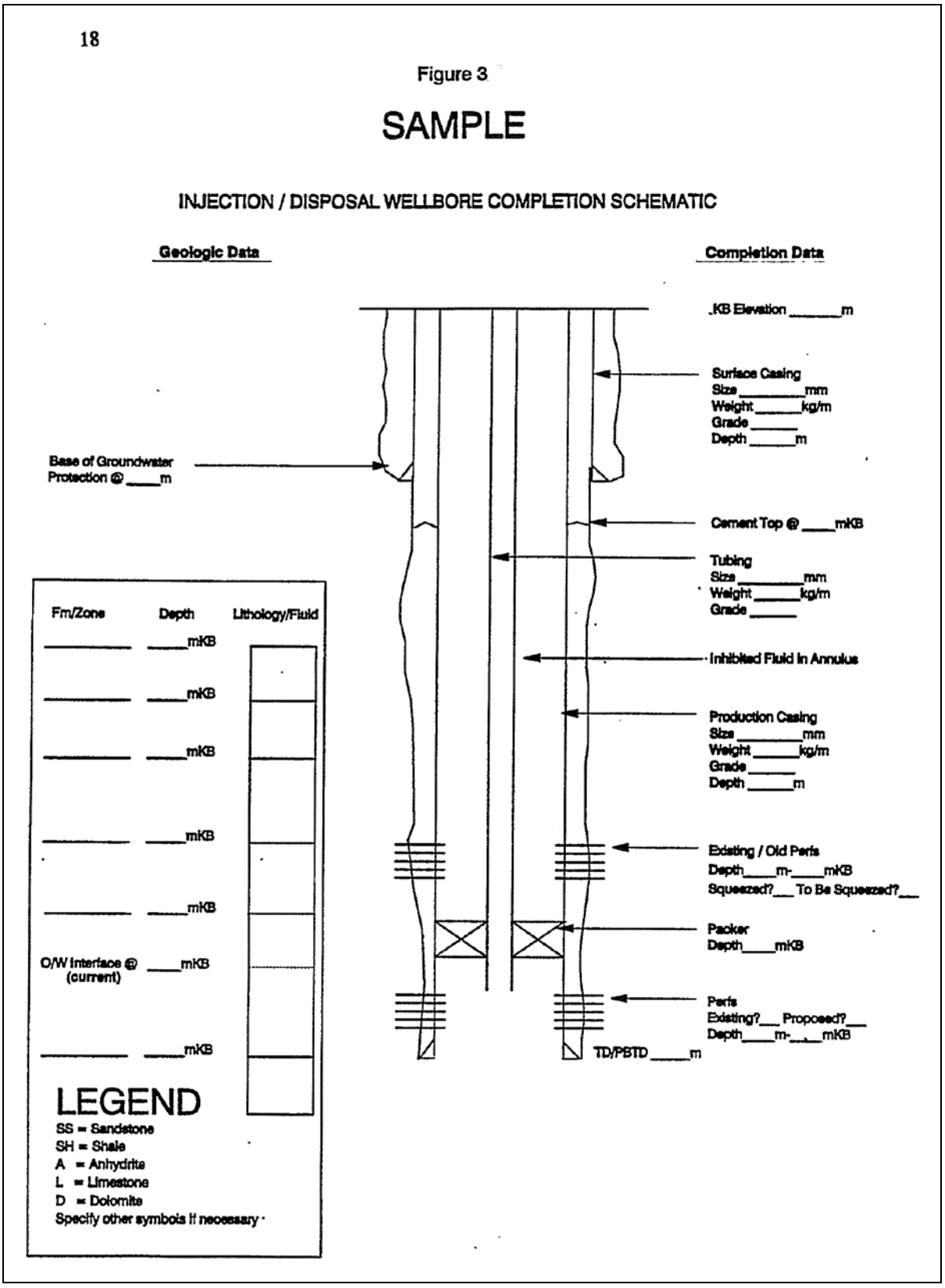
ERCB WELL SUMMARY FOR INJECTION OR DISPOSAL

Figure 2 17

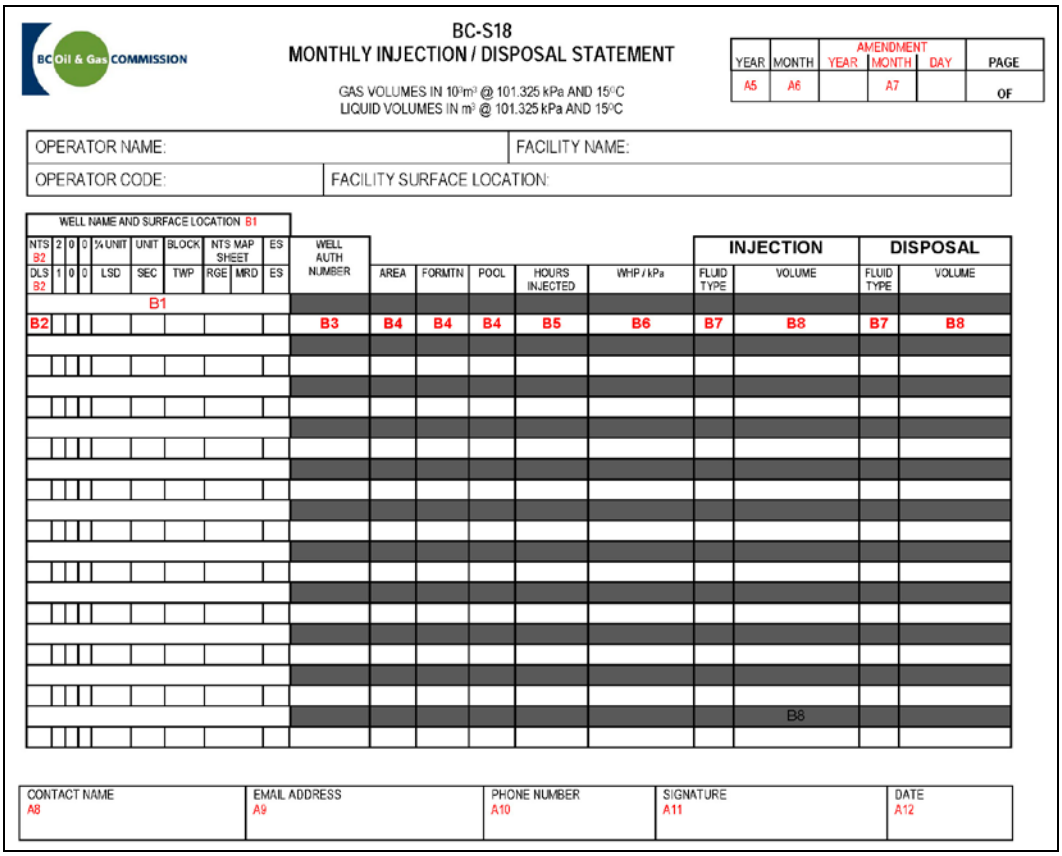
WELL SUMMARY FOR INJECTION OR DISPOSAL

WELL NAME	UNIQUE IDENTIFIER
OPERATOR	FIELD NAME
NAME OF FORMATION / POOL	INJECTION INTERVAL TOP M BOTTOM M
WELL CLASSIFICATION 1a ☐ 1b ☐ II ☐ III ☐ IV ☐	
INJECTED/DISPOSED FLUIDS	SOURCE OF FLUIDS
ANTICIPATED DAILY INJECTION VOLUME (M^3)	MAXIMUM INJECTION PRESSURE (KPA)
FRACTURE GRADIENT KPA/M	ACTUAL ☐ ESTIMATED ☐
SOURCE OF FRACTURE DATA	
CASING INTEGRITY ASSESSMENT	
FINISHED DRILLING DATE DAY MO YR	
CASING INSPECTION LOG RUN NO ☐ YES ☐ (LOG SUMMARY ATTACHED)	CORROSION RATE ACCEPTABLE ☐ UNACCEPTABLE ☐
CASING-TUBING ANNULUS FULL NO ☐ YES ☐	MONITORING FREQUENCY
CASING PRESSURE INTEGRITY TEST NO ☐ YES ☐ (TEST SUMMARY ATTACHED)	DATE OF TEST DAY MO YR
CATHODIC PROTECTION INSTALLED NO ☐ YES ☐	INSTALLATION DATE DAY MO YR
CASING VENT BLOW NO ☐ YES ☐ REPAIRED ☐	CASING FAILURE NO ☐ YES ☐ REPAIRED ☐
HYDRAULIC ISOLATION ASSESSMENT	
CEMENT TOP M	METHOD OF ASSESSMENT
HYDRAULIC ISOLATION LOGGING LOGS AND INTERPRETATION ATTACHED ☐	TO BE CONDUCTED ☐
METHOD OF ASSESSMENT	
LOGGED INTERVAL TOP M BOTTOM M	WELLHEAD PRESSURE DURING LOGGING KPA
CERTIFICATION	
I hereby certify that data given above and on the attached documentation is correct, that interpretations have been made by personnel qualified to make such interpretations, and that injection/disposal operations will be conducted in accordance with ERCB Guide G-51, or as otherwise approved by a representative of the Board.	
SIGNATURE	TITLE
COMPANY	PHONE NUMBER
ADDRESS	

ERCB INJECTION/DISPOSAL WELLBORE COMPLETION SCHEMATIC



BCO&GC MONTHLY INJECTION/DISPOSAL STATEMENT (FORM BC-S18)



BC Oil & Gas COMMISSION

BC-S18
MONTHLY INJECTION / DISPOSAL STATEMENT

GAS VOLUMES IN 10^3m^3 @ 101.325 kPa AND 15°C
LIQUID VOLUMES IN m^3 @ 101.325 kPa AND 15°C

YEAR	MONTH	AMENDMENT YEAR	AMENDMENT MONTH	AMENDMENT DAY	PAGE
A5	A6		A7		OF

OPERATOR NAME:	FACILITY NAME:
OPERATOR CODE:	FACILITY SURFACE LOCATION:

WELL NAME AND SURFACE LOCATION B1															INJECTION		DISPOSAL	
NTS B2	2	0	0	¼ UNIT	UNIT	BLOCK	NTS MAP SHEET		ES	WELL AUTH NUMBER	AREA	FORMTN	POOL	HOURS INJECTED	WHP / kPa	FLUID TYPE	VOLUME	FLUID TYPE	VOLUME
DLS B2	1	0	0	LSD	SEC	TWP	RGE	MRD	ES										
					B1														
B2										B3	B4	B4	B4	B5	B6	B7	B8	B7	B8
																	B8		

CONTACT NAME A8	EMAIL ADDRESS A9	PHONE NUMBER A10	SIGNATURE A11	DATE A12

MONTHLY INJECTION / DISPOSAL STATEMENT – BC-S18 - INSTRUCTIONS

PURPOSE The BC-S18 is used to report the monthly operations of facilities with regard to:

- Water injection / disposal
- Gas injection / storage
- EOR injection
- LPG storage

The BC-S18 must be filed with the Oil and Gas Commission not later that the 25th day following the month of injection / disposal. If the 25th day falls on a Saturday, Sunday or statutory holiday, filing must be made on the next normal business day.

STANDARDS The following standards are to be applied when completing this statement:

Liquid Volumes – record to one (1) decimal place, @ 15°C and 101.325 kPa.

Gas Equivalent Factors – record to three (3) decimal places.

Gas Equivalent Volumes – record to one (1) decimal place, @ 15°C and 101.325 kPa.

Wellhead Pressure – record as a whole number.

NOTES Operators are not required to complete shaded fields on this form.

Unless otherwise stated, the word "month" means the production month to which this statement pertains.

GENERAL INFORMATION

A1 ***Report of*** – provide the full name of the operator responsible for completion of the statement.

A2 ***Operator code*** – insert the applicable 4 digit code assigned to the operator

A3 ***Facility Name*** – insert the name of the reporting facility.

A4 ***Surface location*** – insert the surface location of the reporting facility.

A5 ***Year*** – insert the last two (2) digits of the year for which the statement is made.

A6 ***Month*** – insert two (2) digits to indicate the month for which the statement is made, e.g., January = 01; June = 06, etc.

A7 ***Amendment: Year/Month/Day*** – enter the date on which the amendment is prepared. For the month, use the 2 digit style in A6, above.

A8 ***Contact Name*** – insert the name of the person responsible for completion and submission of this BC-S18.

A9 ***Email address*** – insert the email address of the contact person named above.

A10 ***Telephone*** – insert the phone number of the contact person named above.

A11 ***Signature*** –

A12 ***Date*** – enter the date the statement was completed.

DETAILS OF INJECTION / DISPOSAL

B1 ***Well Name*** – insert the well name and surface location as approved on the "Application for a Well Authorization".

B2 ***Bottom Hole UWI (Unique Well Identifier)*** – insert the 16 character unique well identifier using the NTS (National Topographic Series) format of the DLS (Dominion Land Survey) format. See example below:

WELL NAME AND SURFACE LOCATION
PROGRESS LILY d-085-G/094-G-02

BOTTOM HOLE UWI FOR NTS							
1	2	3	¼ UNIT 4	UNIT 5 – 7	BLOCK 8	NTS MAP SHEET 9 - 14	ES 15, 16
2	**0**	**0**	**B**	**085**	**G**	**094G02**	**00**

WELL NAME AND SURFACE LOCATION
CNRL HZ BUICK a16-14-088-20

BOTTOM HOLE UWI FOR DLS								
1	2	3	LSD 4, 5	SEC 6, 7	TWP 8 – 10	RGE 11, 12	MRD 13, 14	ES 15, 16
1	**0**	**0**	**15**	**14**	**088**	**20**	**W6**	**02**

B3 ***Well Authorization Number*** – insert the 5 digit approval number of the authorization to drill the well as approved on the "Application for a Well Authorization".

B4 ***Area/Formation/Pool*** – insert the 4 digit area code, insert the 4 digit formation code of the formation your well is completed in and the alphabetic suffix, if applicable.

3

B5 ***Hours Injected*** – enter the number of hours of injection or disposal during the month.

B6 ***WHP*** – enter the average operating wellhead pressure as measured in kilopascal gauge pressure.

B7 ***Injection/Disposal Fluid*** – insert the applicable code to indicate the fluid injected or disposed.

02 – Gas (10^3m^3)
03 – Oil (m^3)
06 – Water (m^3)
08 – Waste (m^3)
09 – Solvent (10^3m^3) *
10 – Steam (m^3) **
11 – Air (10^3m^3)
13 – Carbon Dioxide (m^3)
14 – Polymer (10^3m^3)
15 – Nitrogen (10^3m^3)
19 – Oxygen (m^3)
50 – Anhydrous Ammonia (10^3m^3)
52 – Naphtha (m^3)
58 – Diesel (10^3m^3)
59 – Alkaline Water (m^3)
60 – Miscellar (m^3)
63 – Ammonium Nitrate (m^3)

* Includes: LPG, Condensate, Propane, Butanes, Ethane, Ethane Plus, and Pentanes Plus which are converted to gas equivalent volume.

** Cold water equivalent volume.

B8 ***Injection / Disposal Volume*** – enter the metered volume of fluid injected or disposed for each fluid.

www.gns.cri.nz

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