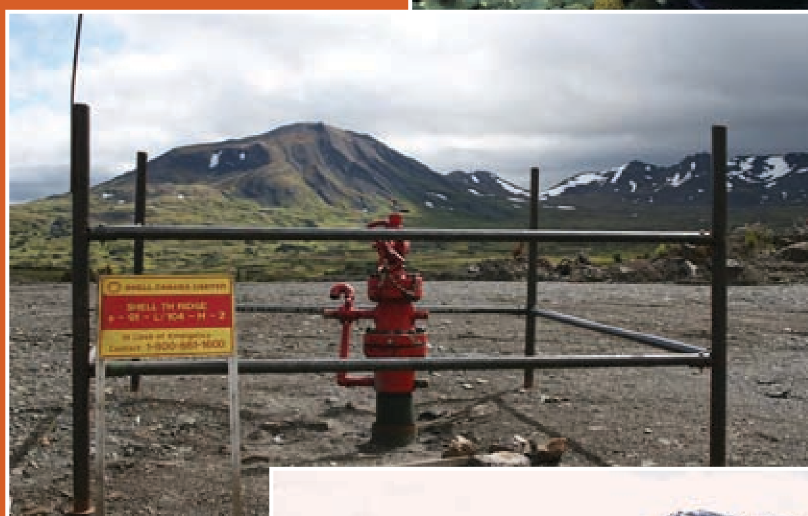
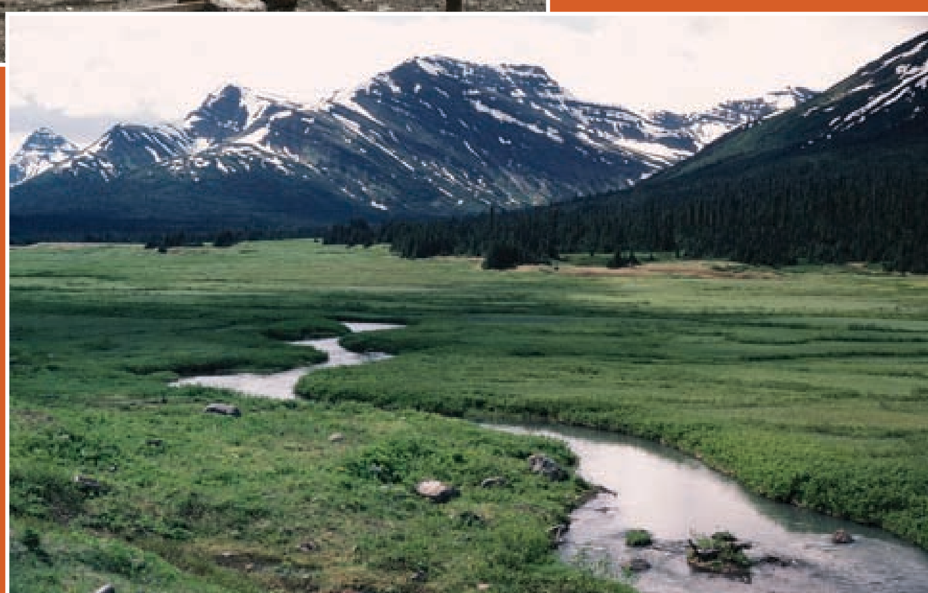
Sustainable Energy Solutions

Coalbed Methane & Salmon: *Assessing the Risks*





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for The Pembina Institute

FOREWORD BY

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About the Pembina Institute

The Pembina Institute creates sustainable energy solutions through research, education, consulting and advocacy. It promotes environmental, social and economic sustainability in the public interest by developing practical solutions for communities, individuals, governments and businesses. The Pembina Institute provides policy research leadership and education on climate change, energy issues, green economics, energy efficiency and conservation, renewable energy and environmental governance. More information about the Pembina Institute is available at http://www.pembina.org or by contacting info@pembina.org.

Foreword by The Pembina Institute

Harmful land, water and wildlife impacts from coalbed methane (CBM) development have already been well documented based on experience in the United States and elsewhere. But proposals to develop CBM resources in the Headwaters region of Northwest British Columbia raise an entirely new question: what are the likely impacts of CBM extraction on salmon?

The Headwaters is a uniquely pristine, sensitive and culturally significant ecosystem where three major salmon-bearing rivers — the Skeena, the Stikine and the Nass — begin. Until now, no studies have been completed to identify and assess possible risks to salmon from CBM activities there, even as the proponent, Shell Canada Limited (Shell), prepares to drill a number of wells.

The Pembina Institute commissioned the report, *Coalbed Methane and Salmon: Assessing the Risks*, in order to begin addressing this knowledge gap and provide essential information for communities, for the project proponent and for decision-makers. The report's findings, although preliminary, raise enough concerns to warrant suspending further CBM activity in the Headwaters area.

Wild salmon in the Skeena, Stikine and Nass watersheds play an integral role in the cultures and the economies of Northwest British Columbia. Analysis in *Coalbed Methane and Salmon: Assessing the Risks* determines that CBM development could threaten salmon found in the area where Shell proposes to drill in two ways:

— First, by changing runoff patterns in a way that increases the amount of sediment in streams, muddying the water and destroying spawning areas;

— Second, by disrupting the groundwater regime in a way that reduces critical groundwater contributions to stream flow, changing the temperature, depth and extent of salmon habitat.

As the report points out, both impacts could be serious; but what we know and what we don't know about the potential risks is very different in each case.

Changes in the runoff pattern are almost certain to occur because, in order to be commercially viable, CBM projects require a lot of land to be cleared for well pads, pipelines, access roads and compressor stations.[i] The only outstanding question is how significant the impacts are likely to be. The answers depend in part on factors such as the anticipated number and location of wells in likely development scenarios — information that the proponent has not yet disclosed.

Changes in the groundwater regime, by contrast, are much more difficult to predict. Early evidence suggests that the Headwaters region has all the ingredients required for impacts to be significant.[ii] But in this case, many fundamental questions remain. In particular, far more scientific information — about the hydrogeology, salmon ecology and bathymetry of the Headwaters region — is needed before the risks can be fully understood.

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[i] Cleared land absorbs less rainwater and melting snow, which means that more runoff flows into streams, often with greater force, increasing the extent of erosion and the amount of sediment carried into waterways.

[ii] Groundwater that enters streams can be critical to salmon survival. In particular, it acts a temperature and flow rate buffer, reducing the severity of impacts from natural and manmade disturbances, and increasing the overall resiliency of salmon ecosystems.

The difficulty is that these two threats to salmon are unlikely to be systematically studied and evaluated under existing British Columbia government regulations for CBM. *Coalbed Methane and Salmon: Assessing the Risks* concludes that, "given the sensitivity of salmon to disturbance in their critical habitats, it is fully possible that impacts cannot be mitigated within acceptable limits." Currently, the project approvals process does not provide an opportunity for affected communities to set limits on acceptable ecological or social impacts and measure a CBM proposal against these standards.

Instead, once development is underway, each successive stage — exploration, pilot production, full-scale development — helps to justify the next, without due consideration of cumulative effects. As infrastructure gets built on the ground, it becomes more and more difficult to address the key question about CBM: given that the impacts may be significant, are communities informed and willing to accept the risks?

Coalbed Methane and Salmon: Assessing the Risks clearly shows that much more research is needed before communities in the Skeena, Stikine and Nass watersheds can make an informed decision about whether or not they support development in the Headwaters region. Allowing CBM activities to proceed in the meantime would undermine their choice. Building new roads, pipelines and wells in this relatively pristine area — even gradually — would begin to create risks that communities may ultimately decide are unacceptable.

In order to address these and other concerns, the government needs to implement effective regulations that acknowledge the unique and often unprecedented impacts associated with CBM. As pressure increases for new oil and gas development across the province, the need for such regulations will only become more urgent.

The Pembina Institute recommends that at a minimum, new regulations respect three principles:[iii]

1. Coalbed methane development should not occur without social license. Communities need to be empowered to decide whether or not they support CBM extraction in their area before development proceeds.
2. Coalbed methane projects should be assessed as large-scale projects at an early stage. CBM resources are typically developed in full with hundreds or thousands of wells — or not at all — so the impacts of commercial-scale scenarios need to be considered from the outset.
3. Some areas may be too environmentally sensitive for coalbed methane development. In remote and pristine environments, the appropriateness of CBM extraction needs to be evaluated based on commercial-scale scenarios, *before* any impacts occur on the ground.

This spring, the British Columbia government showed tremendous leadership by implementing a carbon tax that will reduce the province's demand for fossil fuels and reduce greenhouse gas pollution. It was a visionary step and an important start on the path to a more sustainable future.

Similar leadership and vision needs to be brought to bear on growing concerns about oil and gas development across northern British Columbia, which could have significant impacts on the

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[iii] A backgrounder outlining the need for new CBM regulations in British Columbia, *Concerns About British Columbia's Approach to Coalbed Methane Development*, can be downloaded from http://www.pembina.org/pub/1628. The fact sheet *Coalbed Methane and Salmon: Trial or Error?* fully outlines key principles that should be included in effective CBM regulations. It can be downloaded from http://www.pembina.org/pub/1634.

province’s land, water, wildlife and salmon. Developing effective CBM regulations, and disallowing high-risk activities until these regulations are in place, is an essential first step.

Jaisel Vadgama

The Pembina Institute

May 2008

Executive Summary

GW Solutions Inc. (GW Solutions) was commissioned by the Pembina Institute to prepare a preliminary assessment of potential impacts on salmon and salmon habitat of coalbed methane (CBM) development. The focus was specifically on a tenure held by Shell Canada Limited (Shell) in the Klappan region of Northwest British Columbia (the Shell Tenure).

The Shell Tenure covers an area about one-eighth the size of Vancouver Island and includes the upper headwaters of three major salmon-bearing rivers — the Stikine, Skeena and Nass — as well as some of their tributaries.

Currently, there is no commercial production of CBM anywhere in British Columbia. In North America, the majority of existing CBM operations are found in areas with hydrological, geological, topographical and ecological conditions that are very different from those in the northwest part of the province.

Specifically, throughout the rest of the continent there are no known commercial CBM operations in remote, alpine and subalpine regions or in salmon-bearing watersheds. As a result, relevant empirical information about the relationships between CBM production and salmon health does not exist.

The present analysis was designed as a first effort to identify whether there may be issues of concern. The study delivers four unique findings.

First, field research confirms that salmon spawning areas exist in the upper Skeena and various tributaries within the Shell Tenure. Coho, sockeye and chinook salmon are present, as are steelhead.

Second, existing scientific knowledge combined with basic modelling suggests that there are several pathways by which CBM production could have impacts on salmon and salmon habitat in the Shell Tenure. These include

- reductions in water quality and damage to stream beds due to erosion and soil mobilization, triggered by cumulative development of surface infrastructure (such as roads, pipelines and compressor and well pads);
- changes in the wetted area, flow and temperature of streams due to complex changes in the interaction between groundwater and surface water, triggered by groundwater removal during CBM extraction.

Third, the types of information needed to describe with greater certainty likely impacts of CBM on salmon and salmon habitat, as well as to quantify key indicators, are almost universally missing. These include information about the hydrology, hydrogeology, biology and ecology of the Shell Tenure, as well as detailed build-out plans for Shell's CBM development proposal.

Fourth, in addition to uncertainties caused by data gaps, there are a series of uncertainties beyond the current mitigation requirements of proponents or regulators of the Klappan CBM project. These include potential environmental stresses resulting from climate change, and cumulative impacts resulting from multiple resource developments in any of the affected watersheds. Current provincial regulations do not systematically address the cumulative impacts of multiple CBM wells in a single tenure, let alone the impacts of multiple, adjacent energy developments in a watershed.

This report concludes that further, detailed investigations are essential to determine whether mitigation of impacts will be required and, if so, feasible to implement. Given the sensitivity of salmon to disturbance in their critical habitats, it is fully possible that impacts cannot be mitigated within acceptable limits. This can only be confirmed with additional research.

Coalbed Methane and Salmon

Assessing the Risks

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1. Introduction

1.1 Objectives

This study aims to provide a preliminary assessment of the potential risks and pathways of impacts on salmon and salmon habitat arising from coalbed methane (CBM) development in the Klappan Coalbed Gas Tenure in Northwest British Columbia, held by Shell Canada Limited (Shell).

The use of CBM as an energy source is recent, with commercial production having become established only over the last two to three decades. In North America, the largest CBM operations are in a number of western U.S. states (including Wyoming and Colorado); over the last few years some commercial CBM operations have also been established in Alberta.

Relative to conventional gas development, CBM can be notably intensive in terms of its land footprint and effects on water. Concerns about these and other observed environmental impacts associated with CBM production are difficult to translate directly to the Shell Tenure; this Canadian region is topographically, ecologically, geologically and climatically different from areas in the U.S. with the longest history of CBM operations.

On the other hand, many of the characteristics that distinguish the Shell Tenure are precisely the kind of qualities that could increase its susceptibility to impacts. In particular, the tenure is located

— in a northern environment (with a cooler climate and higher humidity than other locations for CBM operations, such as in Alberta);
— in a remote, relatively pristine area where human presence and industrial activity has been limited to date;
— on uninterrupted habitat for grizzly bear and caribou;
— at the headwaters of three of British Columbia's major salmon rivers — the Stikine, the Nass and the Skeena.

Despite numerous potential concerns associated with CBM development in the Shell Tenure, this report is focused solely on the possible impacts on salmon.

It is widely known that the Skeena, Nass and Stikine rivers are three of British Columbia's most productive salmon-bearing rivers and host important commercial and non-commercial fisheries. However, given that CBM has never occurred anywhere in watersheds of salmon-bearing rivers, there are no background references to help understand potential impacts, and certainly no information specific to the Klappan region.

1.2 Scope and Methodology

This study first established that salmon are found in the tenure area on the upper reaches of the Skeena River and some of its tributaries, and on a tributary of the Nass River. Coho, sockeye and chinook salmon are present, as are steelhead (see section 3.3 for more detailed information).

Initial scoping then identified two potential impacts of CBM as having particular significance:
— impacts on stream quality and spawning habitat due to erosion caused by land disturbance
— impacts on stream flow and stream temperature as a result of groundwater extraction

The two issues have very different profiles.

The first issue — erosion effects arising from land disturbance — is relatively well understood. Increased sediment transport to streams is encountered in the context of many different kinds of infrastructure development, and is known to be potentially harmful to fish. CBM is also well known to generate a large land footprint relative to other kinds of oil and gas development due to a high density of wells, pipelines and roads. Based on what we know from past experience, it is highly likely that erosion effects will be seen in the Klappan. As such, the question is not about whether significant impacts will occur, but to what extent.

In contrast, the second issue — stream flow effects arising from groundwater extraction — is relatively poorly understood. Impacts depend on the relative presence of several complex, localized conditions. These include

- connections between deep aquifers and shallow aquifers
- high rates of groundwater upwelling from shallow aquifers to streams
- salmon sensitivity to changes in the amount of groundwater present in streams and lakes

All of these conditions are known to exist, although not always together, in other locations. There are also preliminary indications — and no definitive evidence to the contrary — that all three may be present in the Klappan Tenure. If so, the effects on salmon could be highly significant. Here, the question of whether or not impacts are likely is as yet unanswered, and critically important.

In light of this scoping analysis, the study initially aimed to model land disturbance and groundwater withdrawal under a likely development (build-out) scenario for the tenure, in the first case to determine the extent of impacts, and in the second to determine both likelihood and extent. However, it was quickly found that none of the necessary data inputs were available for comprehensive modelling.

Given these data limitations, the study focused on describing impact pathways, and on analyzing existing information that could provide preliminary, partial assessments of impacts. In addition, the study identified the key pieces of scientific information that would be necessary to make more robust and complete assessments of risk.

1.3 Report Outline

Findings are organized in the report as follows:

Chapter 2 provides a general overview of the CBM extraction process (Section 2.1) and of environmental impacts typically associated with commercial-scale production (Section 2.2).

Chapter 3 provides a brief introduction to the Klappan Tenure, describing its location and geology, and the significance of its CBM reserves (sections 3.1 and 3.2). The chapter also addresses the question of salmon presence within the tenure, drawing on existing field research to identify streams where coho, chinook and sockeye salmon have been observed (Section 3.3). These data, obtained from a variety of sources, are compiled for the first time in this report.

Chapters 4 and 5 contain assessments of potential risks associated with the two primary impact pathways, respectively: runoff and erosion effects arising from land disturbance, and stream flow and temperature effects arising from groundwater extraction. Each chapter first considers conceptual impact models, then addresses conditions specific to the Klappan Tenure.

Chapter 6 provides a brief overview of additional CBM-related impacts which could have indirect effects on salmon.

Chapter 7 considers factors external to the Klappan project which could nonetheless influence the nature and severity of impacts on salmon. These include climate change (Section 7.1), inadequate regulations (Section 7.2), and cumulative impacts (Section 7.3).

Chapter 8 provides a résumé of the report's conclusions and identifies priorities for additional research needed to better understand the risks identified in this preliminary analysis.

1.4 Acknowledgements

This report was produced with input from LGL Limited (LGL). LGL applied expertise in biology and ecology to sections dealing with impacts on salmon and salmon habitat.

GW Solutions thanks Professor Jack Stanford, Tom Bansak and Erin Sexton from the University of Montana for their input and review, Pembina Institute staff for their collaboration, and numerous people who, through an e-mail, photograph or conversation, provided information and contributed to this work.

2. Coalbed Methane

CBM, also known as coalbed gas, is a natural gas found in coal seams. Its extraction involves technologies and impacts that differ from those of conventional gas drilling. To date, commercial production in North America has been limited to a number of U.S. states and Alberta. In Alberta, the number of CBM wells has increased rapidly over the last few years — from 20 in 2000 to more than 10,000 today. In British Columbia, exploration wells have been drilled, however there is no commercial production in the province.

2.1 Extraction Technology

CBM molecules are held in the cleats (small fractures) and micropores of coal seams at depths ranging from 100 metres (m) to deeper than 1,000 m. When the seams are "wet" (containing water) the adsorption of methane to coal is enhanced by hydrostatic water pressure in the coalbed (Figure 1a). In these cases, producing gas requires water to be pumped from the coalbed. As water is removed, hydrostatic pressure drops, allowing the methane to be released from the cleats and pores of the seam (Figure 2). The methane then migrates into the water stream, where it eventually separates from the water (Figure 1b).

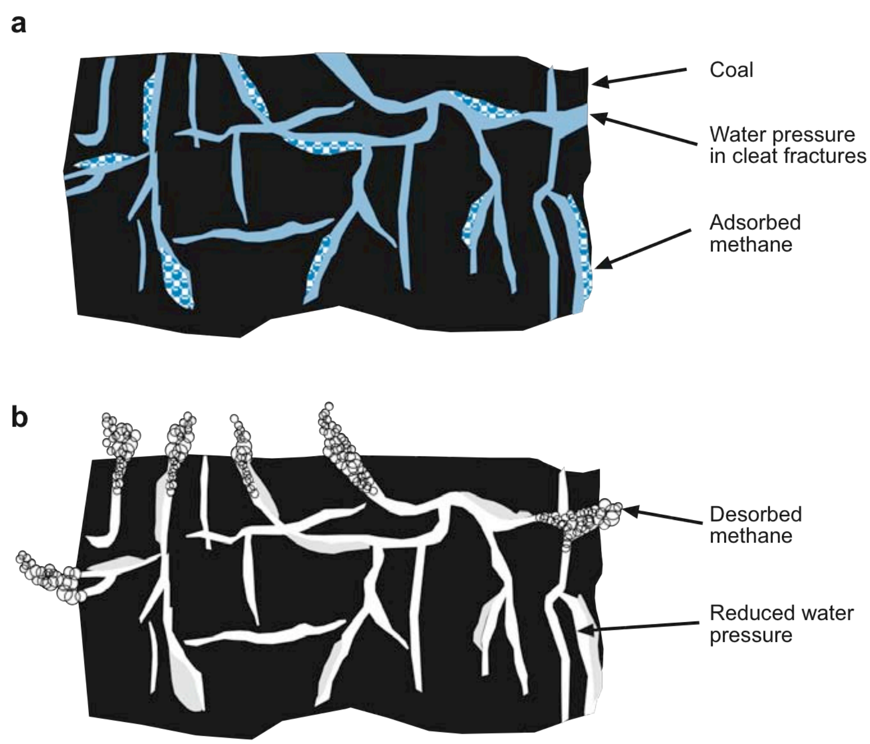

Figure 1: (a) CBM adsorption in coal seams and (b) desorption as a result of water removal (Wheaton and Donato, 2004; Law and Rice, 1993; Rightmire et al., 1984)

The goal of reducing hydrostatic pressure is accomplished by drilling wells that remove groundwater from target seams (Figure 3). This may mean drilling through several layers of rock as coal seams are generally sandwiched between other rock formations. (In the case of the Shell Tenure, other formations include siltstone, sandstone and conglomerate; see section 3.2 for details).

Figure 2: CBM desorption from a piece of coal

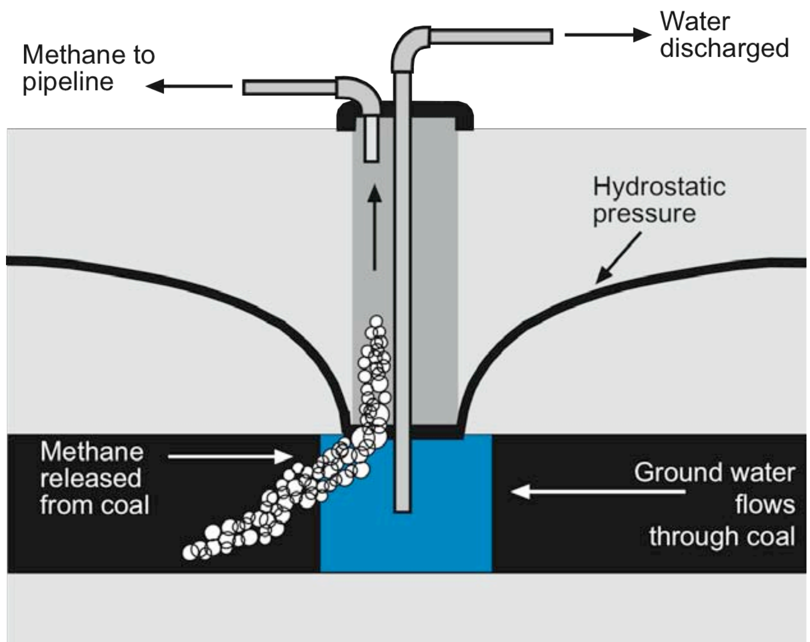

Figure 3: CBM and water production through a CBM well (Wheaton and Donato, 2004)

CBM wells targeting wet seams will primarily extract groundwater in their initial phase of operation. (This produced water can have vastly varying levels of salinity and heavy metal content depending on local conditions.) Over time, as methane bubbles desorb and gradually fill fractures in the seam, the mixture of fluids flowing through a well will contain more methane and less groundwater. At a certain point, the well will reach an optimum economic phase with a high rate of methane extraction. Finally, after several years of operation, the most readily removable methane will have been extracted and the CBM well will no longer be profitable to operate. At this stage, the well will normally be terminated by capping. Figure 4 provides a schematic showing the relationship of water and methane extraction rates over time for a typical CBM well.

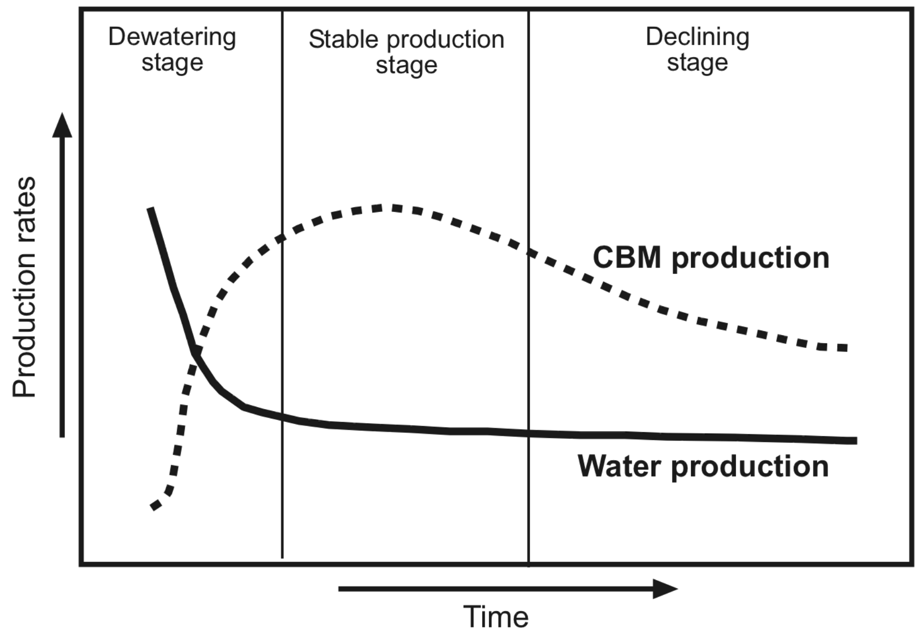

Figure 4: Production stages of a typical CBM well (Wheaton and Donato, 2004)

Greater efficiency in reducing water pressure in coalbeds is often achieved by completing wells in grid patterns, so that pressures are reduced over a larger area. However, the density of wells and well pads varies substantially. For example, if the CBM is deep it may be possible to drill several wells from one well pad. (In parts of Alberta where CBM is particularly deep, one well can reach an area upwards of 1,200 acres.) In the U.S., typical spacing is one well per 320, 160 or 80 acres. In addition to wells, CBM extraction requires a network of well pads, roads and pipelines.

2.2 Potential Environmental Impacts

Given the potential for producing water, and the often high density of wells, CBM development is commonly associated with more intensive environmental impacts than conventional gas development.

Figure 5 provides an overview of environmental effects that have historically been associated with CBM extraction, drawing largely on experience in the U.S. (The figure is not meant to imply that all effects have been observed at a single site.) Although some of these impacts may be expected in the Shell Tenure, the unique geography and ecology of the region suggest that the total impact profile may be very different from existing profiles. Aspects relevant to salmon are discussed in further detail in subsequent chapters.

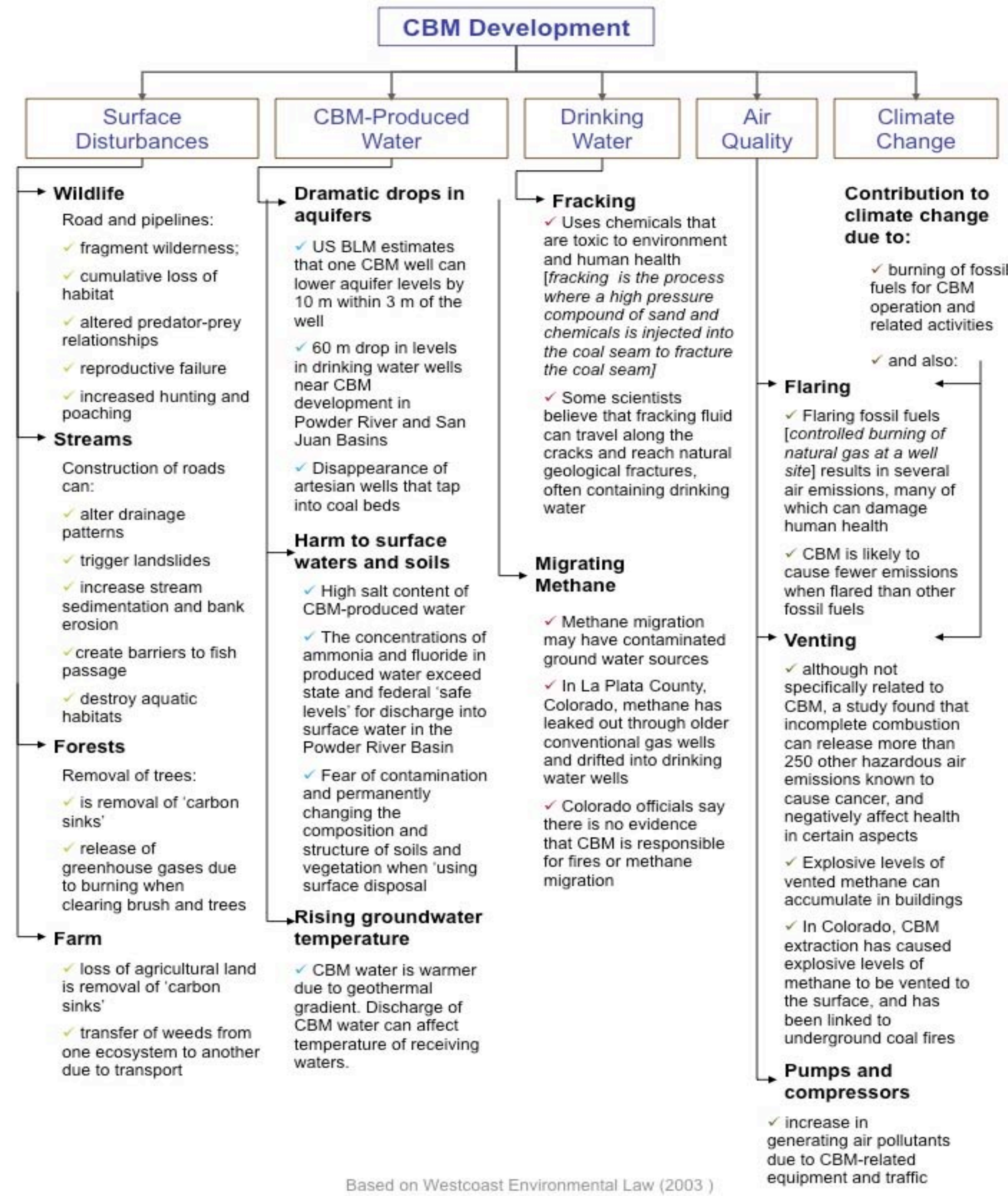

Figure 5: Overview of potential environmental impacts from CBM development and operations (Westcoast Environmental Law, 2003)

3. Local Context

This study is intended to examine specifically how CBM development in the Shell Tenure could lead to adverse impacts on salmon and salmon habitat.

However, very little quantitative information is available to describe the geology, hydrology or ecology of the Shell Tenure area. In part, this is because few resource developments have occurred in the region; as a result, few commercially driven studies (such as hydrological surveys) are on record.

In addition, very little is known from the proponent about likely scenarios for extraction infrastructure, such as the number and location of wells, roads and pipelines. The mountainous terrain is also a complicating factor because the grid patterns used to site CBM wells in other locations are likely inappropriate here. It is not known, for example, whether wells would be concentrated in flatter, more accessible areas such as valley bottoms.

Assumptions, scenarios and conceptual models that have been adopted where detailed information is unavailable are described as part of the specific analyses on land disturbance and groundwater extraction (chapters 4 and 5).

The bulk of this chapter (sections 3.1 and 3.2) provides a high-level overview of the location, resource significance and geology of the tenure area. The final section, 3.3, compiles observations confirming that salmon are found in the tenure area in tributaries of the Skeena River. Previously, this information was not widely known, and had not been systematically documented.

3.1 Location and Significance

The Shell Tenure is located in Northwest British Columbia, approximately 250 kilometres (km) northwest of Smithers, and 100 km southeast of the Tahltan community of Iskut. Tenure was initially granted to an area of 412,000 hectares (ha) — about one eighth the size of Vancouver Island — although isolated pockets of land (primarily on steep terrain) have since been excluded. Tenure rights now extend over an area of about 330,000 ha within the boundaries of the original grant.

The headwaters of three major salmon-bearing rivers, the Stikine, the Nass and the Skeena, are all located within the Shell Tenure, sometimes referred to as the “Sacred Headwaters” region (see Figure 6). The tenure overlaps with the traditional territory of the Tahltan Nation.

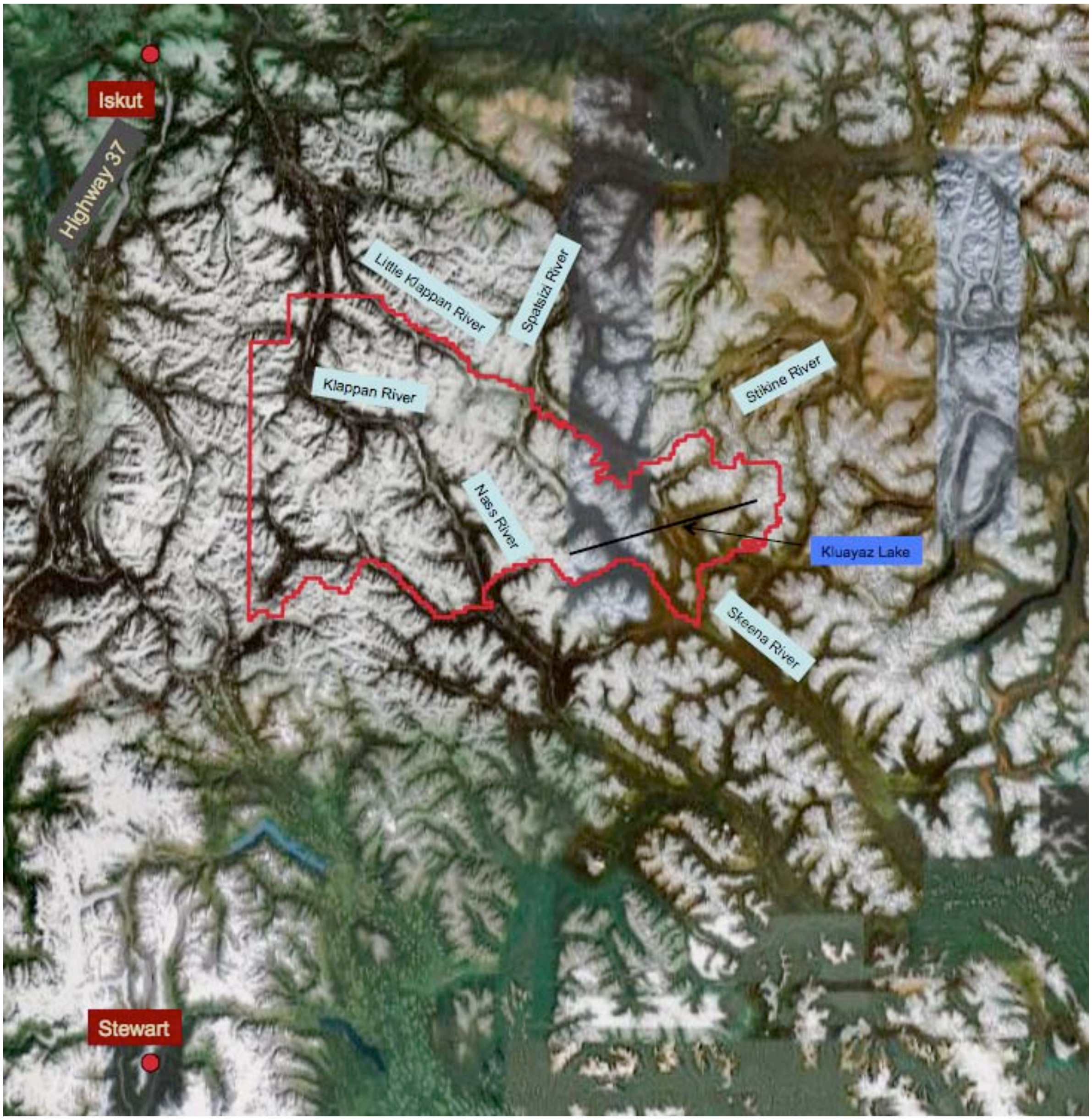

Figure 6: Headwaters of the Nass River, the Skeena River and the Stikine River within the boundaries of the Shell Tenure (in red)

The tenure overlays large portions of the Klappan and Groundhog coalfields (see Figure 7), which are situated within a geological formation called the Bowser Basin (outlined in yellow in Figure 7). According to the Geological Survey of Canada and the British Columbia Ministry of Energy, Mines and Petroleum Resources (MEMPR)[1], the Klappan and Groundhog coalfields (see Figure 8) together contain about eight trillion cubic feet (Tcf) of methane.[2] According to MEMPR, this CBM potential is roughly 9% of British Columbia's total (see Figure 9). Not all of the methane can be commercially extracted.

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[1] Note that MEMPR, the B.C. Ministry of Energy, Mines and Petroleum Resources, was previously known as BCMEM, the B.C. Ministry of Energy and Mines. Both appellations are used in data references, depending on the date of publication.

[2] One Tcf is about enough gas to heat one million homes in Canada for 13 years.

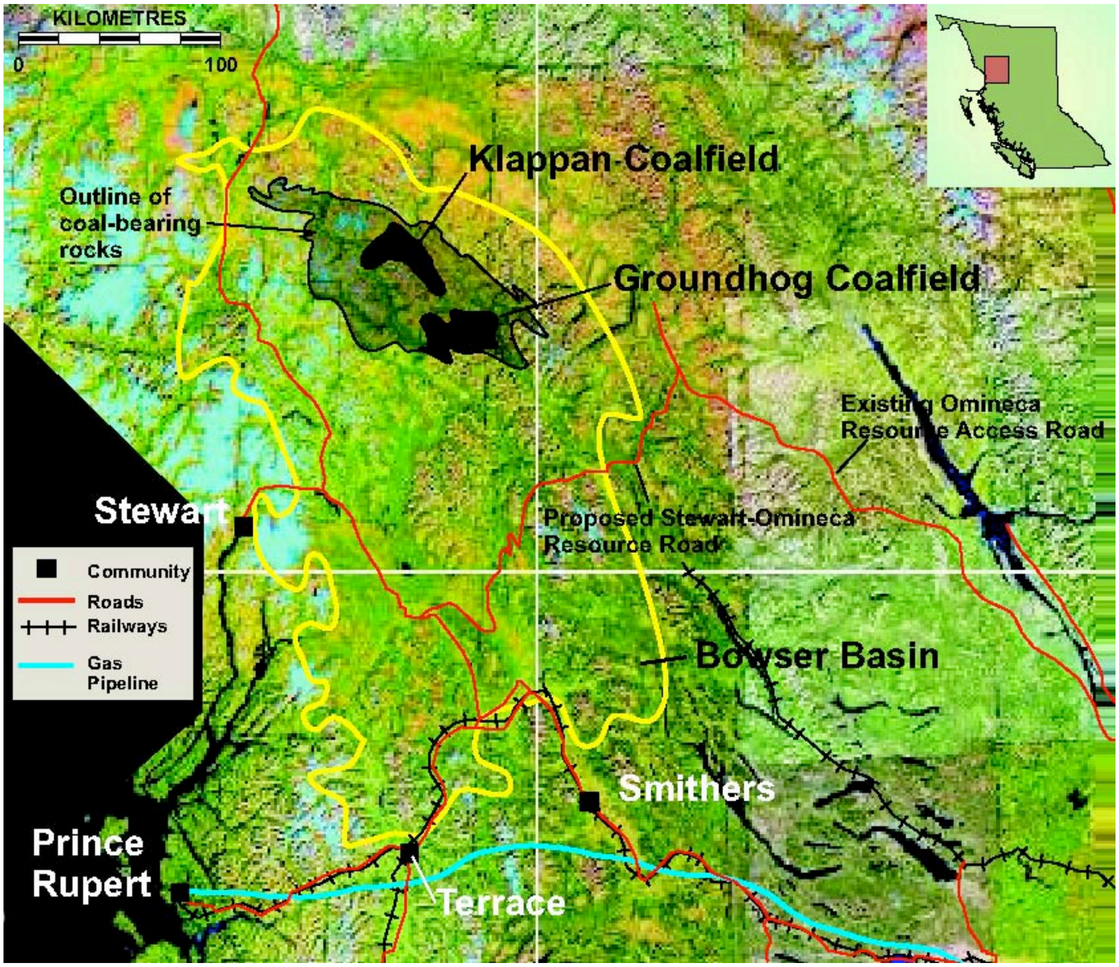

Figure 7: Location of the Klappan and Groundhog coalfields (BC Ministry of Energy and Mines, 2004)

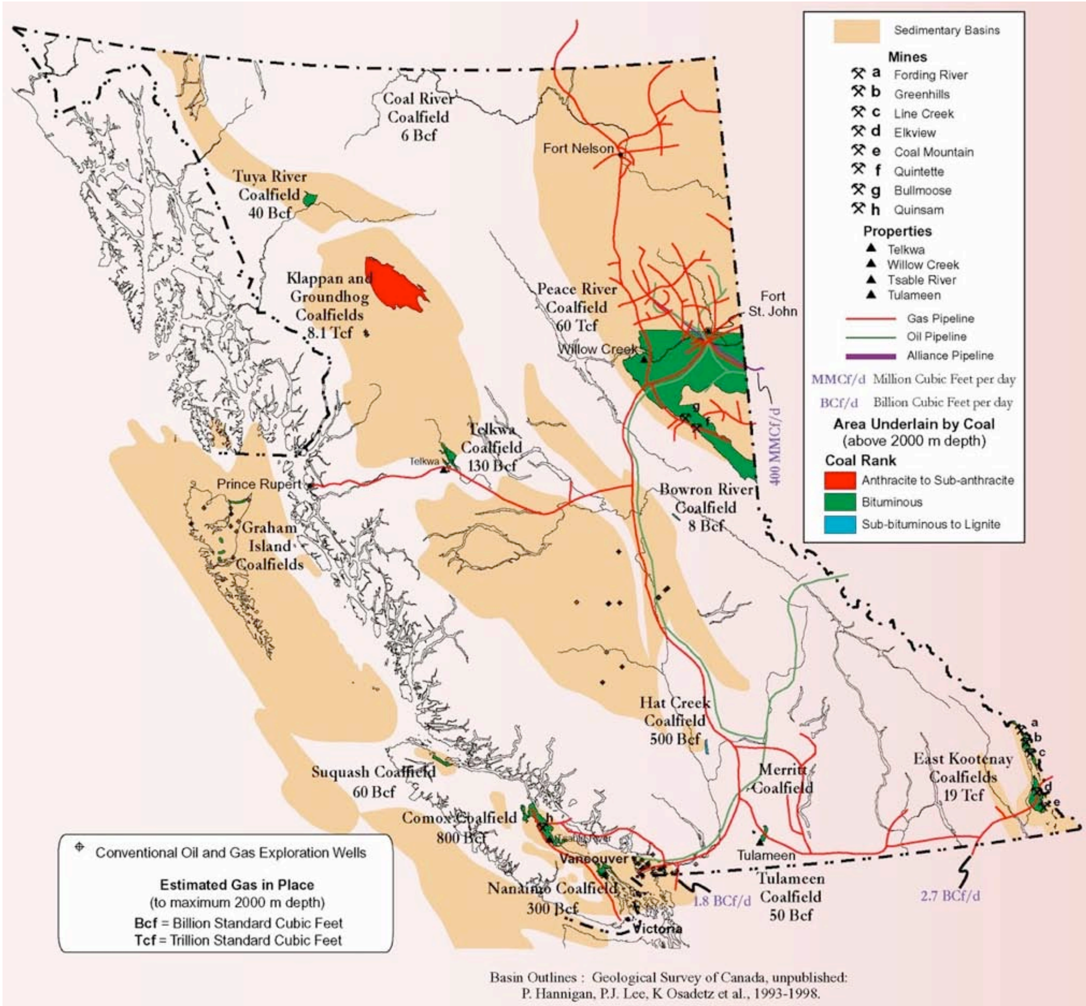

Figure 8: Coalfields and CBM potential in British Columbia (BC Ministry of Energy, Mines and Petroleum Resources)

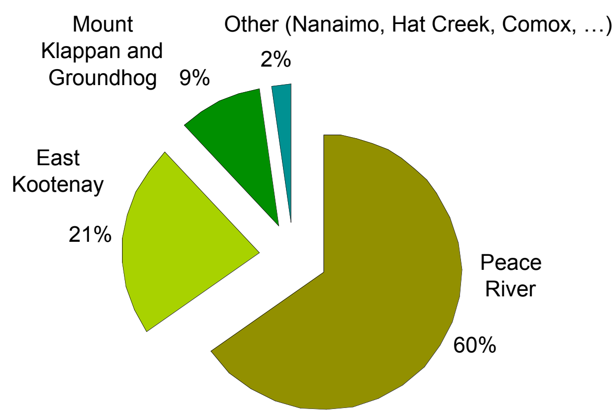

Figure 9: Distribution of CBM in major British Columbia reserves (based on data from Dogwood Initiative, 2004)

3.2 Geology

Coal seams typically occur at varying depths ranging from near the surface to more than 1,000 m deep. The number of seams and their thickness, in addition to hydrostratic pressure, coal rank and the presence of fractures or cleats, determine the CBM potential of each coal layer.

In the Klappan area, coal is contained in the Jura-Cretaceous Currier Formation, which is up to 1,100 m thick and contains up to 25 seams, which can each be up to 7 m thick. The stratigraphic column is also characterized by layers of mudstone, siltstone, sandstone, conglomerate and bentonite. The area is extensively folded with the regional structure dominated by a northwest trending synclinorium (BCMEM 2004).

Coal layers in the Klappan region are ranked as anthracite (semi-anthracite to meta-anthracite). Preliminary analysis from a sample drill core from the region and experience from other anthracite coal deposits suggest that gas recovery could occur at shallow depths of about 150 m down to more profound depths of about 1,400 m (BCMEM 2004).

Figures 10 and 11 provide two stratigraphic columns for the area, one based on the Groundhog coalfield, the other on the Klappan coalfield.

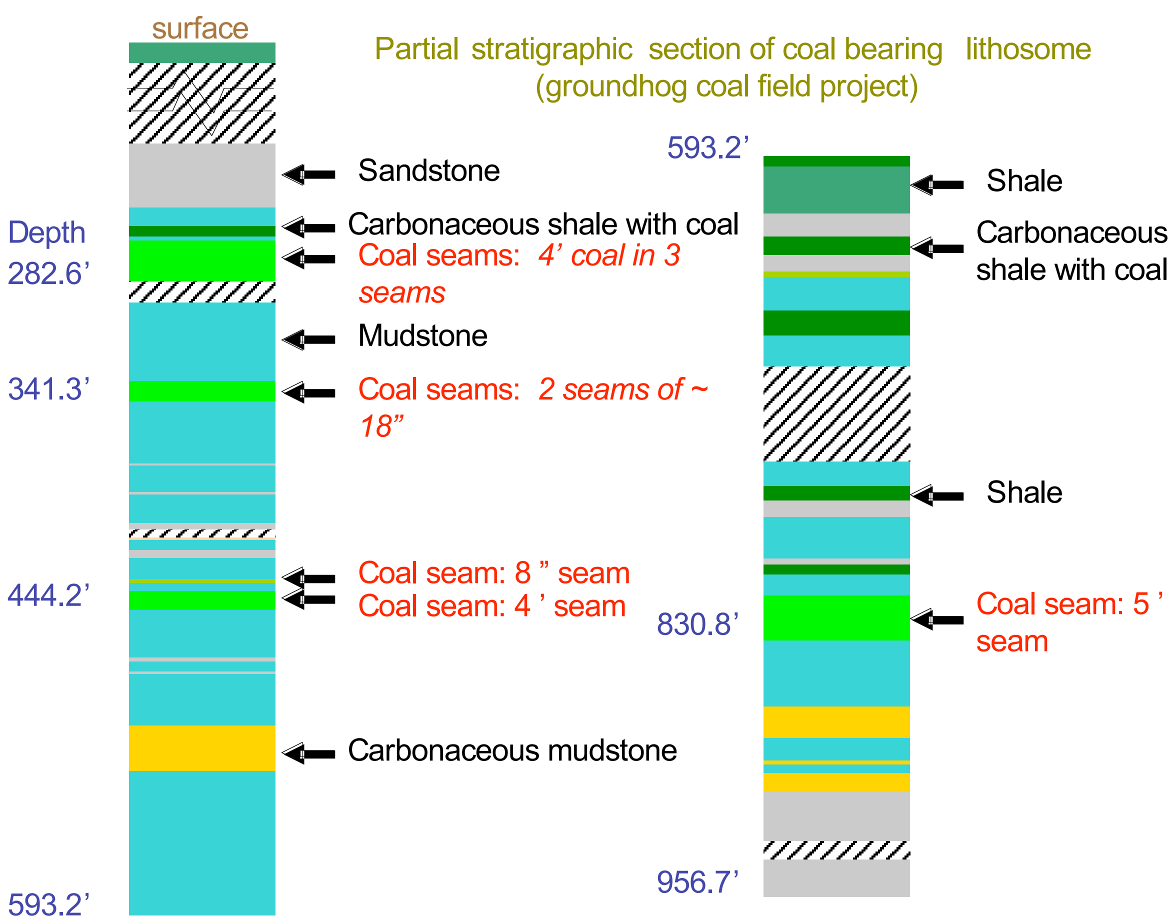

Figure 10: Representative stratigraphic column based on Groundhog stratigraphic information by Tompson et al., 1970

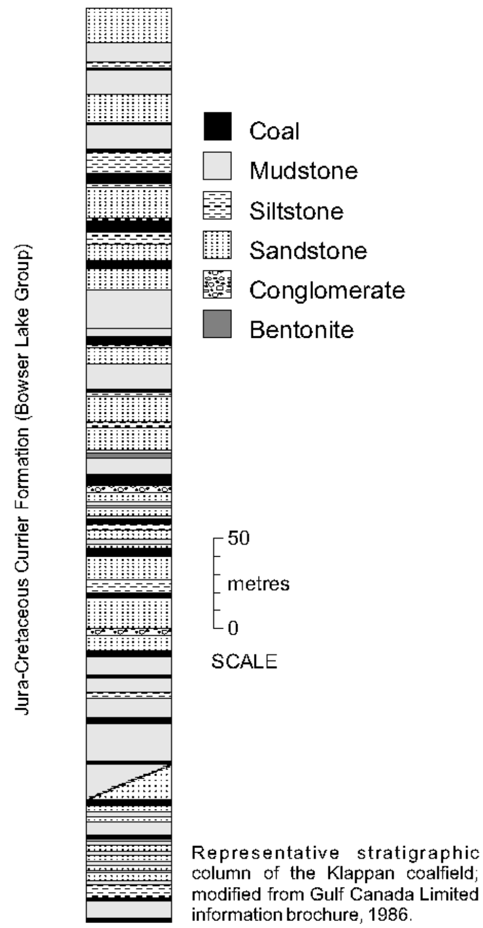

Figure 11: Representative stratigraphic column of the Klappan coalfield (from BCMEM, 2004)

3.3 Salmon- and Trout-bearing Streams within the Shell Tenure

Although the Skeena, Nass and Stikine are well known as productive salmon rivers, the presence of salmon at their headwaters has not been systematically studied. Existing data comes from disparate and varied sources, and is often based on preliminary or ad hoc field research.

It is, however, possible to confirm that salmon and steelhead are found in the mainstem Skeena, in tributaries of the Skeena and in one tributary of the Nass, within the Shell Tenure. Three species of salmon are found: coho (*Oncorhynchus kisutch*), sockeye (*Oncorhynchus nerka*), and chinook (*Oncorhynchus tshawytscha*). The majority of salmon observed in the tenure were in their juvenile stages.

There are also indications that many streams in the area could provide favourable habitat for salmon and steelhead. For example, Otsi Creek in the Skeena watershed has been described as offering excellent spawning gravel and rearing habitat over a stretch of several kilometres. Additional research is needed to better characterize salmon presence and preferred habitat within the area.

3.3.1 Skeena Watershed

Salmon have been observed in streams in the Kluatantan watershed (WC:400-898600-27000). In Kluayaz Creek (WC:400-898600-36400), upstream and downstream of Kluayaz Lake, and in Kluayaz Lake itself, sockeye salmon, chinook salmon and steelhead have been observed spawning and rearing (Rabnet, 2007; Baxter, 1997b; Hancock, 1983). In Kluayaz Lake sockeye have been observed to beach spawn. Year-round presence of juveniles of all three species can be assumed.

In Tantan Creek (WC:400-898600-20900), upstream and downstream of Kluatantan lakes (same WC as Tantan Creek), and in Kluatantan Lake itself, sockeye, chinook and steelhead have been observed to spawn, rear and overwinter (Baxter, 1997; Hancock, 1983). Once again, year-round presence of all three species can be assumed.

In addition to the species found in the Kluatantan tributaries, juvenile coho of two age classes have been observed in the Kluatantan mainstem (Bustard, 1975).

According to Baxter (1997b), steelhead also enter the Kluatantan River from early September on and it is unknown when the in-migration stops. Juvenile Kluatantan steelhead remain in their homestream for four to five years before they undergo parr-smolt-transformation and out-migrate to the ocean (Baxter, 1997b).

Juvenile chinook (LGL, 1984) have been observed in Otsi Creek and in the mainstem Skeena at the confluence with Otsi Creek. Coho salmon were observed in 1975 by Dave Bustard but have not been seen since.[3]

All three salmon species are also found in the mainstem Skeena, since it provides the migration corridor to the above-mentioned tributaries. In addition, parts of the mainstem Skeena within the Shell Tenure are known to serve as rearing, and potentially spawning, habitat for chinook and coho salmon. These include locations above Currier Creek, below Otsi Creek and below Porky Creek (LGL 1984).

3.3.2 Nass Watershed

The upper reaches of the Bell Irving River just within the boundary of the Shell Tenure are known to support populations of chinook, coho and steelhead (Pedology, 1986; SKR Consultants Ltd., 1998), and a limit of upstream migration has not been identified for the Bell Irving River. Juvenile salmon have been observed a short distance upstream of Rochester Creek (Fisheries Information Summary System (FISS) database).

Figures 12 through 15 show locations of known salmon- and steelhead-bearing streams in the Shell Tenure, along with watershed boundaries, limits of the Klappan and Groundhog coalfields, and existing infrastructure.

[3] According to personal communication with Bustard, the fish may have been misidentified; they may have been juvenile chinook. The 1975 investigation by Bustard was intended to be a quick overview of the area and not a comprehensive fish inventory.

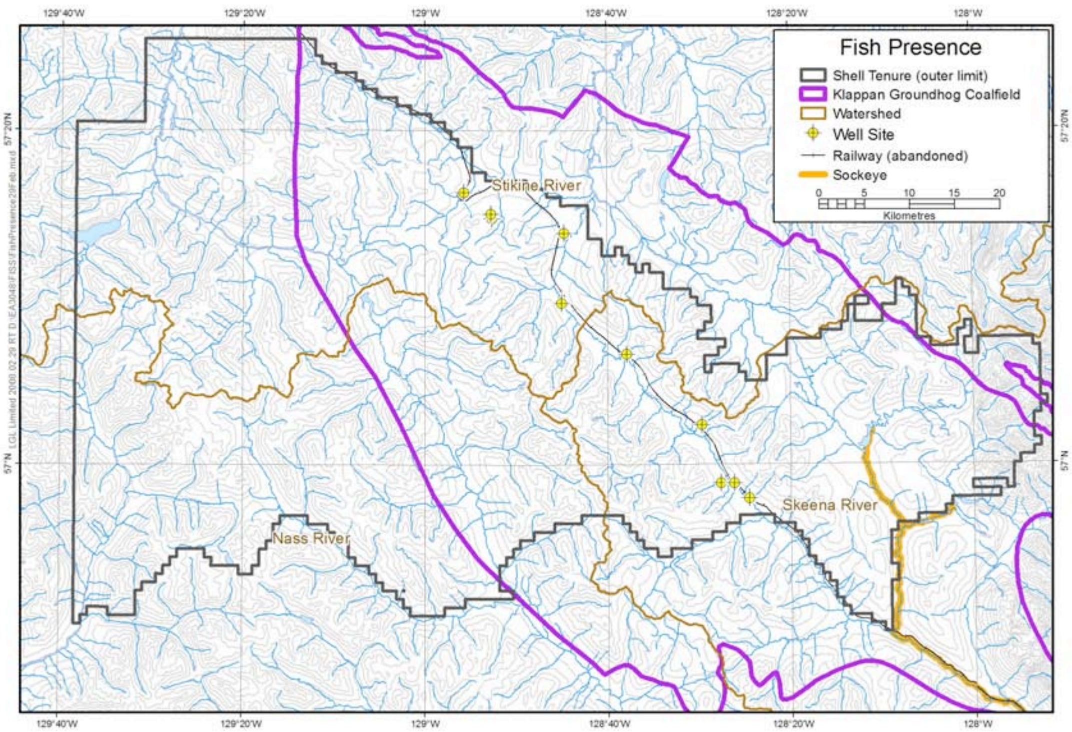

Figure 12: Sockeye presence within the Shell Tenure

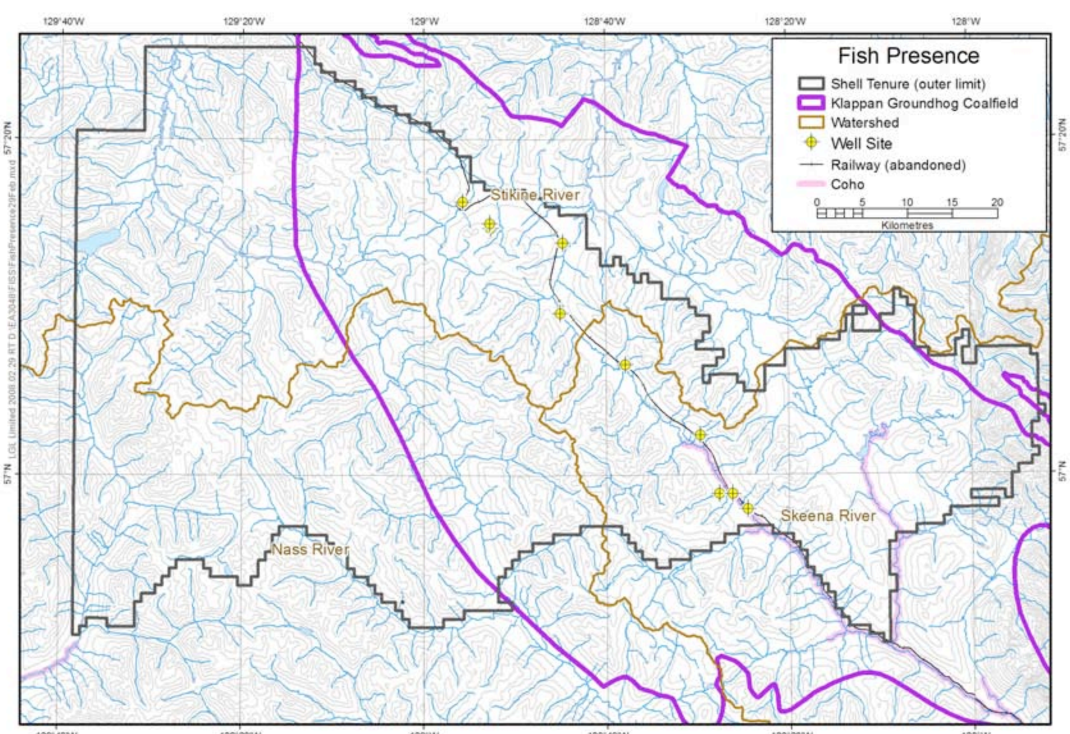

Figure 13: Coho presence within the Shell Tenure

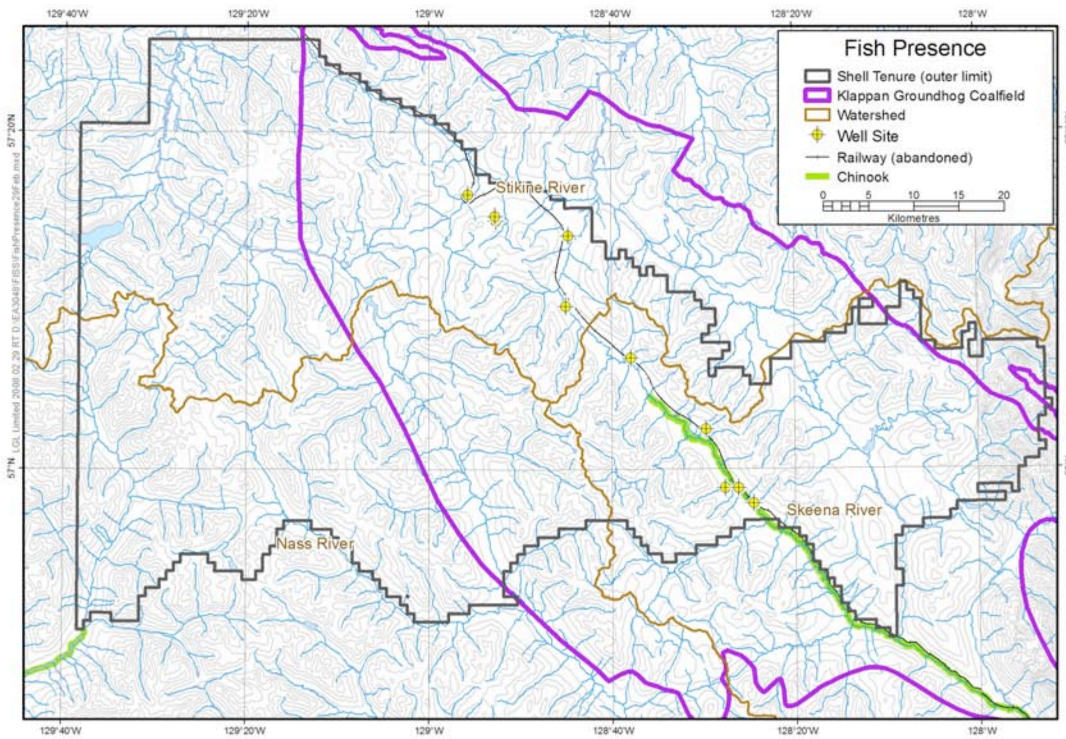

Figure 14: Chinook presence within the Shell Tenure

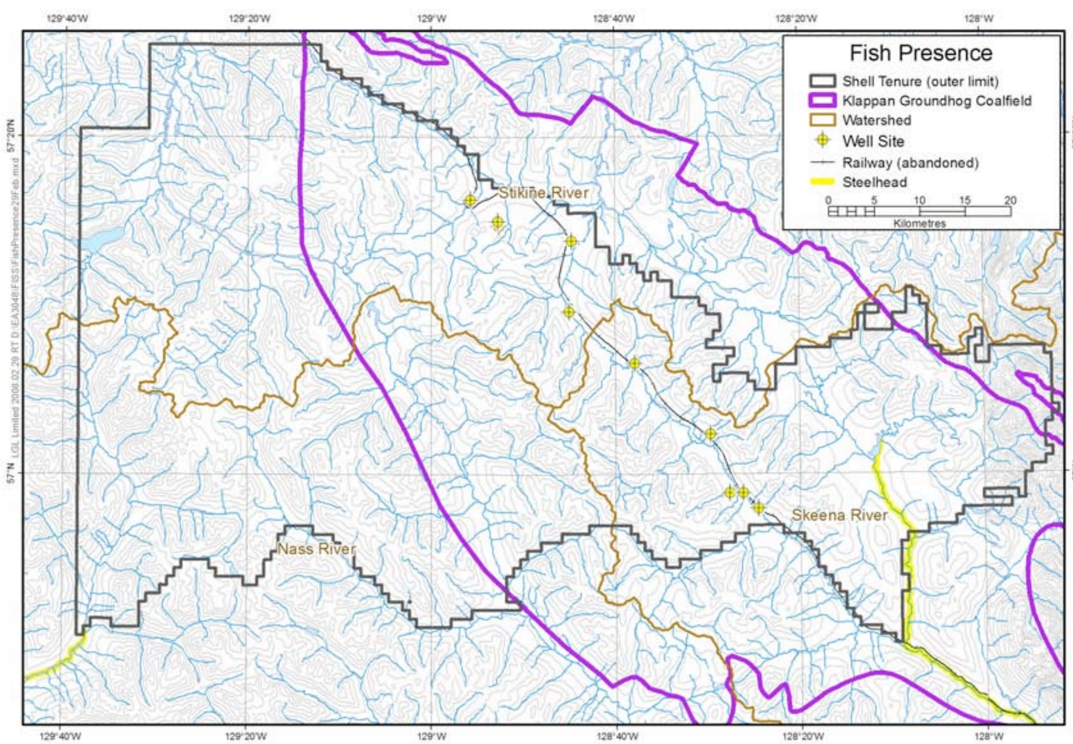

Figure 15: Steelhead presence within the Shell Tenure

Other species found in the tenure include bull trout char (*Salvelinus confluentus*), Dolly Varden char (*Salvelinus malma*) and mountain whitefish (*Prosopium williamsoni*). Char and whitefish were observed throughout the tenure area. In addition, Arctic grayling (*Thymallus arcticus*), Burbot (*Lotta lotta*) and Longnose sucker (*Catostomus catostomus*) were observed in the Spatsizi River (LGL, 1984).

4. Surface Disturbance, Runoff and Erosion

CBM development requires a network of infrastructure that changes land uses and land quality, especially in areas with relatively little industrial activity. For example, areas may be cleared for well pads, and road and pipeline right-of-ways, and to build other facilities, such as camps or compressor stations. Figure 16 shows land impacts from CBM development in the San Juan Basin, New Mexico.

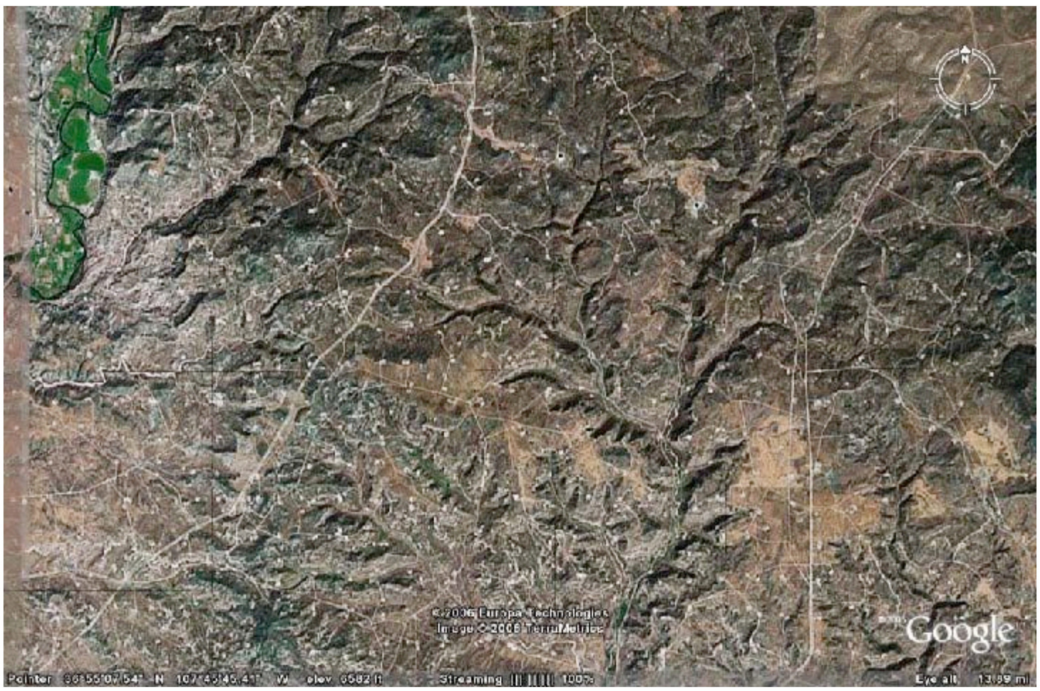

Figure 16: Satellite imagery showing a network of CBM well pads and access roads near the Blancett Ranch, San Juan Basin, New Mexico

4.1 Conceptual Model

As the impervious area in a watershed increases, so too does the runoff volume and the intensity of peak flow events (such as during rain storms). This is because water flows more rapidly over cleared surfaces, well-pads and roads, instead of soaking slowly into the ground. In turn, increased volumes of runoff and increased variation between high and low runoff rates can cause watercourse erosion and progressive degradation of stream quality, including an increase in stream turbidity and changes in the channel cross-section. Loss of riparian corridor integrity (i.e., surface disturbances on land immediately adjacent to streams) can aggravate these effects by reducing ecological buffering capacity.

The first two rows of Figure 17 illustrate the effects of an increase in impervious area on stream quality.

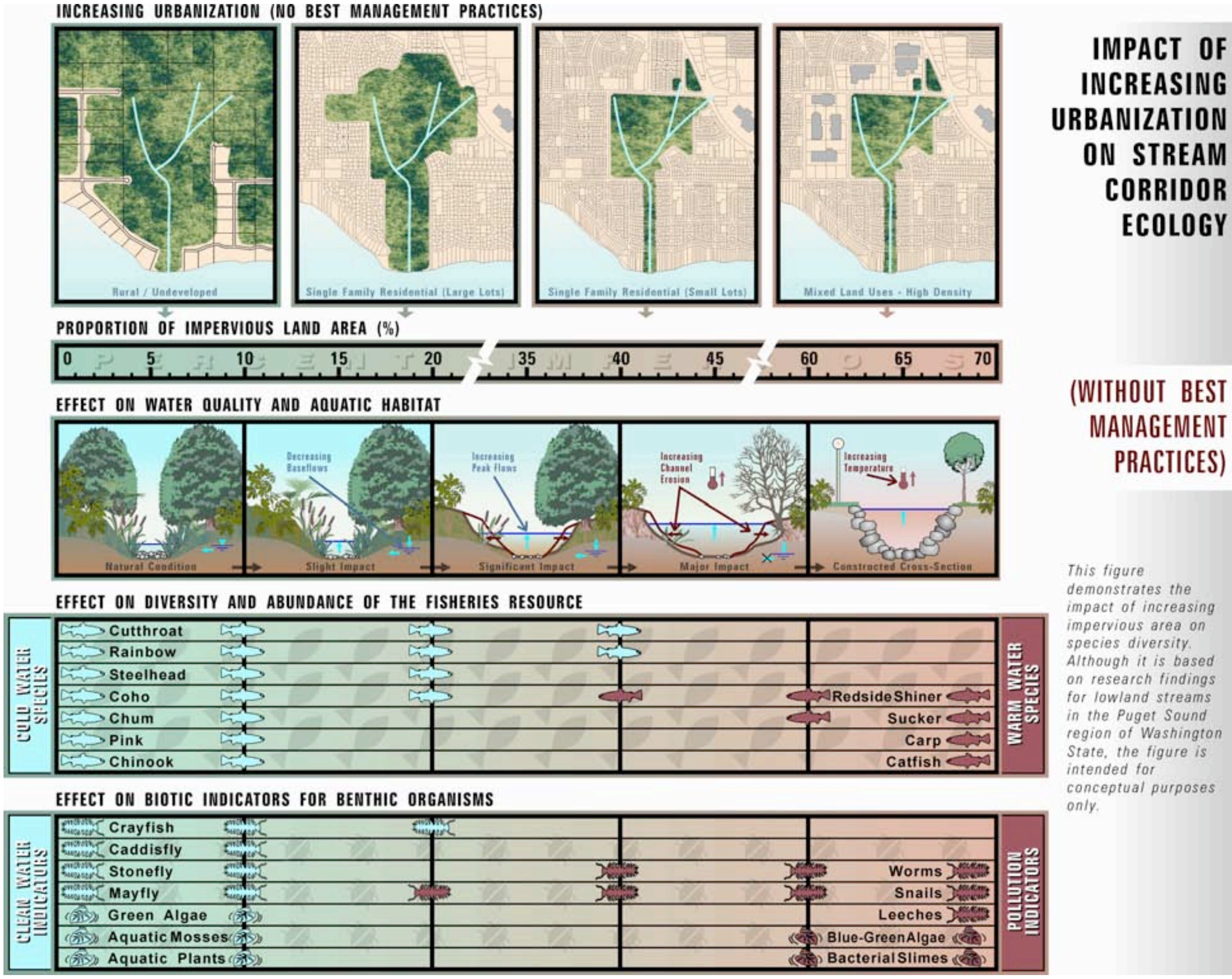

Figure 17: Impact of impermeable areas on stream corridor ecology (*Stormwater Planning: A Guidebook for British Columbia,* 2002)

In general, reductions in stream quality due to increased runoff can lead to a reduction in stream biodiversity, and in particular, to a reduced abundance of cold-water fish. The second two rows of Figure 17 illustrate the associated increases in the values of pollution indicators and reductions in the values of clear water indicators.

There are several mechanisms that explain the impacts of stream degradation on fish. Eroded material causes turbidity, or dirty water, that can irritate fish gills and make it difficult for fish to find food. Eroded sediments can cover spawning beds, smothering fish eggs and juvenile fish that reside in gravel, and reducing the extent of spawning, incubation or rearing habitat available to future generations. Surface disturbances associated with increased erosion can also lead to increases in noxious weed concentrations (Regele and Stark, 2000).

Some of these mechanisms have been studied in specific relation to salmon. For example, it is known that salmonid eggs, larvae and alevins can suffocate or be prevented from emerging following high levels of deposited sediment (Bilby et al., 1989). Juvenile coho salmon have been observed to avoid turbid water, or decrease feeding activity after extended exposure to turbidity (Bilby et al., 1989). Both impacts can lead to an increase in mortality rates.

4.2 Application to the Shell Tenure

The extent of erosion, degradation and stream silting depends on the amount and location of surface disturbance and impermeable areas as well as the effectiveness of mitigation measures. However, no information is currently available from Shell about likely build-out scenarios for the Shell Tenure (which would provide information about the number and location of wells, pipelines and roads etc.).

The analysis therefore uses a range of assumptions to achieve a preliminary, qualitative assessment of potential impacts in the Klappan, as well as to identify unique mitigating and/or exacerbating factors.

4.2.1 Calculation of Impermeable Area

Direct terrestrial disturbance (i.e., vegetation and land cleared or changed in order to make way for infrastructure) depends on the dimensions of cleared areas associated with well pads, roads, compressor stations and so on. For example, CBM well pads typically require clearings greater than 1 ha (about 2.5 acres), which is roughly the size of a baseball field. A road or trail 3 m wide crossing a section of land (a distance of about 1.6 km or 1 mile) creates a clearing of about 0.5 ha (about 1.2 acres).

Sexton (2002) uses empirical data from the Powder River, San Juan and Black Warrior Basins to estimate the total direct disturbance in an area due to CBM development. By combining this information with the number of wells drilled at each location, Sexton calculates an average amount of disturbance associated with one CBM well to be 1.62 ha. This average factor incorporates disturbance due to roads, utility and gas lines, well pads and compressor stations. In the present study, given the absence of project-specific information, Sexton's factor is used to estimate direct disturbance.

Indirect disturbance, which refers to cases where existing uses of land are diminished as a result of proximity to cleared or directly disturbed land, is much harder to estimate.[4] A key example of indirect disturbance is loss of habitat across a wide area, due to the presence of cut-lines and infrastructure within that area.

Sexton (2002) finds that wildlife displacement tends to occur across the entire area of a well field (a collection of adjacent wells), and within a zone about 0.8 km wide around the perimeter of the field. This means that indirect disturbance per well depends on the density of wells, and on the shape of the field. In the present study, a range of well field configurations is used to calculate a range of indirect disturbances estimates.

Table 1 summarizes estimates of direct and indirect disturbance that would be associated with a range of different development scenarios involving 200, 1,000, 2,000 and 5,000 wells.[5]

[4] Although indirect disturbance is not linked to runoff, erosion and stream degradation rates, it is relevant to ecosystem impacts, discussed in Chapter 6. Calculations of direct and indirect disturbance are combined in this chapter for ease of reference.

[5] These scenarios were chosen in the absence of documented build-out plans. At the lower end, CBM developments typically involve hundreds of wells; 200 wells are assumed here. At the higher end, 5,000 wells is estimated as slightly larger than a scenario where 40% of the 8 Tcf in total reserves is recovered; where individual well life is 20 years (although the field as a whole may be in place for longer); and where production averages 100,000 cubic feet per day per well. (This would require 4,400 wells.)

The analysis assumes a well density of four wells per section, equal to a placement of one well per 160 acres.[6] (In a grid configuration, this corresponds to a distance of about 800 m between wells.) Note that a spacing scenario of 800 m between wells was also the basis for a development model for the area presented in a document by the Geoscience Branch of the British Columbia Ministry of Energy and Mines (2004).

The MEMPR website currently indicates that wells may in fact occur at a higher density, eight per section. (In a grid pattern, this corresponds to a distance of about 565 m between wells.) In the U.S., CBM wells are typically drilled at a density of two, four or eight per section, although in a few cases they have been drilled at a density of 16 per section.

Table 1: Estimated direct and indirect disturbance of CBM development in the Shell Tenure

<table>
<tr><th colspan="2">Number of wells</th><th>0</th><th>200</th><th>1,000</th><th>2,000</th><th>5,000</th></tr>
<tr><td colspan="2">Configuration</td><td>n/a</td><td>1 field[a]</td><td>5 fields[a]</td><td>10 fields[a]</td><td>continuous[a]</td></tr>
<tr><td colspan="2">Direct disturbance
(% of total tenure area)</td><td>0 %</td><td>0.08 %</td><td>0.4 %</td><td>0.8 %</td><td>2 %</td></tr>
<tr><td colspan="2">Indirect disturbance
(% of total tenure area)</td><td>0 %</td><td>4–9 %[b]</td><td>> 20%[c]</td><td>> 40%[c]</td><td>> 100%[d]</td></tr>
<tr><td colspan="7">Notes</td></tr>
<tr><td>a</td><td colspan="6">Assumptions are made about the number of distinct fields, or clusters, of wells in each scenario in order to permit estimates of indirect disturbance. Note that if the number of fields were increased (with fewer wells per field), the extent of indirect disturbance would also increase.
— In the 200-, 1,000- and 2,000-well scenarios, fields of 200 wells each are assumed.
— In the 5,000-well scenario, at a density of four wells per section, wells would cover 1,250 sections or 324,000 ha, which is about 80% of the total tenure area. In this context — and especially given that some alpine portions of the tenure may be entirely inaccessible to drilling — it is assumed that wells would be distributed across the entire tenure.</td></tr>
<tr><td>b</td><td colspan="6">A 200-well field with a density of four wells per section covers 50 sections (or about 12,900 ha). Because indirect disturbance occurs within the field and in a “border area” around the field, disturbance tends to be minimized when the field perimeter is smallest. Thus, the 4% minimum disturbance is calculated based on a roughly square arrangement of wells (which has a relatively small perimeter for a given area). By contrast, the 9% maximum is calculated based on a linear or thin rectangular arrangement (which has a relatively large perimeter for the same area).</td></tr>
<tr><td>c</td><td colspan="6">A 1,000-well field with a density of four wells per section would cover 250 sections, or about 64,800 ha. The 20% minimum disturbance calculated here corresponds to five distinct square fields. Similarly, a 2,000-well field would cover 500 sections or 129,500 ha. The 40% minimum disturbance corresponds to ten distinct square fields.
A maximum disturbance has not been estimated, as it would take more detailed calculations to determine the five or ten thinnest, longest fields that can nonetheless fit separately within the tenure, given its irregular shape.</td></tr>
<tr><td>d</td><td colspan="6">A 5,000-well field would most likely mean development of the entire tenure area. The area of indirect disturbance is therefore the tenure area plus an area 0.8 km-wide zone around the entire tenure. An indicative estimate of 105% is derived if the tenure area is modelled as a rectangle with a length to width ratio of 2:1.</td></tr>
</table>

[6] One section is equal to one square mile (mi^2), 2.6 square kilometres (km^2), 640 acres or 260 hectares.

4.2.2 Probable Effects and Qualitative Considerations

As Table 1 indicates, the greater the number of wells drilled, the greater the amount of land clearing. In turn, conceptual models suggest that as the amount of impermeable or reduce-permeability area increases, so too do the rates of erosion and the impacts on salmon.

Without detailed information about surface geography (including soil and rock types, vegetation, detailed topography and stream data), actual erosion effects are impossible to model. However, some qualitative conclusions can be drawn for the Shell Tenure.

First, the effects of access corridors on runoff and associated erosion have already been observed within the tenure. In reference to the Ealue Lake Road and the BC Rail rail grade access to the Upper Klappan, Rabnett (2007) points out that "poor design related to the rail grade alignment, river encroachments, culvert installations, and unstable conditions causing mass wasting was not dealt with . . . ."

Effects associated with CBM development would tend to be much more significant than already observed impacts — both because the density of roads and associated infrastructure would be higher than that typically observed, and because the affected area would be larger and would implicate a greater number of streams.

Second, erosion tends to increase with the steepness of the terrain, and impacts tend to be more evident in smaller streams than in larger rivers (Trombulak and Frissell, 2000). The Shell Tenure is associated both with mountainous terrain and a large number of small tributary streams.

Impacts may also be more pronounced if the mountainous terrain forces a concentration of drilling in relatively flat areas, including land directly adjacent to streams and rivers.

Third, ephemeral or seasonal streams found in alpine areas such as the Shell Tenure typically act as "transport highways" that deliver fine sediment to larger streams (Bilby et al., 1989). However, ephemeral streams are often neglected in analysis and by regulations. For example, although the British Columbia Forest and Range Practices Act prescribes detailed regulations for mitigating impacts from roads that cross fish-bearing steams, many ephemeral streams would be classified as non–fish-bearing. In these cases, culverts are built to protect roads from wash out, but are not required to prevent streams from delivering sediment into larger watercourses.

Fourth, runoff and erosion effects are likely to persist for as long as roads and other disturbances remain in place (Trombulak and Frissell, 2000). This issue may be particularly important in the Shell Tenure, where vegetation growth is limited by a generally cool climate and short growing season. In other words, reclamation, whether natural, or by deliberate re-planting, may take longer than usual. For example, Figure 20 shows a cutslope that has not been in use for 30 years. Areas of bare soil persist and the rate of natural re-vegetation appears to be slow.

Finally, it is important to note that some eroded material will be transported out of the tenure area (likely at lower concentrations, and with substantially less acute impacts, than within the tenure). As a result, there may be impacts on salmon downstream of the tenure area in all three watersheds — Skeena, Stikine and Nass — in addition to the impacts on salmon in the Skeena tributaries within the tenure.

5. Groundwater Extraction

Groundwater extraction is a unique feature of CBM production, occurring when methane is held in wet coal seams.

Produced water has been observed in many exploration wells drilled in British Columbia, including those in the Shell Tenure, which means that effects related to groundwater extraction need to be considered.

In the U.S., where CBM development has been underway for many years, concerns have arisen about impacts from releasing this produced water into the environment above-ground, because it can often be saline, or contain heavy metals. Such concerns would likely be avoided in British Columbia, as the government has strongly indicated its intention to disallow surface disposal.[7]

However, groundwater extraction can have other environmental impacts, including effects on stream flow and temperature, both of which are addressed in this chapter.

5.1 Conceptual Model

CBM wells, such as those that would be drilled in the Klappan, can drain large amounts of water from coals seams. This can lead to impacts on surface stream flow if two conditions are met:

1. As a result of draining coal seams, close-to-surface, or "shallow," aquifers are also drained, lowering the groundwater level in certain areas. This is likely to happen when there are pathways for water to flow from shallow to deep aquifers (i.e., when geological conditions create "connectivity" between shallow and deep aquifers).[8]

2. The drop in groundwater level is significant enough to affect the interaction of groundwater and surface water in "hyporheic zones," the areas immediately under and around streams and lakes and other groundwater return zones adjacent to streams. (Figure 18 illustrates how groundwater and streams interact in the hyporheic zone. Figure 19 illustrates how a water-extracting well (in this case, a shallow one) could lower groundwater levels to depths (i.e., line ⑤) that could be below the hyporheic zones in some areas.)

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[7] If produced water is not disposed of on-site at surface, other handling methods are needed, such as deep re-injection, or trucking or pipelining off-site. Each of these procedures is associated with its own potential impacts and risks.

[8] Under certain conditions, CBM wells may be shallow enough to extract water directly from close-to-surface aquifers. In these cases, connections between deep and shallow aquifers are not necessary for stream flow effects to arise. Regarding the Klappan, likely depths of CBM wells relative to aquifer locations is unknown. For present purposes, a conservative assumption is made, namely that most wells will extract water from deep aquifers.

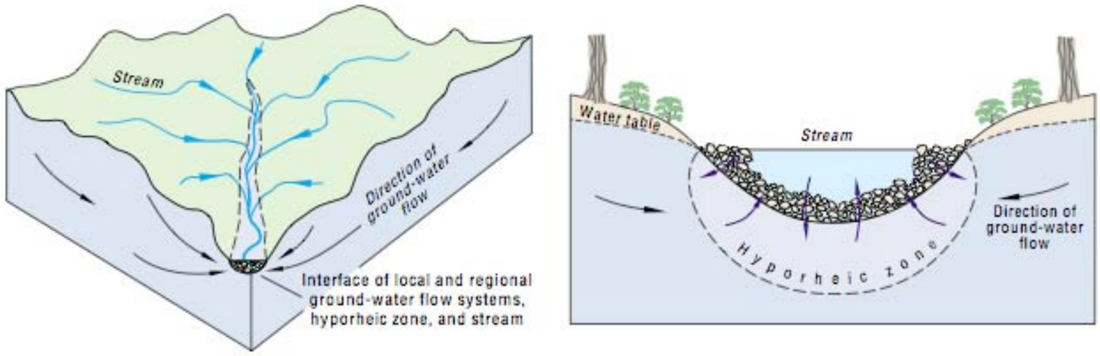

Figure 18: Illustration of the hyporheic zone and groundwater flow to a stream (USGS Circular 1139)

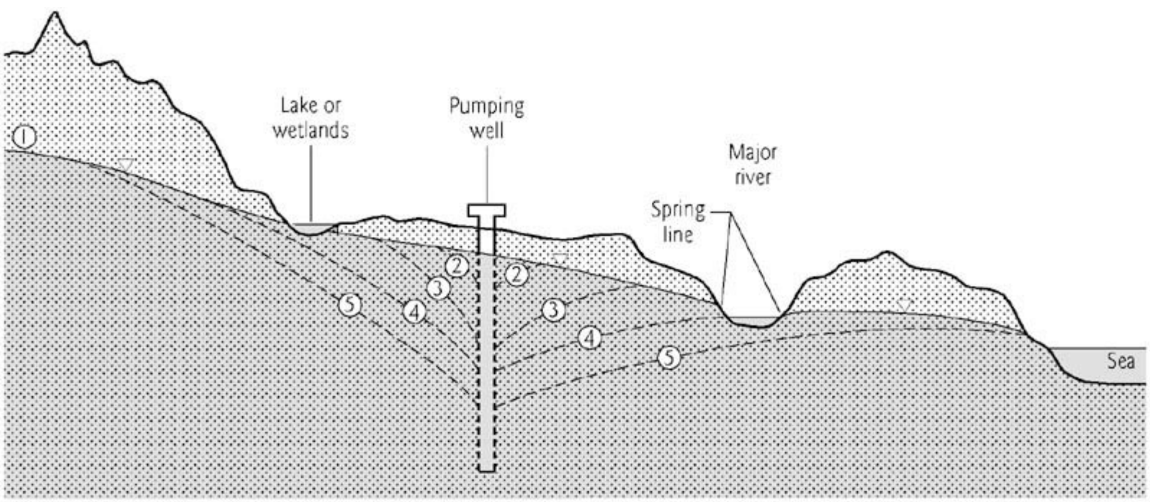

Figure 19: Increasing drawdown with pumping time for a typical water-extracting well (Paul L. Younger, 2007)

In general, when the hydraulic connectivity is high due to the presence of faults or fractured zones, deep groundwater extraction will tend to *reduce* the total amount of shallow groundwater entering streams. If this happens, the effects on fish can be extremely significant, especially during the drier months of the year when groundwater discharge becomes a more significant contributor to surface water flow.

A Department of Fisheries and Oceans guidance document (Ingmundson and Engelbrecht, 2005) lists the following general impacts of groundwater extraction:

— reductions in flow, water level and surface water availability in year-round and seasonal rearing and spawning habitats;
— impacts on groundwater flow (springs, seepage) critical for maintenance of forest and grasslands habitat, or wetlands related to fish habitat;
— changes in surface water temperature caused by groundwater removal;
— changes in chemical and biological surface water quality.

The analysis in this report focuses on two aspects — an overall reduction in flow volume, and changes in stream temperature — in the specific context of salmon.

5.1.1 Flow Effects

In streams with a high proportion of groundwater ("groundwater-dominated" streams), a reduction in groundwater inflow will significantly reduce the total volume of flow. This can lead to reductions in the depth of surface water and extent of wetted area, and to changes in flow dynamics, all of which can have implications for salmon survival.

Potential Dewatering of Reds

A reduction in the wetted perimeter of streams and lakes could leave the edges of spawning grounds permanently or temporarily exposed, which could lead to either a partial or complete loss of offspring, depending on the spatial and temporal extent of flow reduction (Silver et al., 1963).

Effects on Salmonid Larvae in Spawning Gravel

Water depth and current speed are essential to ensuring the stable flow of oxygen through the gravel's interstitial spaces, where the eggs of all salmonid species incubate, and where the hatched larvae absorb their yolk sacs in preparation for emergence. Small reductions in flow are initially met with an upward movement of alevins or yolk sack larvae. Larger flow reductions cause the larvae to leave the interstitial spaces altogether, leaving them vulnerable to predation or death by physical force. Alevine larvae do not display the robustness of fry. They are fragile, and are adapted to movement in the interstitial of the spawning gravel, not in open water.

Increased Juvenile Mortality in Winter

It is not known where juvenile salmonids in the Shell Tenure area overwinter. Generally, overwintering is a time of low metabolism and little or no food, especially in a high altitude alpine and oligotrophic environment. Juvenile chinook and coho salmon commonly divide available habitat by occupying the faster and shallower water and the slower and deeper water, respectively (Mundy, 1969). An overall reduction of available habitat resulting from lower base flows in winter could impede the opportunity to partition habitat and lead to more competition for space and food.

Disproportionate Effects on Chinook Spawning

Chinook spawning locations are variable in their water depth and gravel size (Healey, 1991) but have a common denominator of high flow rates through the spawning gravel (Healey, 1991). Chinook salmon have the largest eggs of all Pacific salmon and therefore the smallest surface-to-volume ratio; in other words, they have the least surface area to exchange oxygen with their environment (Rounsefell, 1957; Healey, 1991). Therefore, they are likely to be more susceptible to low oxygen levels than are other species; probably to counteract this oxygen need, they commonly spawn in areas with high subgravel flow (Russel et al., 1983). As a result, only relatively small areas are suitable for chinook spawning, and chinook have a tendency to form spawning clusters, leaving most of the river unused. For these reasons, a reduction in flow through the spawning gravel could affect chinook salmon more than other salmon species.

5.1.2 Temperature Effects

Groundwater has a high degree of thermal constancy: it keeps a relatively steady temperature from day to night and from season to season, usually close to the mean annual air temperature. This means that groundwater-dominated streams have smaller daily and annual fluctuations in temperature than those dominated by surface runoff.

In particular, groundwater-fed streams tend to be cooler in the summer and warmer in the winter than are surface-fed streams.

Any reduction in groundwater inflow will tend to increase temperature fluctuations, especially leading to colder winter temperatures (including more ice formation) and warmer summer temperatures. Both conditions can stress salmon.

Effects on Behavioural Thermoregulation

In many streams, salmon maintain their body temperature at a level above or below ambient conditions by staying in stream pockets with higher or lower temperatures than the average. This can help the fish to conserve energy, optimize growth, find suitable oxygen levels and locate areas of high organic nutrient contribution (Power et al., 1999). The phenomenon is called behavioural thermoregulation and often includes taking advantage of temperature variations near sites of groundwater upwelling into streams. A reduction in upwelling could reduce the extent of areas suitable for thermoregulation, and would likely impact fish behaviour.

Chinook salmon are also known to spawn selectively in groundwater upwelling areas (Geist, 2000; Geist et al., 2000).

Box 1: Bull Trout as an Indicator Species for Upwelling

Bull trout is a species known to be highly dependent on groundwater upwelling (Baxter and McPhail, 1999). Accordingly, it can serve as a relatively reliable indicator of upwelling, and would be worth particular study in an area where the importance of groundwater contributions to streams needs to be determined.

Bull trout are reportedly found on the Shell Tenure in Kluakaz Creek (WC:400-986500) (Bustard, 1975), Garner Creek (WC:400-983200) (Bustard, 1975), Otsi Creek (Bustard, 1975) and the Nass River above Nass Lake. More rivers will likely be added to this list once more stock assessment field work is completed in the future.

Decreased Winter Survival of Eggs

River-type chinook salmon, the common headwater and alpine form of chinook salmon in the Skeena watershed, typically spawn from late July to early September (Department of Fisheries and Oceans, unpublished, from Healey, 1991). This is a time of higher water temperatures and low flows. Egg incubation starts following the high-temperature season and continues through the winter. In winter, a reduction in the amount of relatively warm groundwater entering streams would decelerate incubation speed and allow more anchor ice to kill eggs as a result of freezing in the winter. Eggs of the later-spawning coho salmon would be exposed to similar challenges.

Delayed Hatching of Fry

The time at which coho and chinook salmon emerge from gravel is linked to the severity of the previous winter. However, the window of opportunity for fry to grow to a size that allows survival through the following winter is very short in an alpine environment. If colder winter water temperatures delay egg development and delay the entry of fry into rivers — until water is adequately warm — the chances of fry finding enough food to prepare for the winter are reduced.

Algal Growth, Invertebrate Populations and Food Availability

Increased summer water temperatures could influence the periphyton community (the matrix of algae, cyanobacteria, heterotrophic microbes and detritus) quantitatively or qualitatively (Hetrick et al., 1998). Parts of the invertebrate community feed on periphyton organisms and could therefore be indirectly affected (Hetrick et al., 1998), in turn altering the survival of juvenile salmonids that rely on these organisms for food.

5.1.3 Effects on Steelhead

In general, steelhead likely face similar impacts as salmon, although some seasonal cycles will be different. For example, steelhead in the Upper Skeena spawn from April to June, with eggs incubating over the summer and fry emerging before fall. This means that, unlike coho and chinook, cold winter temperatures have no bearing on egg survival.

However, steelhead generally enter rivers in the fall in order to spawn the following spring. As overwintering habitat the fish often choose lakes, lake outflows or deep pools in the mainstem of a river close to their natal tributary (Burgner et al., 1992). During this time, they do not feed, but instead metabolize a good part of their body tissue, leaving them relatively sensitive and vulnerable. Reductions in water volumes, lower water temperatures and an increase in anchor ice — all potential results of groundwater extraction — could adversely impact steelhead during winters, reducing growth and survival rates.

5.2 Application to the Shell Tenure

Without extensive primary research, it is not possible to model groundwater extraction in the Klappan. Hydrogeological data, such as the location of aquitards, fractures and other factors affecting interconnectivity between shallow and deep aquifers, are not available. Nor is information about the typical proportions of groundwater in overall stream flow.

However, several different qualitative observations are suggestive of potential interactions between deep groundwater and surface water (mediated by close-to-surface aquifers).

First, the geology of the Shell Tenure is similar to other places where faults and fracture zones provide pathways for water to move underground to great depths. In particular, the Klappan area shows similarities with the San Juan Basin — a typical asymmetrical, Rocky Mountain basin composed of interbedded sandstone, siltstone, shale and coal.

Second, the tenure's mountainous topography means large elevation differences, sometimes as much as 800 m to 1,000 m from valley bottom to ridge top, that could provide enough hydraulic head to drive deep groundwater flow.

In fact, strong artesian conditions were encountered at several depths (179 m, 242 m and 311 m) in one of three exploration wells recently drilled in the tenure (Shell TH Summit), confirming the presence of deep groundwater flow driven by pressure from higher recharge areas.

Third, effects of warm water discharges have been observed in and adjacent to the tenure, as reported by an outfitter:

— The slopes on the western shores of the Lake Hotlesskwa (at the southeast corner of Spatsizi Park, adjacent to the Shell Tenure) have year-round seeps.

— The Kluayaz River (a tributary of Kluatantan River in the southeast corner of the tenure) generally remains ice-free year round.

Warm water springs can signal the existence of pathways between deep and surface aquifers, because they generally consist of groundwater that has emerged at the surface after being heated by geothermal gradients deep underground.

Whether the depth of transport pathways may be comparable to, or greater than, the depth that would be reached by CBM wells in the tenure is difficult to say without further analysis, or knowledge of expected drill depths.[9]

The following three sub-sections offer indicative, preliminary analyses to provide a better sense of the potential significance of impacts in the Klappan:

5.2.1: A preliminary calculation of the water balance shows that a not insignificant amount of water (on the order of 1% of the total annual recharge) could be removed from the Shell Tenure as a result of commercial-scale production.

5.2.2: Modelling from the Powder River Basin shows that in places where connections between deep and shallow aquifers do exist, the drawdown in the water table due to CBM production can be significant, and can extend to areas at great distance from well fields.

5.2.3: Bathymetry from a lake near the tenure reveals a relatively shallow profile. This suggests that even small reductions in the water table, on the order of a few metres, could affect groundwater upwelling in surface waterways.

5.2.1 Calculation of the Water Balance

It is understood that current plans call for off-site disposal of produced water. Therefore, CBM operations would result in a net removal of water from watersheds and aquifers within the tenure boundary.

Table 2 compares estimates of annual net runoff and infiltration with estimates of CBM groundwater extraction. The extraction figures are based on an assumed produced water ratio of 1 barrel (Bbl) per 1,000 cubic feet (Mcf) (B. Ryan, personal communication), and an assumed total recovery of 40% of the 8 Tcf Klappan reserve, spaced evenly over a project life of 40 years. These figures suggest that enough water to fill as many as 200,000 Olympic swimming pools would be removed over the course of the project, which works out to more than 5,000 a year, or more than ten a day.

[9] In an extreme case, the Liard River Hot Springs near the British Columbia–Yukon border was revealed to consist of rainwater that had travelled to an estimated depth of 3.2 km, reaching temperatures of 120 °C, before moving upwards and discharging at surface.

Table 2: Quantity and Relative Significance of Groundwater Extraction

Precipitation and Runoff Factors	
Mean precipitation ‘P’ (m/yr)	0.6
Mean evapotranspiration ‘E’ (m/yr)	0.4
Mean runoff and infiltration ‘P-E’ (m/yr)	0.2
Tenure area ‘A’ (m^2)	4,120,000,000

Runoff and Extraction Amounts	1 day	1 year	40 years
Total annual runoff and infiltration ‘A*(P – E)’ (10^6 m^3)	2.3	820	33,000
Total annual runoff and infiltration ‘A*(P – E)’ (OSPE)*	900	330,000	13,000,000
Total CBM water extraction (10^6 m^3)	0.03	13	510
Total CBM water extraction (OSPE)	14	5,100	200,000
*OSPE is “Olympic Swimming Pool Equivalent,” a unit of 2,500 m^3			

Comparison	
Extraction as a proportion of runoff	~ 1.5%

Extracted amounts are calculated to be roughly 1.5% as much as annual recharge from runoff and infiltration. Although there is significant uncertainty associated with this figure (due to production assumptions and rounded factors), extracted amounts may be said to be on the order of 1% of the total annual recharge. This is a non-negligible amount, especially given that effects are unlikely to be uniformly distributed, and may be concentrated in certain areas.

5.2.2 Significance of Groundwater–Surface Water Interactions

In estimating aquifer drawdown from CBM extraction, the effects of multiple wells need to be considered at the same time. Generally, the principle of superposition applies, which means that at any given location, the separate influences of nearby wells can be added to estimate the total drawdown. According to Roscoe Moss Company, “If several wells are pumping from the same aquifer, the drawdown at any point in the aquifer is the net sum of the individual drawdowns as if each well were operating alone” (1990). The principle of superposition is illustrated in Figure 20. (In diagram (B), the blue lines indicate the drawdown caused by each well. The red line indicates their sum, which is the net drawdown effect observed as a lowering of the water table.)

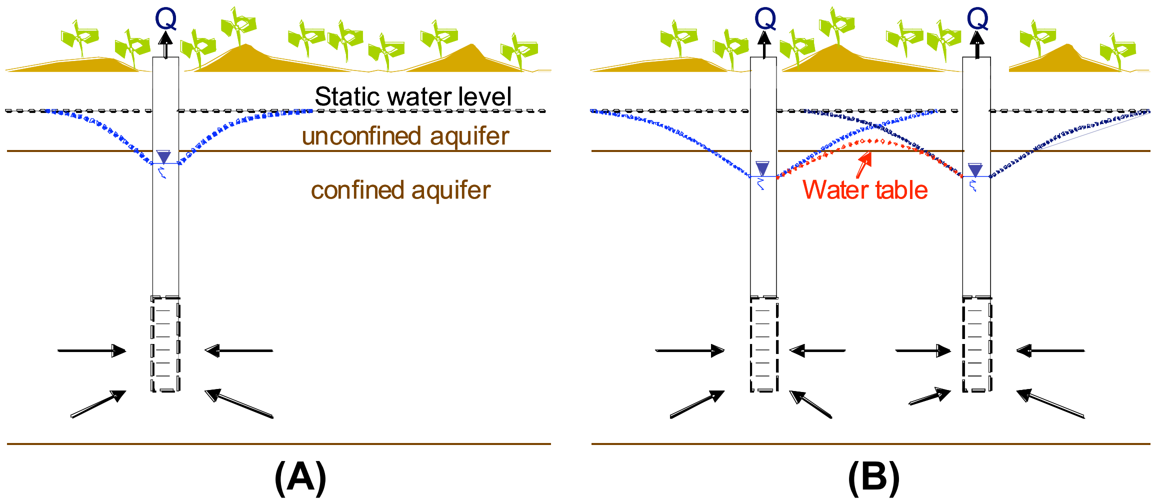

Figure 20: Illustration of cumulative drawdown from multiple wells

Due to a lack of data, cumulative drawdown effects from commercial-scale CBM development in the Shell Tenure cannot be modelled. However, some insights and parallels can be drawn from a three-dimensional numerical simulation modelling study performed for the Powder River Basin.

Wheaton and Metesh (2002) applied MODFLOW (McDonald and Harbaugh, 1988) and Ground Water Vistas (Rumbaugh and Rumbaugh, 1998) to the Hanging Woman Creek area. Their goal was to understand basin-level effects, rather than to predict impacts at specific locations. In particular, the authors were interested in understanding how the water table would be affected by drawdown from multiple wells — both within the well field itself, and in surrounding areas.

The study's key assumptions are listed in Table 3, along with key differences between conditions in the Powder River Basin and those in the Shell Tenure.

Table 3: Key Assumptions and Conditions in the Powder River Basin Drawdown Study

Modelling Assumptions	
— Uniform thickness — Uniform aquifer parameters — Constant regional recharge/discharge relationships — Well design and pumping scheduling — Isolated CBM fields — No density changes due to degassing — No aquifer compression due to long-term pumping — No bio-film growth and decay due to chemistry changes — Only porous media (ignored fracture dominated flow in areas of faulting) — One township-sized CBM well field (36 mi^2) — Uniform well spacing — No aquifer–stream interaction	
Key Differences between the Powder River Basin and the Shell Tenure	
Powder River Basin	**Shell Tenure**
— Arid surface geography	— Cool, wet, alpine and subalpine ecosystem
— CBM production at relatively shallow depth in thin, continuous coal layers	— CBM production at relatively greater depth
— Produced water disposal at surface, on-site	— Produced water treatment and disposal off-site

The model was run for a period of 45 years: 5 years with no CBM production, 30 years with extraction in the entire field, and finally, 10 years with no production. In total, 1,082 wells were modelled, at a density of eight per square mile, with extraction occurring from three different layers in the coalbed: the Anderson, Canyon, and Wall coalbeds, situated at depths of 200–230 feet (ft), 480–500 ft, and 650–660 ft, respectively.

A selection of detailed results is presented in Box 2.

At a conceptual level, three conclusions are noteworthy:

— The extent of drawdown within the well field is significant. For example, after 20 years of extraction, drawdown in two of the coalfields is about 500 ft (about 150 m).

— Drawdown is also observed at distances of several miles from the well field. For example, after 20 years of extraction, drawdown at a distance of 4 miles (mi) from the field is 50 ft (about 15 m, at a distance of over 6 km).

— The water table is not restored to pre-production levels for several years. In the most extreme case, 70% recovery was seen after 10 to 12 years.

These results show that large-scale CBM production will significantly lower the water table when shallow and deep aquifers are closely connected, or when extraction occurs at shallow depths. They also show that effects extend far beyond the immediate perimeter of well fields.

Although there is no way to predict effects in the Shell Tenure based on these results, they do provide one of the few order-of-magnitude estimates of possible impacts. Figure 21 simply superimposes on the Shell Tenure areas that would experience at least 10 ft (3 m) of drawdown, according to the Powder River results, and assuming a well field with an area of 36 sections. Initially, this 10 ft drawdown zone is restricted to the well field. After about 20 to 25 years of production, it extends about 10 miles (16 km) beyond the field in every direction.

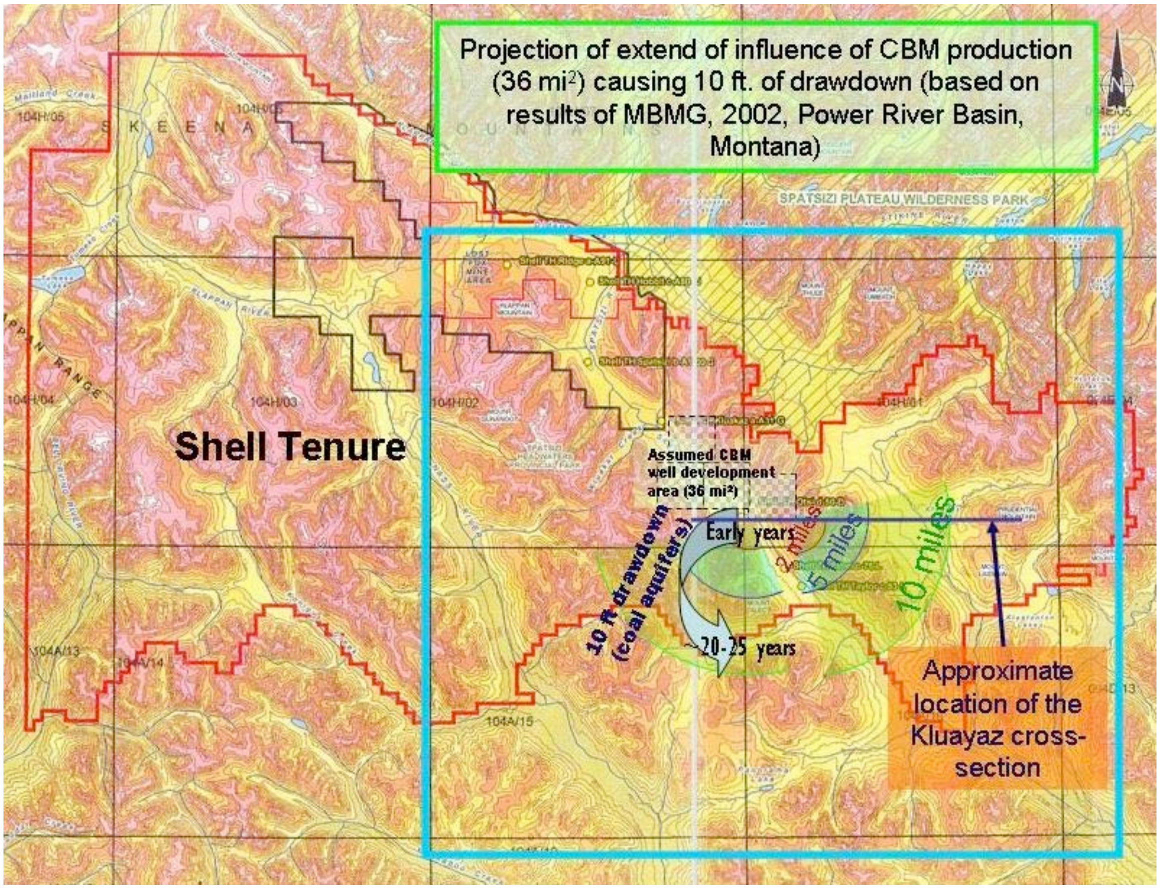

Figure 21: Drawdown zone of 3 m, as modelled in the Powder River Basin Study, and superimposed on the Shell Tenure

At a minimum, this suggests that if underground aquifer connections exist in the Shell Tenure, and if groundwater–stream interactions could be disrupted by drops in the water table on the order of a few metres, then stream flow effects may be significant.

Box 2: Detailed Results from the Powder River Basin Drawdown Study

— After 10 years of pumping in the southern half of the well field in the Anderson coal layer
  - the greatest drawdown was about 220 ft, and occurred in the area closest to the fault where the coal is deepest;
  - some 20 ft of drawdown was produced at a distance of about 2 mi upgradient of the well field and 5 ft of drawdown was produced at distance of about 3 mi.

— At the end of 25 years (i.e., 20 and 10 years pumping of wells in the south and north half of the well field, respectively)
  - maximum drawdown in the Anderson coalbed was about 240 ft
  - the Canyon and Wall coalbeds exhibited drawdown of 450 to nearly 600 ft
  - a drawdown of 50 ft has reached about 4 mi south of the well field in the Canyon and Wall coal beds (north of the fault)

- recharge from surface waters is evident in the Anderson coalbed, but much less so in the deeper coalbeds
- maximum drawdown in the upper (unconfined) layer is about 6 ft.

— Water-level recovery:

- Water-level recovery results from redistribution of water in storage in the aquifer and from recharge.
- Complete water-level recovery will not occur until recharge water reaches the impacted area (Wheaton and Metesh, 2002).
- Water levels in the Anderson coal aquifer are restored within about 70% 10 to 12 years after pumping ceases.
- Water levels in the Canyon and Wall coalbeds recover to within about 90% of pre-development levels within about five years after pumping ends.
- Recovery occurs more quickly at greater distances from the well field.
- Recovery in overburden and interburden units is similar to that of adjacent pumped coal seams.

5.2.3 Bathymetric Considerations in Groundwater-Stream Interactions

Although quantitative hydrogeological data is not available for the Shell Tenure, principles outlined in Section 5.1 can be applied to illustrate the direction of groundwater flow from recharge to discharge areas based on topography. This is demonstrated for an east–west cross-section in the southeast corner of the tenure which includes the salmon-bearing waters of Kluayaz Lake and Kluayaz Creek. (Figure 22 plots the elevation profile along the cross-section. Note that the location of the cross-section is identified in Figure 21.)

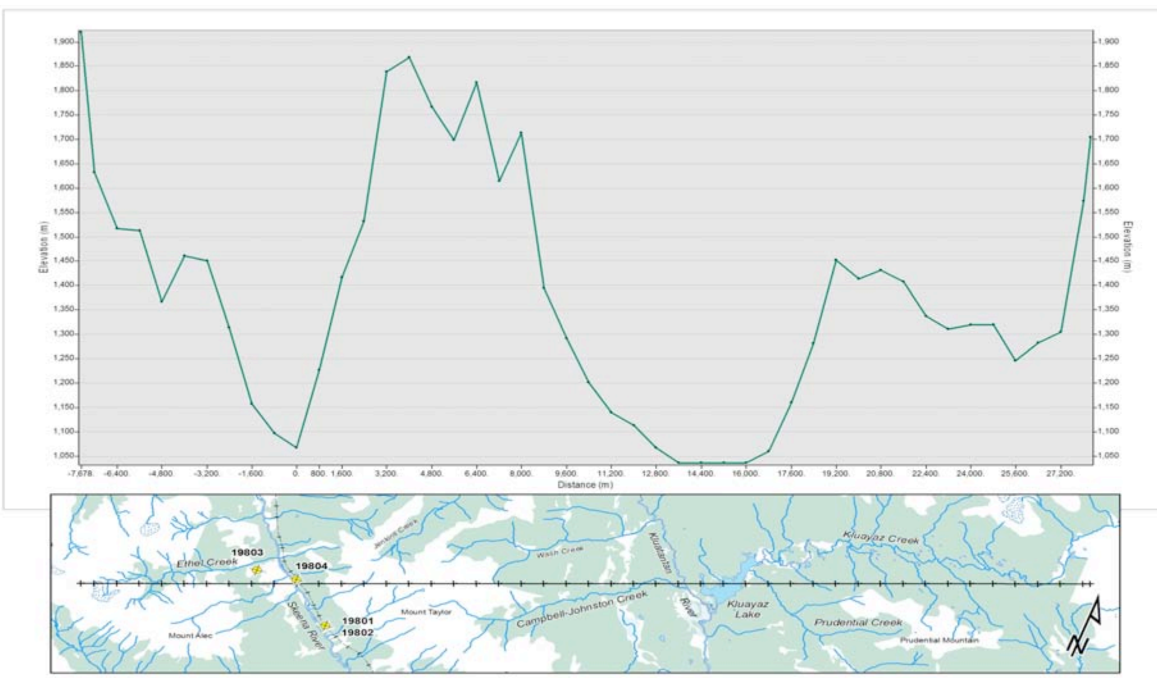

Figure 22: Elevation profile along an east-west cross section in the Shell Tenure

In Figure 23, hydrogeological principles are applied to illustrate the direction of flow in an "unmanaged" scenario (i.e., one where no water is extracted as a result of CBM production). In the diagram, the thin blue line shows surface elevation, while the grey line conceptually illustrates the water table. (Two coal seams are also indicated at depths of about 500 m and 1,500 m below the lowest surface elevation.)

Importantly, in both valleys, the elevation of the water table is never lower than the elevation of surface waterways. As a result, groundwater moves, under the influence of hydraulic pressure gradients, from elevated recharge areas to valley bottoms, where it flows into either the Skeena River or Kluayaz Lake.

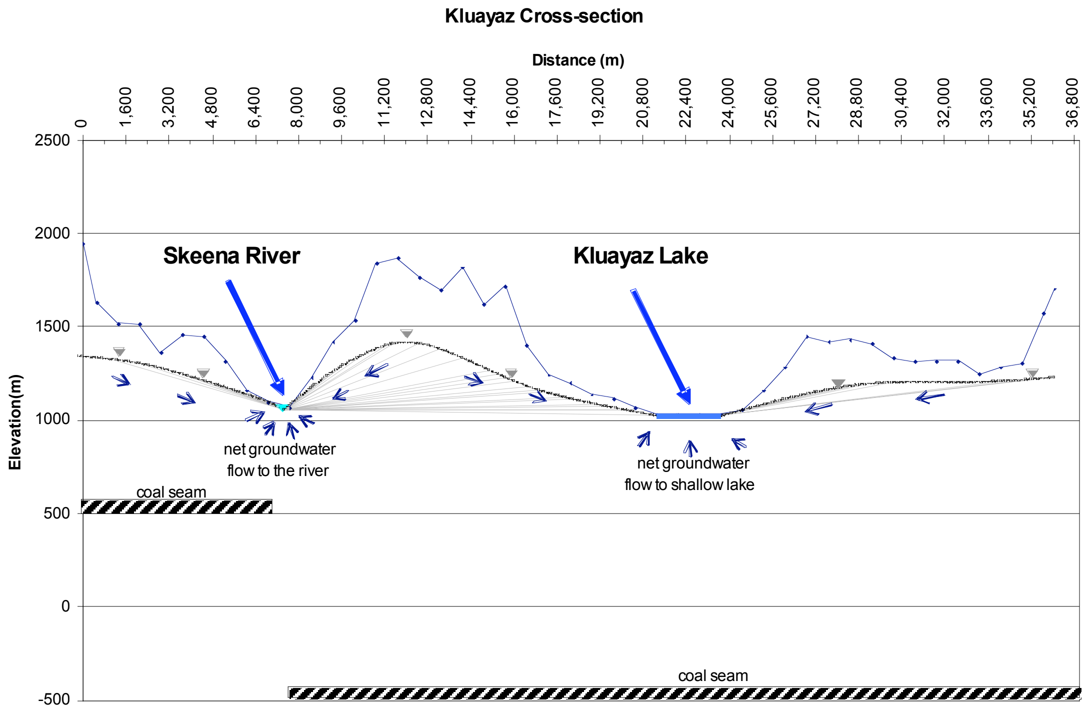

Figure 23: Conceptual illustration of the water table and shallow groundwater flow

In Figure 24, the same hydrogeological principles are applied to a scenario in which wells are being drilled to extract CBM from the coal seams. For simplicity, wells are uniformly spaced at intervals of 800 m, irrespective of surface elevation. In the diagram, the brown vertical lines represent CBM wells. The thick blue line, generally occurring as an arc between adjacent wells, conceptually shows the lowered level of the water table due to groundwater extraction.

Here, the drop in the water table near the Skeena River and Kluayaz Lake is of particular interest. As the inset shows, water table elevation in valley bottoms is now at the same height or *lower* than the river / lake elevation. This means that the amount of groundwater flowing into surface waterways will be reduced, or in extreme cases, the direction of flow may reverse completely; rivers and lakes may begin to drain water into shallow aquifers.

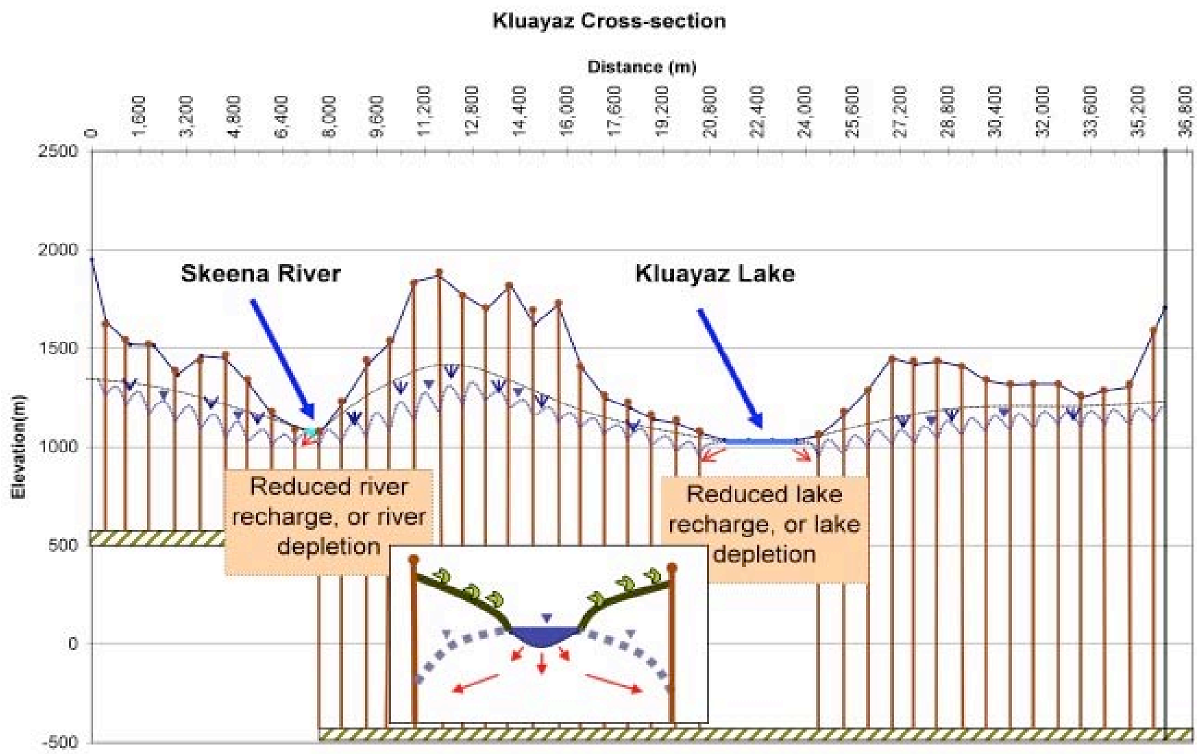

Figure 24: Conceptual illustration of a drop in the water table due to deep groundwater extraction

In order to predict likely effects in specific locations, several types of information are needed. At a minimum, these include

— data about the characteristics of hyporheic zones, the areas underneath streams and lakes where groundwater–surface water exchanges take place;
— quantified estimates of likely drops in the water table;
— depth profiles of streams and lakes, also known as bathymetric information.

There is no bathymetric information available for Kluayaz Lake, one of the waterways identified as salmon habitat (see Section 3.3). However, a bathymetric profile is available for the Kluatantan Lakes, located at the same elevation in the nearest valley to the south (see Figure 25).

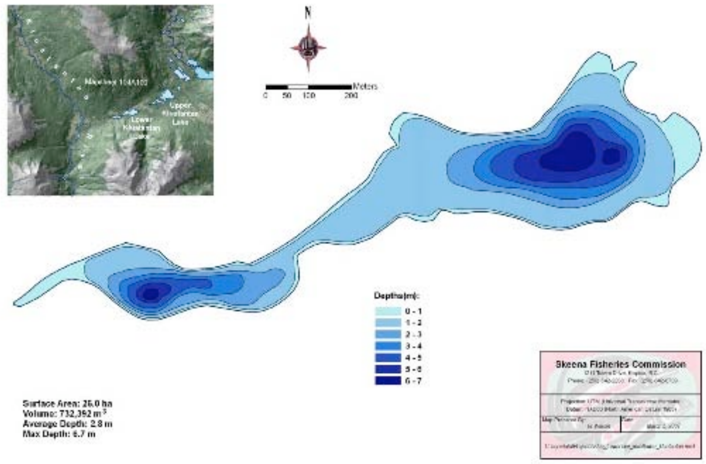

Figure 25: Bathymetric profile of Lower Kluatantan Lake

The profile of Lower Kluatantan Lake indicates an average depth of 2.8 m, which is relatively shallow. This means that a drop in the water table of just a few metres may affect any existing groundwater flows into the lake. (As outlined in Section 5.2.2, the Powder River Basin modelling study estimated drawdown of a few metres, even at a distance of 10 mi from a well field, after 20–25 years.)

This example illustrates the specific importance of further characterizing surface water features in the Shell Tenure.

6. Other Impacts

It was beyond the scope of this study to focus on impacts beyond effects arising from land clearing and groundwater extraction. However, there are other ways CBM extraction could affect salmon. A few of these are highlighted below. In most cases, these impacts are indirect, and therefore relatively less significant than direct impacts.

6.1 Produced Water Disposal

Disposal of groundwater produced by CBM wells is often associated with significant environmental impacts because it can be highly saline. Arsenic, ammonia, boron, iron, manganese, radium, fluoride and high sodium absorption ratios have also been observed in CBM produced water (Regele and Stark, 2000).

Discharges to the environment can lead to the destruction of riparian vegetation, alteration of water chemistry, salinization of soils and so on.

In the Shell Tenure, many potential risks associated with the disposal of produced water will be avoided, as on-site disposal is no longer permitted in British Columbia. Instead, Shell Canada is understood to have proposed disposal and treatment off-site.

Off-site disposal and treatment is not without its own risks, however. Although the risks are low, most transport options — including pipelining and trucking — still carry the possibility of spills and inadvertent releases. In the case of the Shell Tenure, enough water to fill several Olympic swimming pools is likely to require transport every day. If spills were to occur within the tenure, or near salmon habitat elsewhere, salmon could be adversely affected.

6.2 Methane Contamination

In wet coal seams, CBM extraction is generally preceded by water extraction in order to reduce pressure and allow CBM to flow freely. In some cases, CBM may flow slowly to locations other than well heads. This can result in methane contamination of shallow ground water, or direct percolation of methane to the surface through soil or waterways. Both phenomena have been observed in the U.S. (Chafin 1994). Methane contamination is associated with explosion risks, water contamination and soil infertility.

6.3 Ecosystem Impacts

In addition to direct effects on salmon health and salmon habitat, CBM can lead to an overall degradation of ecosystems. In particular, impacts on terrestrial wildlife can be significant. Key issues (as outlined by West Coast Environmental Law, 2003) include the following:

- Roads and pipelines fragment wilderness, eliminating continuous patches that are essential to large mammals such as bears and caribou. As calculated in Subsection 4.2.1, a single well field with 200 wells could make 4 – 9% of the Shell Tenure inaccessible to wildlife. With 2,000 wells, the likely disturbance would cover at least 40% of the area.
- Roads and pipelines can also alter predator–prey relationships. Wolves, for example, are able to move faster along roads than in the forest, increasing predation pressures on caribou. In general, the presence of roads and pipelines is highly correlated with changes in species composition and population sizes (Trombulak and Frissell, 2000).

— Noise pollution from compressor stations could drive wildlife away (Trombulak and Frissell, 2000). The sound volume of a compressor is approximately 50 decibels (dB) at a distance of 100 m.
— Reproductive failure in birds is known to be higher near linear disturbances.
— Hunting and poaching by humans increase when roads open up previously inaccessible areas.

There may also be specific issues related to reclamation of CBM development sites. Restoration of native plant communities is often not feasible after development because the integrity of the soil is reduced and will no longer support native vegetation (Sexton, 2002).

7. Sensitivity Analysis

In analyzing potential impacts on salmon from land disturbance and groundwater extraction, many information gaps were identified. However, in addition to identifying uncertainties that could be addressed by further research, there were other uncertainties pinpointed that may be impossible to eliminate, or that may be outside the control of project proponents. Some of these latter uncertainties are outlined below.

7.1 Sensitivity to Climate Change

Salmon that currently spawn, incubate or rear in the Shell Tenure are generally not exposed to the extreme limits of their thermal tolerance zone. Temperatures may need to climb by as much as 2°C before inducing thermal stress from overwarm conditions. However, given that a 2°C increase in average global temperatures over the next few decades is being considered as one of the likely scenarios of climate change (Morgan et al., 2001), thermal stress for salmon is a distinct possibility.

More importantly, increases in summer water temperature as a result of reduced groundwater inflow (see Subsection 5.1.3) could be exacerbated by even small, short-term average temperature increases as a result of climate change.

7.2 Sensitivity to Inadequate Regulations

Because CBM is a relatively new industry in British Columbia, the provincial government lacks regulatory frameworks to address multiple terrestrial and aquatic impacts that are unique to the CBM industry. This creates additional risks in that key impacts may not be identified, or attempts made at mitigation, before projects proceed.

7.3 Sensitivity to Cumulative Impacts

One particular regulatory flaw is that the British Columbia and federal governments have no systematic tools for conducting cumulative impact analyses of CBM projects. Permitting is done on a well-by-well basis, or for clusters of wells. At no point in the process is there an automatic trigger for environmental assessment of full-field development. This means that under existing regulations, the full impact of CBM development on the Shell Tenure would never be assessed through provincial or federal processes.

To date, two small-scale environmental assessments have been completed in the Shell Tenure. The first considered three investigation wells drilled in 2004, concluding that the impact was negligible, based on the footprint and duration of the activities, and the fact that well sites were located close to an existing disturbance (from a rail grade). The second assessment, completed in 2005, looked at four wells on new well sites and three wells on existing sites. It concluded that "the proposed new test well site locations and the expansion of existing well sites are environmentally satisfactory" (TERA Environmental Consultants, 2005).

If development were to proceed, the next "environmental assessment" could be for an application to drill 50 or 100 "pilot" wells. Given existing impacts from exploration wells, it is possible that only incremental impacts would be considered, and that these would be judged to be low or negligible. In essence, impact would be compared not to original ecosystem conditions, but to existing impacts.

This kind of "incrementalist" approach can lead to gradual encroachment on a pristine area. At each turn, further development appears acceptable, because of the development that has been allowed in the past. For instance, once 100 wells have been constructed, it may appear "normal" to consider scaling-up from 100 to 1,000 or even 5,000 wells. However, the perspective of going from an area without any wells to an area with 5,000 wells will have been lost.

In this context, it is essential that even preliminary assessments in pristine areas consider full-field CBM development scenarios, rather than just one or a few wells at a time.

In addition, cumulative impacts due to other activities within or near the Shell Tenure may need to be considered. For example, a coal mine is being proposed at Mount Klappan, and would lead to additional land disturbances, as well as other land and water impacts. These are also unlikely to be addressed under existing regulations.

Finally, at a more regional scale, northern British Columbia is undergoing rapid growth in energy-related activities. Figure 26 indicates existing wells in Northeast British Columbia; according to the Oil and Gas Commission database, there are over 23,000 wells drilled in the mapped area. Unfortunately, very little is known about the hydrogeological conditions of any part of northern British Columbia. Should CBM development be considered in multiple locations, regional-scale watershed impacts may need to be investigated.

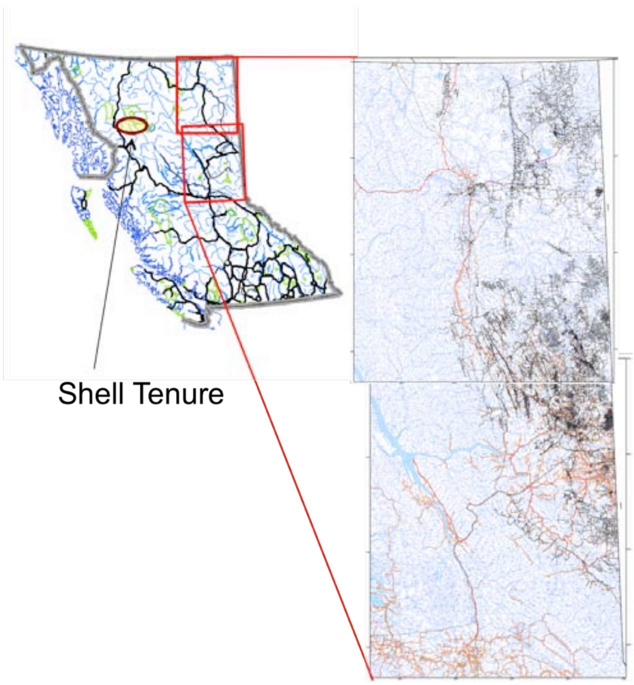

Figure 26: Location of oil and gas wells in Northeast British Columbia

7.4 Sensitivity to Economic Factors

The economic outcome resulting from negative impacts on salmon in the Shell Tenure as a result of CBM development would depend on the number of fish that spawn in the area, and their role in commercial or recreational harvests along migratory routes.

The overall value of the Skeena River fishery was assessed at $109 million in 2006 through a study funded by the Northwest Institute for Bioregional Research. However, without information about the number of fish in the Shell Tenure, it is impossible to develop an estimate, in monetary terms, of potential impacts to fisheries.

8. Conclusions and Recommendations

CBM extraction can have very significant environmental impacts. It requires a much higher density of wells, roads and pipelines than conventional gas, and typically leaves a large footprint on the land. Before CBM can be extracted, groundwater must often be removed from coal seams.

In addition to these general concerns, Shell's proposal for CBM development raises unique concerns related to salmon. The Shell Tenure includes the headwaters of the Stikine, the Nass and the Skeena — three of British Columbia's most important salmon-bearing rivers.

In this report, it was determined that salmon are found in the Upper Skeena and tributaries located *within* the Shell Tenure itself. Key species present are coho (*Oncorhynchus kisutch*), sockeye (*O. nerka*), and chinook (*O. tshawytscha*) salmon. Furthermore, steelhead and rainbow trout (*O. mykiss*), and Bull Trout char (*Salvelinus confluentus*) are also found in the area.

This gives rise to the possibility of direct impacts on salmon as a result of CBM activities within the tenure.

Two potential impacts, land disturbance and groundwater extraction, are particular cause for concern.

Land Disturbance

Land disturbance could lead to increased runoff, increased erosion, and increased sediment loads in streams. Stream turbidity would affect overall salmon health, and increased sediment deposition could damage spawning grounds.

The risks are significant because CBM development is necessarily intensive in terms of its footprint on land. If 1,000 wells were drilled in the tenure, about 0.4 % of the area would be directly cleared for infrastructure such as well pads, roads and pipelines. (In the Shell Tenure, 0.4% is equivalent to 16 km^2, or the area of 2,700 football fields.) If 5,000 wells were drilled, 2% of the area would be affected.

As a result, erosion and sediment effects are almost certain to occur, but the extent is unknown. A priori, impacts would tend to increase as the density of wells increases, and could be highly dependent on the specific location of wells.

Groundwater Extraction

Groundwater extraction at the depth of CBM wells could induce drawdown in shallow aquifers, and ultimately reduce the amount of groundwater entering surface streams and lakes.

This phenomenon is extremely complex and difficult to predict, but the impacts could be highly significant for salmon. Groundwater is essential to maintaining flow and wetted areas in some streams, and can also act as a buffer against daily and seasonal temperature fluctuations. A reduction in groundwater upwelling could lead to such impacts on salmon as more eggs freezing in winter, fry hatching too late to feed adequately, and lower winter survival for juvenile fish.

Whether these effects would arise at all is presently unknown. Stream flow impacts from groundwater extraction depend on the presence of specific geological and hydrological conditions. While preliminary analysis suggests that the necessary conditions may exist in the Shell Tenure, much more research is needed. At a minimum, the presence of these conditions cannot be discounted based on current knowledge.

In evaluating impacts, three key information gaps were identified:

1. CBM production has never before been attempted in salmon-bearing watersheds. As a result, there is no existing empirical or experiential data on impacts.
2. Very little is known about the proposed build-out scenario for the Shell Tenure. Without a sense of well densities, well locations and other infrastructure plans, impact pathways cannot be modelled.
3. Very little scientific data is available about the Shell Tenure and the entire Klappan region. This means that the geology, ecology and hydrology of potential impact areas are almost unknown.

These critical gaps will hamper any efforts to determine salmon-specific and overall ecological impacts of CBM in this region.

As a result, the report concludes that further, detailed investigations are essential to determine whether mitigation of impacts will be required and, if so, feasible to implement. Given the sensitivity of salmon to disturbance in their critical habitats, it is fully possible that impacts cannot be mitigated within acceptable limits. This can only be confirmed with additional research.

8.1 Recommendations

The authors of this study recommend that if further certainty around the potential effects is desired, steps be taken to characterize the following, in the specific context of the Klappan ecosystem:

— baseline climate information;
— size and spatial distribution of salmon populations, for different species, and at different stages in the life cycle (i.e., spawning, incubation, juvenile stages and so on);
— role of wetlands in salmon rearing, as flooding buffers, and in other ecological functions;
— morphology, gradient flow rates and temperature of salmon-bearing streams, including seasonal variations;
— total suspended solids (TSS) content in streams, with particular attention to sites near existing land disturbance;
— groundwater content, as a proportion of total stream flow;
— location of specific groundwater upwelling areas in streams and wetlands;
— temperature and chemistry of streams, partly in order to identify groundwater upwelling sites;
— location of ice-free or snow-free zones, to identify upwelling sites;
— salmon, trout and steelhead behaviour in relation to upwelling areas.

In addition, it is essential to have a better understanding of the geology of the region, and in particular, to determine the extent of groundwater connection between deep and shallow aquifers. Basic research and conceptual modeling should be augmented with simulation modeling.

Finally, the authors note that there is currently a lack of regulations that would require the proponents to assess the full implications of a CBM project in the Shell Tenure, including many of the impacts described here. This kind of regulatory approach is not adequate given the magnitude and complexity of long-term impacts from CBM.

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10. Closure

Conclusions and recommendations presented herein are based on information provided in part by others. The assessment has been carried out in accordance with generally accepted engineering practice. No other warranty is made, either expressed or implied. Engineering judgment has been applied in developing the recommendations in this report.

This report was prepared by personnel with professional experience in the fields covered. Reference should be made to the ‘GW Solutions Inc. General Conditions and Limitations’, attached as an appendix to this report.

GW Solutions was pleased to produce this document. If you have any questions, please do not hesitate to contact me.

Yours truly,

GW Solutions Inc.

Gilles Wendling, Ph.D., P.Eng.

President

11. GW Solutions Inc. Reports: General Conditions

This report incorporates and is subject to the following “General Conditions”:

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This report pertains to a specific area, a specific site, a specific development, and a specific scope of work. It is not applicable to any other sites, nor should it be relied upon for types of development other than those to which it refers. Any variation from the site or proposed development would necessitate a supplementary investigation and assessment. This report and the assessments and recommendations contained in it are intended for the sole use of GW SOLUTIONS’s client. GW SOLUTIONS does not accept any responsibility for the accuracy of any of the data, the analysis or the recommendations contained or referenced in the report when the report is used or relied upon by any party other than GW SOLUTIONS’s client unless otherwise authorized in writing by GW SOLUTIONS. Any unauthorized use of the report is at the sole risk of the user. This report is subject to copyright and shall not be reproduced either wholly or in part without the prior, written permission of GW SOLUTIONS. Additional copies of the report, if required, may be obtained upon request.

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During the performance of the work and the preparation of this report, GW SOLUTIONS may have relied on information provided by persons other than the client. While GW SOLUTIONS endeavours to verify the accuracy of such information when instructed to do so by the client, GW SOLUTIONS accepts no responsibility for the accuracy or the reliability of such information which may affect the report.

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The client recognizes that property containing contaminants and hazardous wastes creates a high risk of claims brought by third parties arising out of the presence of those materials. In consideration of these risks, and in consideration of GW SOLUTIONS providing the services requested, the client agrees that GW SOLUTIONS's liability to the client, with respect to any issues relating to contaminants or other hazardous wastes located on the subject site shall be limited as follows:

(1) With respect to any claims brought against GW SOLUTIONS by the client arising out of the provision or failure to provide services hereunder shall be limited to the amount of fees paid by the client to GW SOLUTIONS under this Agreement, whether the action is based on breach of contract or tort;

(2) With respect to claims brought by third parties arising out of the presence of contaminants or hazardous wastes on the subject site, the client agrees to indemnify, defend and hold harmless GW SOLUTIONS from and against any and all claim or claims, action or actions, demands, damages, penalties, fines, losses, costs and expenses of every nature and kind whatsoever, including solicitor-client costs, arising or alleged to arise either in whole or part out of services provided by GW SOLUTIONS, whether the claim be brought against GW SOLUTIONS for breach of contract or tort.

4.0 JOB SITE SAFETY

GW SOLUTIONS is only responsible for the activities of its employees on the job site and is not responsible for the supervision of any other persons whatsoever. The presence of GW SOLUTIONS personnel on site shall not be construed in any way to relieve the client or any other persons on site from their responsibility for job site safety.

5.0 DISCLOSURE OF INFORMATION BY CLIENT

The client agrees to fully cooperate with GW SOLUTIONS with respect to the provision of all available information on the past, present, and proposed conditions on the site, including historical information respecting the use of the site. The client acknowledges that in order for GW SOLUTIONS to properly provide the service, GW SOLUTIONS is relying upon the full disclosure and accuracy of any such information.

6.0 STANDARD OF CARE

Services performed by GW SOLUTIONS for this report have been conducted in a manner consistent with the level of skill ordinarily exercised by members of the profession currently practicing under similar conditions in the jurisdiction in which the services are provided. Engineering judgement has been applied in developing the conclusions and/or recommendations provided in this report. No warranty or guarantee, express or implied, is made concerning the test results, comments, recommendations, or any other portion of this report.

7.0 EMERGENCY PROCEDURES

The client undertakes to inform GW SOLUTIONS of all hazardous conditions, or possible hazardous conditions which are known to it. The client recognizes that the

activities of GW SOLUTIONS may uncover previously unknown hazardous materials or conditions and that such discovery may result in the necessity to undertake emergency procedures to protect GW SOLUTIONS employees, other persons and the environment. These procedures may involve additional costs outside of any budgets previously agreed upon. The client agrees to pay GW SOLUTIONS for any expenses incurred as a result of such discoveries and to compensate GW SOLUTIONS through payment of additional fees and expenses for time spent by GW SOLUTIONS to deal with the consequences of such discoveries.

8.0 NOTIFICATION OF AUTHORITIES

The client acknowledges that in certain instances the discovery of hazardous substances or conditions and materials may require that regulatory agencies and other persons be informed and the client agrees that notification to such bodies or persons as required may be done by GW SOLUTIONS in its reasonably exercised discretion.

9.0 OWNERSHIP OF INSTRUMENTS OF SERVICE

The client acknowledges that all reports, plans, and data generated by GW SOLUTIONS during the performance of the work and other documents prepared by GW SOLUTIONS are considered its professional work product and shall remain the copyright property of GW SOLUTIONS.

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Where GW SOLUTIONS submits both electronic file and hard copy versions of reports, drawings and other project-related documents and deliverables (collectively termed GW SOLUTIONS’s instruments of professional service), the Client agrees that only the signed and sealed hard copy versions shall be considered final and legally binding. The hard copy versions submitted by GW SOLUTIONS shall be the original documents for record and working purposes, and, in the event of a dispute or discrepancies, the hard copy versions shall govern over the electronic versions. Furthermore, the Client agrees and waives all future right of dispute that the original hard copy signed version archived by GW SOLUTIONS shall be deemed to be the overall original for the Project. The Client agrees that both electronic file and hard copy versions of GW SOLUTIONS’s instruments of professional service shall not, under any circumstances, no matter who owns or uses them, be altered by any party except GW SOLUTIONS. The Client warrants that GW SOLUTIONS’s instruments of professional service will be used only and exactly as submitted by GW SOLUTIONS. The Client recognizes and agrees that electronic files submitted by GW SOLUTIONS have been prepared and submitted using specific software and hardware systems. GW SOLUTIONS makes no representation about the compatibility of these files with the Client’s current or future software and hardware systems.