Transportation Safety Board of Canada
Bureau de la sécurité des transports du Canada

RAILWAY INVESTIGATION REPORT
R05V0141

DERAILMENT

CANADIAN NATIONAL
FREIGHT TRAIN A47151-05
MILE 56.6, SQUAMISH SUBDIVISION
GARIBALDI, BRITISH COLUMBIA
05 AUGUST 2005

Canada

Transportation Safety Board of Canada — Bureau de la sécurité des transports du Canada

The Transportation Safety Board of Canada (TSB) investigated this occurrence for the purpose of advancing transportation safety. It is not the function of the Board to assign fault or determine civil or criminal liability.

Railway Investigation Report

Derailment

Canadian National
Freight Train A47151-05
Mile 56.6, Squamish Subdivision
Garibaldi, British Columbia
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Synopsis

At approximately 0720 Pacific daylight time on 05 August 2005, Canadian National freight train A47151-05, proceeding northward from Squamish to Lillooet, British Columbia, derailed nine cars including one load of sodium hydroxide (UN 1824), also known as caustic soda, and eight empty cars at Mile 56.6 of the Squamish Subdivision near Garibaldi, British Columbia. Approximately 40 000 litres of the caustic soda spilled into the Cheakamus River, causing extensive environmental damage. There were no injuries.

Ce rapport est également disponible en français.

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Appendices

Figures

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1.0 *Factual Information*

1.1 *The Accident*

On 05 August 2005, at approximately 0624 Pacific daylight time,[1] Canadian National (CN)[2] freight train A47151-05 (the train) departed Squamish, British Columbia, on the Squamish Subdivision destined for Prince George, British Columbia (see Figure 1). The method of train control was the Occupancy Control System, authorized by the *Canadian Rail Operating Rules* and supervised by a rail traffic controller (RTC) located in Edmonton, Alberta. The train consisted of 5 locomotives on the head end, 3 loads and 141 empties with 2 remote locomotives behind the 101st car. It was about 9340 feet long and weighed approximately 5002 tons.

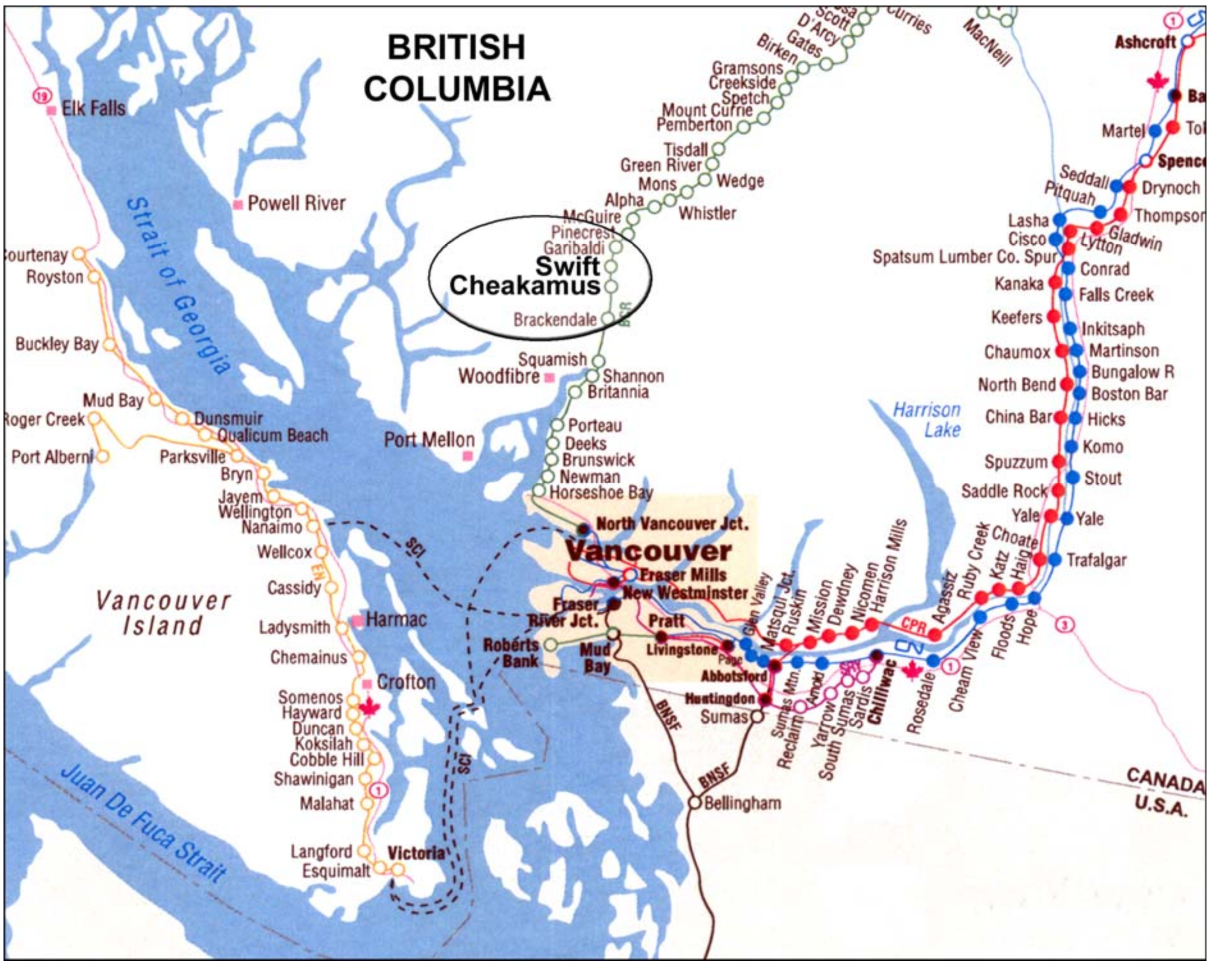

Figure 1. Location map

1 All times are Pacific daylight time (Coordinated Universal Time minus seven hours).

2 See Glossary at Appendix G for all abbreviations and acronyms.

Figure 2 shows the track profile along the subdivision.

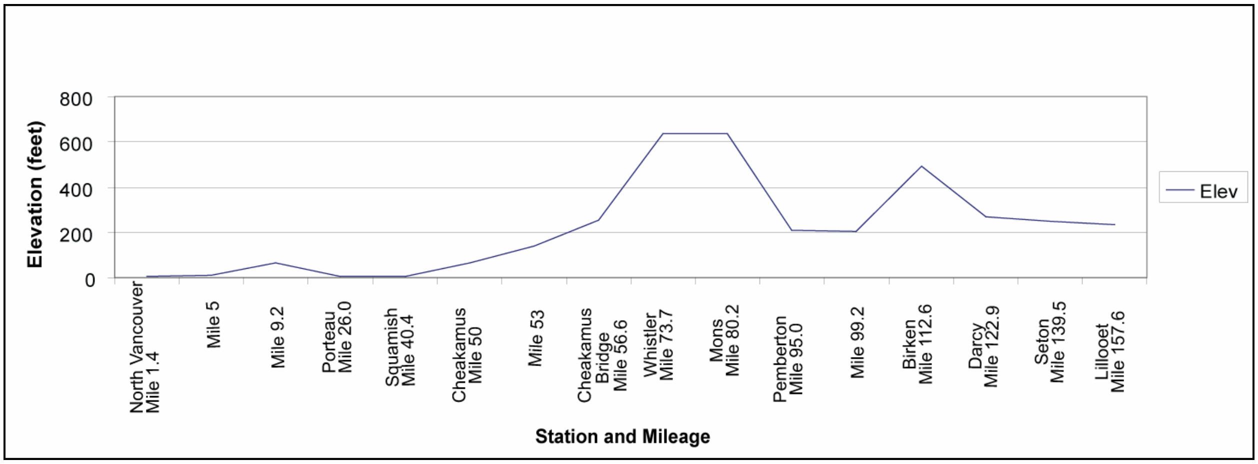

Figure 2. Squamish Subdivision elevation profile (train proceeding from left to right)

The train was marshalled as follows:

- 5 locomotives on the head end, followed by
- 1 empty box car,
- 3 tank cars loaded with sodium hydroxide,
- 6 empty centre beam flat cars,
- 97 empty chip gondola, box and flat cars,
- 2 remote locomotives,
- 37 empty box and chip gondola cars.

The second, fourth and fifth lead locomotives were online providing 11 800 horsepower (HP) on 18 driving axles. The lead locomotive, BCOL 4607, was isolated and the third locomotive was shut down. The remote locomotives were online but not loading.

Locomotive Consist

Head End:

1. BCOL 4607 (lead), six axles, GEF-40 Dash 8, 4400 HP
2. BCOL 4645, six axles, GEF-44 Dash 9, 4400 HP
3. BCOL 4651, six axles, GEF-44 Dash 9, 4400 HP
4. BCOL 766, six axles GMF-30 SD40, 3000 HP
5. CN 2568, six axles, GE Dash 9-44CW, 4400 HP

Remotes:

1. BCOL 4652, six axles, GEF-44 Dash 9, 4400 HP
2. BCOL 4621, six axles, GEF-40 Dash 8, 4400 HP

Both the lead locomotive consist and the remote locomotive consist comprised General Electric (GE) Dash 8 and GE Dash 9 locomotives. However, both consists were marshalled with an older, Dash 8 locomotive in the lead position. The Operator Interface Module (OIM) on the Dash 8 does not display the actual power output or "loading status" of the remote power whereas the more current Dash 9 does so.

The train crew, a locomotive engineer and a conductor, were ordered at 0530 to take the train from Squamish to Lillooet, British Columbia. They met fitness and rest standards established to help ensure the safe operation of trains. The conductor was making his second trip on the Squamish Subdivision in 19 months and second trip in main-track service in 11 years. The locomotive engineer was familiar with the subdivision. He was qualified to operate distributed power[3] (DP) trains between Squamish and Prince George. He had operated DP trains for a number of years up until the time BC Rail (BCR) stopped doing so in June 2003. He had operated DP trains on the Squamish Subdivision since the resumption of northbound DP train operation by CN in June 2005. DP was implemented on southbound train A47051 in April 2005.

The inbound and outbound crews were both in Squamish at the same time and a transfer between crews took place. The North Vancouver crew had received DP trouble alarms that should have alerted them to a potential DP problem, but no irregularities were noted and passed on to the Squamish crew. Although the topography between North Vancouver and Squamish does not necessarily require DP, the train was intended to be run with operative DP out of North Vancouver and continue onward to Prince George.

The zone speed is 25 mph from Mile 10.9 to Mile 42.0 on the Squamish Subdivision. The train reached a maximum speed of 25.2 mph in throttle position 5 at 0644:17 near Mile 40 then began to reduce speed as it ascended the grades north of Cheakamus. Because the locomotive engineer believed that the locomotives in the remote consist were not providing tractive effort, the locomotive engineer performed a test to confirm this suspicion. This was accomplished by using a DP system feature that allows the remote consist to be operated independently from the head-end consist. The remote consist was placed in throttle position 8 and the lead locomotive consist was throttled down to idle.

Although the locomotive event recorder (LER) indicated that controlling remote locomotive BCOL 4621 was in throttle position 8, there was no resulting forward push. Train speed continued to decrease, leading the crew to conclude that the remote locomotives were either not online or were not working. With the train travelling at 8.5 mph, the locomotive engineer brought the lead locomotive, BCOL 4607, online, adding 4400 HP and six more driving axles to the train for a total of 16 200 HP and 24 driving axles.

[3] Distributed power trains have additional operating locomotives positioned in the train; for example, at the midway point, two-thirds of the way back or at the rear. The distribution of power enables the operation of longer, heavier trains while providing a means to control or minimize in-train forces.

1.2 Locomotive Event Recorder Information

Zone speed was 35 mph between Mile 42.0 and Mile 50.8 on the Squamish Subdivision. With the added horsepower, the train increased speed to a maximum of 34.2 mph in throttle position 8 at 0649:51.7. The throttle was then reduced as the train approached Mile 50.8 where a new zone speed of 20 mph began. The train reached a maximum speed of 36 mph at 0651:11.2 in throttle position 5 and the throttle was then manipulated until a speed of 22.7 mph was achieved in throttle position 8 at 0658:56.5. The train was able to proceed close to track speed up the grades of 1.04 per cent to 2.14 per cent between Mile 51 and Mile 56.

Before the accident, as the train negotiated the mountain grades and heavy curvature in throttle position 8, the LER recorded the first of several wheel slips at 0659:39, indicated by a sharp increase/decrease in speed in one or two seconds. About 15 minutes later, while travelling at 14 mph with the throttle in position 8, through a set of reverse curves across the Cheakamus River Bridge at Mile 56.6, the train went into emergency.

After making the necessary emergency broadcast and notifying the RTC, the conductor initiated an inspection of the train, discovering that nine cars (the 4th to the 12th) had derailed to the west (inside) of the 12-degree 20-minute left-hand curve at the Cheakamus River Bridge. A total of four cars had fallen off the bridge; tank car PROX 64041, a load of 73 per cent concentration sodium hydroxide (4th car), and three empty centre beam flat cars. The tank car struck the concrete bridge pier and landed on the north bank of the river (see Photo 1) and the three empty centre beam flat cars behind it landed on their sides on the river bed. The four derailed cars following, three empty centre beam flat cars and an empty wood chip gondola car, were on their sides. The 12th car, an empty wood chip gondola, was upright, with only the B-end[4] (north) end derailed.

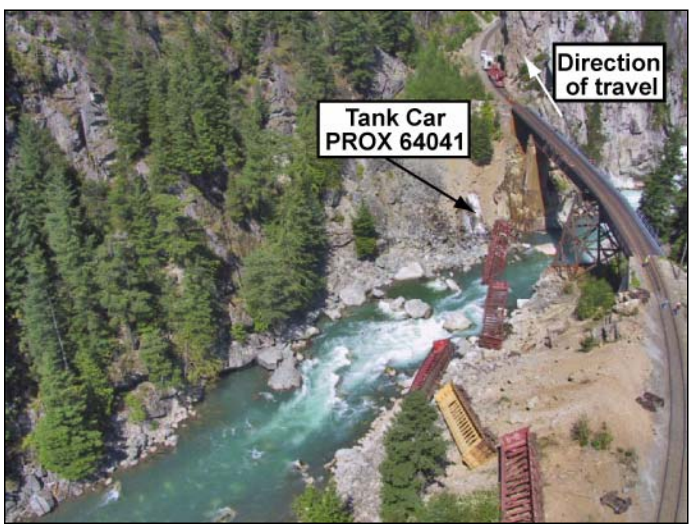

Photo 1. Tank car position after the derailment

4 Components on railway rolling stock are referenced to either the A-end or the B-end of the car. The hand brake is located at the B-end. From the B-end looking toward the A-end, the right side of the car is to the right and the left side of the car is to the left. Wheels and bearings number from the B-end and include a side reference; for example, wheels R1, R2.

The 9347-foot train was stretched over approximately 18 curves, half of which were greater than or equal to nine degrees on ascending grades between 1.90 per cent and 2.10 per cent.

Weather conditions were clear, slight north-northeast wind and 15°C.

1.3 Tank Car PROX 64041

Tank car PROX 64041 was a non-pressure tank car, type 111A100W3, built in November 1984. The derailed tank car fell off the west side of the Cheakamus River Bridge, onto the north bank, and came to rest on its right side with the manway facing downstream at an angle of about 30 to 35 degrees. The jacket was severely damaged and damage to the tank itself was most severe at the AL location, which at this point, was the top corner of the lower (downhill) end of the tank. All valves and the manway cover had been sheared off the car. The manway had also been dented at the A-end. The trucks separated from the car and most of the rigging and safety appliances were gone. Spilled product had coated the entire top of the car as well as most of the surrounding area to about 20 m upstream and 25 m downstream.

Initial assessment performed at 1245 indicated that about one-fifth of the load remained in the downward end of the car. Shipping documents indicated that there had been 86 433 kg or 51 540 litres of product in the car at origin. The temperature of the product remaining was measured at 99°C.

In discussions with the shipper, Nexen Chemicals, it was learned that the product would begin to solidify at 62°C. The option of pumping out the remaining product was discarded due to the car location and concern that the product would solidify in the lines while pumping it out. It was believed that, even with the damage to the tank itself, the car could withstand being dragged up the bank to track level. The product was therefore allowed to solidify in the car.

All openings were sealed and the car was pulled back up the bank on August 12 without any release of remaining product. There were no visible tears in the tank and no product contamination that indicated that there were any additional breaches in the tank. On August 14, two cranes lifted the damaged tank into a gondola car. The car was moved to Garibaldi Siding, the tank was wrapped in polyethylene, and the car was moved to North Vancouver for disposition.

1.4 Cheakamus River Watershed

The Squamish River watershed drains an area of 3650 square kilometres of the Coastal Mountain Range in southwestern British Columbia. The Squamish River and its five tributaries, including the Cheakamus River, are a significant habitat for all five species[5] of Pacific salmon and steelhead trout, as well as other fish, marine life, terrestrial mammals, birds, and invertebrates. The Cheakamus River is a major tributary of the Squamish River and drains an area of 1070 square kilometres. The Cheakamus River extends 26 km downstream of the accident site to its confluence with the Squamish River.

[5] sockeye, coho, pink, chinook, chum

The Cheakamus River is a scenic, popular recreation area as well as a traditional food source for First Nations groups living within the boundaries of the District of Squamish. The river valley is also a major transportation corridor to central British Columbia with Highway 99 and the Squamish Subdivision of CN following the Cheakamus Valley from Squamish to Whistler. Construction of the Squamish Subdivision was completed in 1952 and follows the Cheakamus Valley from approximately Mile 49 to Mile 73.

There are two fish hatcheries located downstream from the spill. The larger of these two is the Tenderfoot Creek Hatchery, which produces approximately 1.6 million chinook smolts (fish about two years old), 300 000 coho smolts and 100 000 chum fry (recently hatched fish) each year. Up to three million pink salmon and 100 000 steelhead trout are added to the production in some years, depending upon escapement levels and fishery requirements.

1.4.1 Spill and Environmental Impact

First reports from the scene indicated that the tank car was leaking sodium hydroxide, but it was not clear how much liquid had been spilled. CN contacted the shipper, CANUTEC and two dangerous goods emergency response contractors to assess the situation. The contractors both arrived at about 1100, and around 1300, it was reported that approximately 40 000 litres of 73 per cent solution sodium hydroxide (NaOH) had spilled from the tank car onto the surrounding rocks and into the Cheakamus River. Sodium hydroxide is an essential ingredient in an array of industrial operations, including pulp and paper, textiles, soap and detergents, bleach, petroleum products, and alumina, along with many other uses in the chemical processing industry. Sodium hydroxide is an alkaline, colourless, odourless, corrosive chemical (pH of 14) that can cause severe eye and skin burns and other soft tissue damage.

Foaming of the water was observed where there was some mixing of the sodium hydroxide in the fast-moving, turbulent waters in the Cheakamus River Canyon, but most of the sodium hydroxide made its way downstream as a concentrated, high pH "slug." This was due to the temperature and density[6] of the sodium hydroxide solution and lack of hardness in the river water, which reduced the ability of the river to buffer or absorb the effects of the chemical release. By mid-afternoon, pH[7] measurements of the river 200 m downstream of the spill were a neutral 7. Normal pH for the river is 6.9 to 7.1.

The sodium hydroxide quickly affected aquatic life in the Cheakamus River and lower Squamish River, causing fish gill tissues to haemorrhage and skin burns. The spill killed fish and benthic invertebrates of every species and age class present in the river, which had been exposed to the sodium hydroxide solution. The low tide at the time of the derailment while the contaminant went down the river into Howe Sound provided refuge for some survivors in back channels and off-channel habitat.

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6 Specific gravity of sodium hydroxide is 2.1 (that is, 2.1 times as dense as water)

7 Scale between 1 and 14 used to measure alkalinity or acidity of solutions. Low pH indicates acidity and high pH indicates alkalinity.

There was no danger to eagles, ospreys, and animals that ate the fish carcasses. Approximately 5000 fish were collected by fisheries technologists, biologists and volunteers (Pacific Streamkeepers Federation) to be weighed, measured and analyzed. Some invertebrates and eggs appeared to survive, but the full extent of the loss is yet to be determined. A report written by a consultant for the British Columbia Ministry of Environment and the federal Department of Fisheries and Oceans calculated that 500 000 fish from 10 different species encompassing all age classes of fish present in the river died as a result of the spill[8] (see Appendix A).

A 20 per cent solution of acetic acid was sprayed on the rocks and low-volume pumps used to inject acetic acid subsurface at the derailment site to neutralize the sodium hydroxide. Dolomite lime was made available to neutralize the acetic acid if necessary. Caustic soda leaching from the river banks, rocks, pools, and back channels was measured following periods of major rainfall between August 17 and October 28 and no increase in pH was recorded.

1.4.2 *Health Effects of the Spill*

Although CN reported the derailment and spill as required, early reports from the derailment site were not clear regarding the scope of the spill, danger to public health, toxicity and downstream impact on the river. The District of Squamish initially thought that the derailment and chemical spill were more an environmental issue than a public health one. The Vancouver Coastal Health Authority (VCHA) initially advised that no public health hazard existed due to the fast, high-volume dilution of the chemical in the time elapsed since the derailment.

Shortly thereafter, the VCHA and the District of Squamish both issued a public health advisory affecting the Cheakamus and Squamish rivers and estuary (based on reports of dead fish and more accurate information about the extent of the spill received from a Public Health Inspector and others on site). News of the public health advisory was distributed to the approximately 125 water users by a volunteer network, the Royal Canadian Mountain Police (RCMP) and broadcast on radio station Mountain FM.

The two notices issued following the spill recommended a water advisory banning domestic use of water from 48 wells within 100 m of the Cheakamus River while sampling was being undertaken, and a recreational water users advisory banning use of the Cheakamus River. The recreational advisory was lifted within 24 hours and the drinking water advisory was removed after 48 hours. The consumption of healthy fish was deemed safe on August 9. Water from wells outside the immediate vicinity of the Cheakamus River and municipal water sources within the District of Squamish were unaffected by the spill.

There were no reported injuries resulting from the spill.

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[8] "Assessment of the CN Rail Caustic Soda Spill, August 5th, 2005 on the Cheakamus River," report authored for the British Columbia Ministry of Environment and the federal Department of Fisheries and Oceans by Instream Fisheries Research Inc.

1.5 Track Information

The bridge over the Cheakamus River Canyon is located on a 12-degree 20-minute left-hand curve to the south leading to a 13-degree right-hand curve to the north on a 2 per cent ascending grade. The bridge is a four-span open-deck plate girder with timber bridge ties. The north pier is concrete and the south pier is a steel frame tower. The bridge deck was 82 feet above the river. There was no damage to the track, but the west ends of 63 timber bridge ties were broken off completely or partially when the derailed cars fell off the bridge.

The low rail of the left-hand curve approaching the bridge was 1991 head-hardened 115-pound Sydney. The high rail was 1999 head-hardened 124-pound JKVY Hayange, the track ties were steel and the rails were secured with elastic fasteners.

The low rail of the right-hand curve north of the bridge was 1991 head-hardened 115-pound Sydney. The high rail was 2000 head-hardened 124-pound JKVY Hayange. The rails were on wood ties.

The high rail was supported on cast premium tie plates secured to the wood ties with screw spikes. The low rail was supported on 14-inch steel tie plates fastened with five spikes per plate. The low rail was box-anchored every tie with channel lock anchors. Ballast was crushed rock. There was a dual rail, hydraulic lubricator just south of the bridge that had pumped grease covering the whole rail head, ties and ballast in the area.

1.5.1 Rail Lubrication

Effective utilization of locomotive tractive effort depends on the available adhesion between the locomotive wheels and rail. Adhesion is a function of locomotive weight, and the level of friction at the point of wheel-rail contact; that is, effective tractive effort is μW, where W is the total weight on the driving wheels and μ is the coefficient of friction between wheel and rail. The coefficient μ is often taken as 0.25, although values as high as 0.30 can occur. The friction or adhesion factor represents the percentage of locomotive weight on the drivers that is available as effective tractive effort. Environmental factors such as rain, frost, and snow can reduce the available friction. Additionally, contaminants applied to the top of rail, such as wayside lubricant and leaves, can degrade the available friction and promote locomotive wheel slip when operating in heavy traction.

There are many wayside lubricators on the heavily curved Squamish Subdivision. In addition, top of rail friction modifier lubrication is applied every second day with a hi-rail truck. Although locomotive slip was recorded in this incident (some slip always occurs between the wheel and the rail), reduced top of rail friction has not been identified as a serious operational problem.

At 8.5 mph in maximum throttle with 16 200 head-end horsepower ascending a 2.0 per cent grade, wheel slip would be expected. CN's *Locomotive Engineer Operating Manual*, Form 8960 (January 2005), Section C2.7, discusses wheel slip. Modern locomotive adhesion control systems typically provide three levels of wheel slip correction/protection. To minimize nuisance flashing of the wheel slip light, the first two stages of wheel slip correction do not trigger the wheel slip alarm and light. The wheel slip light is only illuminated if and when wheel slip occurs that requires third stage correction. Hence, significant wheel slip can occur before the wheel slip light is illuminated in the locomotive cab. If the load meter on the lead locomotive does not indicate a loss of power when the wheel slip warning is given, one of the trailing locomotives will have wheels slipping. A slipping wheel or wheels on a locomotive (loss of adhesion) can, in most cases, be detected and corrected automatically. The automatic wheel slip detection system will reduce the power to the traction motors and apply sand to the rails until the wheel(s) have stopped slipping. Wheel slip can also be controlled manually by applying sand and/or reducing throttle.

1.5.2 Track-Train Dynamics

A combination of lateral (L) and vertical (V) forces exist at the wheel-rail interface. The ratio of lateral-to-vertical (L/V) forces determines the likelihood of a derailment. The tendency toward derailment increases as the ratio increases; that is, a high lateral and low vertical force (empty cars) will tend to push the wheel flange up and over the gauge face of the rail or will push (loaded car) the rail with sufficient force to cant the rail outward and roll over the rail.

Longitudinal train forces are transmitted serially through the train between the coupler pivot points. When a train is being pulled on tangent track, the train is in draft; the longitudinal forces are tensile and act along the centreline of the track. When a train is operating on curved track, the longitudinal forces (whether compressive or tensile, that is, pushing or pulling) and related coupler angles cause lateral forces at the vehicle centre plates, which are transmitted by the wheels to the rails. The magnitude of the lateral forces at the rail varies directly with the magnitude of the longitudinal force, the coupler angle, grade, and degree of curvature. Steep gradients and sharp curves add rolling resistance, increasing train forces. High lateral forces result in a high L/V ratio and, under these conditions, a wheel tends to climb and/or the low rail will roll over. L/V ratios can be kept below critical levels by limiting longitudinal forces.

Longitudinal force can be managed by limiting the number of driving axles and horsepower in the locomotive consist. Limiting maximum allowable throttle position and/or limiting maximum trailing tonnage can also maintain longitudinal forces to an acceptable level for the applicable topography. Many railways limit the tractive effort of the locomotive(s) in the consist to 250 000 pounds or less, the Association of American Railroads (AAR) recommended limit for trains with grade B couplers. Both BCR and CN's operating instructions limit lead, remote and helper engine consists to 13 500 HP and 18 driving axles on conventional trains on ascending grades between Cheakamus and Mons on the Squamish Subdivision.

When operating in high-degree curvature, excessive longitudinal forces can produce critical lateral forces on any rail car. The severity increases with light weight cars, longer cars, and for long-short car combinations. For any given degree of curve, the greatest coupler angle occurs when a long car is coupled to a short car. High L/V ratios can be developed when cars of 80 feet or longer are coupled with cars of less than 50 feet in length.[9] The marshalling of train A47151

[9] The length of 80 feet is the AAR standard in the development of marshalling guidelines found in Chapter 3 of the AAR report *Track Train Dynamics to Improve Freight Train Performance*, AAR-R-185, "TTD Guidelines for Optimum Train Handling, Train Makeup, and Track Considerations," November 1979 (see Appendix B).

had long, empty cars coupled behind three shorter tank cars and a box car. The L/V ratio can be reduced by limiting the tonnage trailing the long car–short car, taking into account the actual grade and track curvature.

The maximum grade on the Squamish Subdivision is taken to be 2.2 per cent. There are many 12-degree curves as well as several 13- and 14-degree curves. Using Table 3-2 in Chapter 3 of the AAR report *Track Train Dynamics to Improve Freight Train Performance*, AAR-R-185, "TTD Guidelines for Optimum Train Handling, Train Makeup, and Track Considerations," the maximum tonnage permitted to trail cars 80 feet or longer on curves between 12 degrees and 14 degrees on a 2.2 per cent ascending grade is between 2555 and 3154 tons. Since the highest concentrations of longitudinal force occur behind the locomotives, trains heavier than 2555 tons must handle empty cars 80 feet or longer in the rear portion of the train.

CN's operating instructions are the same as those that were in effect under BCR. CN's Operating Manual, Section 3.0 (Equipment Handling), specifies the tonnage limit for conventional train operation on ascending grades between Cheakamus and Mons to no more than 2700 tons trailing any empty car that is more than 80 feet in length. Section A-4 limits trains handling loads and empties to 18 driving axles and 4200 tons and the trailing tonnage inclusive of loads and non-driving locomotives to 4600 tons. Loads are to be marshalled immediately behind the locomotives, subject to the marshalling requirements of dangerous commodities.[10] The total tonnage on train A47151-05 was 5002 plus an additional 400 tons for the two non-operating remote locomotives, which exceeded the trailing tonnage limit of 4600 tons by 17 per cent as calculated for a conventional train.

1.6 *Former BC Rail Operations*

Train operation on the steep grades and sharp curvature on the former BCR route between North Vancouver and Prince George demands extra care to avoid derailments. BCR was aware of the challenging physical environment and engaged the services of various experts in the development of its operating practices.

1.6.1 *Southward Trains*

Before 1999, the vast majority of loaded southward trains moving from Prince George to North Vancouver were DP powered with two GE Dash 8/Dash 9 locomotives at the head end and one GE Dash 8/Dash 9 remote locomotive located approximately one-half to two-thirds of the way behind the lead locomotives by car count. The mechanical staff in Prince George prepared and qualified DP locomotive consists when required. These trains weighed approximately 10 000 tons, which is slightly below the maximum haulage capacity for the three GE Dash 8/Dash 9 locomotives. With this tonnage, the train was able to reach Darcy, Mile 122.9, where all loaded southbound trains were pushed, with helper locomotives, up and over the mountains to Mons, Mile 77.4.

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10 For improved track-train dynamics, AAR guidelines recommend that heavy cars be marshalled close to the locomotives and empty cars be marshalled to the rear of the train.

BCR's review of train operating practices determined that the tractive effort capability of three GE Dash 8/Dash 9 locomotives in conventional operation would not exceed the drawbar capacity of the car equipment; therefore, there was no competitive advantage to running DP trains. It was recommended that only southward trains moving from Prince George to North Vancouver that exceeded 11 000 tons would run as DP trains. A train of this weight required at least four GE Dash 8/Dash 9 locomotives to reach Darcy.

The tractive effort capability of four GE Dash 8/Dash 9 locomotives in conventional operation easily exceeds the drawbar capacity of the car equipment; therefore, it was further recommended that the locomotives for a train this heavy be configured with two locomotives at the head end and two locomotives in the remote location one-half the way back in the train by car count. This recommendation was adopted in the spring of 2002, but from then until the spring of 2005, there were no southward DP trains operating between Prince George and North Vancouver.

1.6.2 Northward Trains

At BCR, the great majority of cars on northward trains were empties. The BCR General Operating Instructions (GOIs), commonly referred to as the "orange book," Section 10.1, which came into effect on 01 April 1995, limited lead, remote and helper engine consists to 13 500 working horsepower. Section 10.4 limited northward conventional trains[11] on ascending 2 per cent grades between Squamish, Mile 40.4 of the Squamish Subdivision, and Kelly Lake, Mile 192.6 of the Lillooet Subdivision, to 4600 tons, a maximum of 12 000 HP and a maximum of 80 cars when handling only empties.

When handling loads, the 80 empty car limit may be exceeded by the number of loads in the train. Loads must be handled immediately behind the lead consist, subject to dangerous goods marshalling instructions. DP was used on any train that had more than 80 empty cars. These restrictions were put in place to reduce the risk of long trains with light, empty cars stringlining[12] the sharp curves due to high tractive effort on steep grades. The mechanical staff situated in North Vancouver prepared and qualified DP consists when required.

DP operating instructions were revised and adopted in 2001. There were no written instructions as to how a train with non-functioning remote locomotives was to be handled. It was understood, however, that the moment that a DP train lost its ability to operate the remote locomotives, it became a conventional train for all operating intents and purposes and had to be operated under the provisions and instructions for conventional train operation.

A train design and make-up study was undertaken in 2003 to review this operating instruction and recommend other viable options for running northward conventional trains safely using a maximum of three GE Dash 8/Dash 9 operating on the head end. This study used New York Air Brake's Train Dynamics Analyzer in Fort Worth, Texas, United States, to simulate the L/V forces that would be developed as the train negotiated the curves. The AAR report *Track*

11 Train without remote locomotives positioned anywhere in the train.

12 Stringlining a curve occurs when the flanges of the wheels climb the inside rail and derail rather than travel around the curve. Due to high longitudinal and associated lateral forces while pulling, the train has a tendency to straighten out like a string pulled taut.

Train Dynamics to Improve Freight Train Performance, AAR-R-185, "TTD Guidelines for Optimum Train Handling, Train Makeup, and Track Considerations," November 1979, was also consulted (see Appendix B). Several actual test trains were analyzed in the grade territory between Squamish and Mons.

Following this review, Sections 10.1 and 10.4 of the GOIs were withdrawn. Northward conventional trains operating on ascending grades between Cheakamus and Mons, Pemberton and Birken, and Fountain and Kelly Lake were then restricted to a maximum of 13 200 working horsepower; tonnage was not to exceed 4600 tons and a maximum of 80 empties.

These restrictions were revised again in August 2003 stating that

- no more than 2700 tons are to trail any empty car that is more than 80 feet in length;
- any loaded car must be handled as close as possible to the head end;
- there is a maximum of 12 driving axles on trains handling empties only;
- there is a maximum of 18 driving axles on trains handling loaded and empty cars provided the tonnage of the empties does not exceed the haulage capacity for 12 driving axles and the trailing tonnage does not exceed 4600 tons.

The horsepower restriction was replaced with a restriction on the number of driving axles because it is excessive tractive effort not horsepower that will cause trains with long, empty cars to stringline and derail when operating through sharp curvature and on steep grades. A further revision in March 2005 removed the requirement that tonnage of the empty cars not exceed the haulage capacity for 12 driving axles and restricted trains with loaded and empty cars to 4200 tons.

Before the 2003 revision to the GOIs, BCR was running a three-train schedule northward on a daily basis. With the previous conventional train instructions (80 empties when handling conventional trains), BCR did not have the capacity to move all the tonnage with the three conventional trains unless remote locomotives or DP was used. Once the conventional train instructions were revised, DP was no longer necessary to move the tonnage.

From the time the recommendation was adopted until the spring of 2005, all northward trains operating between North Vancouver and Prince George were operated as conventional trains. Another recommendation adopted by BCR for general freight service limited the maximum permissible driving axles for a working consist of GE Dash 8/Dash 9 locomotives to 18 (three locomotives). Other locomotives could be added to the train provided they were coupled to the lead consist, and were isolated or shut down.

1.7 Operation of Former BC Rail Following Acquisition by CN

If problems with the remote power were encountered en route, the train crew would report it to CN's Network Operations Centre (NOC) who would consult with one of the four road foremen in place at the time. The road foremen were long service, experienced supervisors responsible for providing training and technical advice on train handling and engine service problems to locomotive engineers. If repairs could not be made en route, the NOC would advise what tonnage to set off and where in order to ensure that the train was handled in compliance with conventional train instructions.

Other than the locations specified in the operating bulletin for ascending grades for conventional trains, the only limiting factor was the locomotive consist "A" rating;[13] that is, the maximum amount of tonnage that a locomotive consist could pull over the controlling grade. Even over the critical areas between Cheakamus and Mons, there were never more than two units in the remote consist and rarely more than three on the head end. The "A" rating would be the controlling factor under these conditions; therefore, instructions other than where to locate the remote locomotives in the train were not required. Given the BCR schedule of three trains per day, running a train with 150 cars was seldom required except to move backlogged traffic following a main-line closure.

The NOC managed train size by the operating parameters of the Cheakamus Canyon when necessary, but primarily by siding lengths to facilitate train meets. Generally, all northward train lengths were kept between 6300 and 6700 feet, depending on the location opposing trains were scheduled to meet. Northward trains would need to fit between siding switches to allow heavier, longer southward trains to pass. A 6700-foot DP train would have no difficulty ascending the grade between Cheakamus and Mons. A conventional train was restricted by bulletin and could not achieve such a train length and still comply with the instructions.

1.7.1 Canadian National Train Operation – General Operating Instructions and Monthly Bulletins

On 15 July 2004, CN acquired the BCR system. In order to achieve operational efficiencies and cost reductions, CN planned on one train per day, using its main-line corridor eastward from Prince George for the balance of the traffic. In addition, southward tonnage originating at Quesnel and Williams Lake was moved northward through Prince George. Subsequently, it became evident that Prince George could not handle the extra tonnage and it was necessary to reroute more northward traffic than anticipated back through North Vancouver to relieve the congestion at Prince George. This extra tonnage was more than could be handled by one conventional train. Running two or more shorter trains instead of one longer train would be difficult given that there were now crew shortages due to the reduction of employees. After the acquisition, there was significant personnel turnover, including operational staff reductions and retirements. In the summer of 2005, supervisors were required to operate trains to make up for this shortfall.

Longer trains, which are more cost-efficient to operate than multiple trains, could move the tonnage if DP were used. CN envisioned the use of long DP trains as part of its operating plan following the acquisition of BCR and, in June 2005, CN resumed long train operations on the North Vancouver–to–Prince George route based on operating practices in BCR's GOIs and monthly bulletins in effect.

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13 CN does not use the former BCR "A" tonnage ratings but rather dispatches tonnage on the basis of horsepower per ton.

On 24 March 2005, Operating Bulletin 29 was issued limiting conventional trains on ascending grades between Cheakamus (Mile 50.5) and Mons (Mile 77.4) to no more than 2700 tons trailing any empty car that is more than 80 feet in length. In addition, a maximum of 18 driving axles was permitted on conventional trains handling loaded and empty cars provided the tonnage of cars does not exceed 4200 tons and the trailing tonnage inclusive of loads and non-driving locomotives does not exceed 4600 tons. The requirement for a maximum of 12 driving axles on trains handling only empty cars was removed.

The section entitled "Equipment Handling – CN Operating Manual Section 3.0" of the August 2005 monthly reissue of operating bulletins restricted lead, remote and helper engine consists to a maximum of 13 500 working horsepower on conventional trains (no remotes). The August bulletin reissue repeated the trailing tonnage restrictions in the March 2005 Operating Bulletin 29.

CN and BCR GOIs have always required that cars less than 50 feet in length must not be marshalled next to cars longer than 80 feet in length with the exception of a caboose on the rear of a train. Six of the cars following the three short loaded tank cars were empty centre beam flat cars between 79 feet 7 inches and 80 feet 6 inches in length. The three loaded 44-foot tank cars were marshalled behind a 55-foot empty box car behind the locomotives in accordance with the requirement that loaded car(s) must be placed immediately adjacent to the locomotive consist notwithstanding marshalling requirements of dangerous commodities (not next to the locomotive consist).

CN and BCR operating manuals do not discuss train length or tonnage limits for trains operating with DP other than to require the remote consist locomotives to be positioned in the train one-half to two-thirds behind the lead locomotive consist using car count.

All four people in the road foreman positions left BCR shortly after the CN acquisition (the last former BCR employee in this position retired in December 2005). The four positions have since been reduced to one. A complete description of key train operations on the Squamish Subdivision at the time of the derailment can be found in Appendix C.

1.8 Safety Management Systems

The *Railway Safety Management System Regulations* are the result of amendments to the *Railway Safety Act*, which came into force on 01 June 1999. These amendments included a requirement for safety management systems (SMS), as well as a new authority for Transport Canada (TC) to monitor safety performance and compliance with the regulations through auditing and analysis of safety performance indicators.

Under Part 2 (e) of these regulations, effective 31 March 2001, all federally regulated railway companies are required to implement and maintain an SMS that includes a process for

> (i) identifying safety issues and concerns, including those associated with human factors, third-parties and significant changes to railway operations, and
>
> (ii) evaluating and classifying risks by means of a risk assessment.

Part 2 (f) of these regulations require railway companies to include risk control strategies in their SMS. When a risk assessment is carried out by a company before a major operational change, there is no requirement for the company to provide the risk assessment to TC (other than in response to an audit request).

TC worked with CN as part of the process leading up to the acquisition of BCR by CN on 15 July 2004. CN prepared a Safety Integration Plan that was reviewed at length with TC and a number of changes to the associated plans were made as a result of these discussions. This process reviewed 19 issues, including safety culture and practices, SMS, regulatory reporting, operating practices, and work/rest and medical standards. Two areas of specific focus were

- the replacement of rock patrols with remote sensors in some areas; and
- the reduction in the number of northbound trains from three to four trains daily to a single train per day.

No formal risk assessment was performed before CN's decision to operate DP trains, although TC agreed that operating one train per day made the overall system safer as it would minimize the possibility of conflict with the passenger service between Lillooet and Darcy.

Since BCR had operated DP trains in the past according to train handling instructions approved by the former provincial regulator, the British Columbia Safety Authority, CN decided that no formal risk assessment was required when it resumed running DP trains over the territory.

1.9 Distributed Power and Remote Setup

The DP system allows powered locomotives to be located other than in the head-end locomotive consist, to be distributed throughout a train, and to be controlled by the lead locomotive just as if they were coupled for multiple unit operation. The system provides control of the remote (rearward) unit by command signals transmitted over a radio link with the brake pipe acting as a backup link. The designation "remote locomotive" applies to the controlling locomotive in a remote locomotive consist.

DP supplies the air brake system at two points in a train and provides the following advantages:

- quicker charging of brake pipe and faster application and release of air brakes;
- smoother stops, including emergency stops, as a result of the reduction of slack run in;
- improved and more selective application of tractive force, which results in smoother operation; and
- faster acceleration, reduced head-end drawbar strain, and the ability to handle longer trains without separation from overpowering.

Setup of remote locomotives in DP is done according to step-by-step procedures detailed in BCR's Locotrol II, Module 28, revision of September 2000, BCR's GOIs, Section 8, revision of March 2001, and since the acquisition by CN, CN's *Locomotive Engineer Operating Manual*, Form 8960, Section H. These instructions must be followed precisely to ensure the proper setup of the remote locomotive consist. The remote locomotive setup is done on the OIM in the controlling locomotive in the remote locomotive consist.

The DP LERs were reviewed to determine the condition of the remote locomotives. The DP for train A471 was set up and tests were performed in North Vancouver between 1420 and 1425 on August 4 by the locomotive engineer from train A470 and the electrician from Thornton Yard. Locomotive BCOL 4607 was set up as the controlling head-end locomotive or "master" and the locomotive BCOL 4621 was set up as the controlling remote locomotive or "slave." The electrician from Thornton Yard completed CN Mechanical Form MP213 verifying that the DP setup was done in accordance with established procedures and no exceptions were noted.

CN's wayside automatic equipment identification (AEI)[14] information for train A471 indicated that head-end locomotives were positioned facing forward or northbound except for the fifth locomotive, CN 2568, which was facing backward or south. Both remote locomotives BCOL 4652 and BCOL 4621 were facing backward or south, the same direction in which they arrived in North Vancouver on train A470.

When BCR was running remote locomotives on the North Vancouver–to–Prince George corridor, there was mechanical staff at both locations that would take the inward locomotives pre-assigned to a subsequent DP train, re-sequence and test the equipment for proper operation before the locomotive engineers took control of the power. Locomotive engineers were not expected to set up their power in remote mode and test it.

After the CN acquisition, locomotive engineers in North Vancouver were required to set up their remote locomotive consists with the help of an electrician from CN's Thornton Yard as mechanical staff positions in North Vancouver had been abolished. At this time, CN decided that no formal or refresher training in DP setup and operation was warranted because BCR personnel were previously trained and experienced in DP operations and BCR operating instructions had not changed following the acquisition.

BCR mechanical personnel were deemed qualified and experienced in DP setup and troubleshooting and electricians newly tasked with performing DP setup at North Vancouver had received instructions from two experienced electricians from Prince George. No formal training was provided to locomotive engineers but job briefings were conducted regarding implementing DP on train A470. In addition, the road foreman provided assistance on the shop track at times to both mechanical personnel and operating crews in setting up and testing DP locomotives.

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14 Wayside radio frequency–based system that uses electronically coded tags to automatically identify rail cars, locomotives, intermodal vehicles and end-of-train devices. The tags are placed on both sides of the cars and are encoded with various information such as car/locomotive number, length, number of axles and bearing type. Locomotive orientation can be determined from side indicator code.

1.9.1 Locomotive Faults and Alarms

Six out of the seven locomotives on train A471 were manufactured by GE and faults on GE locomotives are discussed in CN's *Locomotive Engineer Operating Manual*, Form 8960,[15] Section E.2. The diagnostic information display (DID) panel is a terminal that allows locomotive engineers to access the locomotive's on-board computer. Level 1 of the GE-9 computer system is the normal operating level of the DID panel and allows locomotive engineers to view the locomotive status and view and reset most faults that occur on the locomotive during operation.

The DID panel has three Level 1 operating modes that indicate the status of the locomotive: READY, ALARM and FAULT modes. The READY mode indicates that all locomotive systems are operating properly and the locomotive is ready to operate at full power. The ALARM mode indicates that one or more faults have occurred that would restrict locomotive operation. This mode turns on the alarm bell, displays the highest priority SUMMARY fault message (those conditions that have the greatest effect on the locomotive's ability to operate normally) and the "Silence" option on the menu line to allow the operator to silence the alarm.

The on-board computer records any abnormal conditions (faults) it detects during operation and may place restrictions on the locomotive's operation to protect the equipment. Locomotive faults will result in the activation of a Train Line 2 (TL2) alarm. All TL2 general alarms consist of an audible and visual warning (a red light shows on the panel) whenever malfunctions occur. These alarms are common and can occur for a variety of reasons. All TL2 general alarms on the remote power are relayed to the lead locomotive and are displayed on the DP OIM control console in the controlling head-end locomotive. An indicator lights up and an audible alarm sounds. Pressing the reset switch on the OIM silences the audible alarm but does not eliminate the display that indicates the alarm condition.

In FAULT mode, the computer will reset some faults automatically while certain other faults may require the locomotive engineer to take corrective action by pushing a reset button to return the locomotive to READY mode. Resetting a fault removes the operating restrictions imposed by it and the related SUMMARY messages are no longer displayed. Several faults may impose the same operating restrictions and will result in the same SUMMARY message. A fault may impose more than one operating restriction and therefore display more than one SUMMARY message. Under normal operating conditions, the SUMMARY message will display the highest priority operating restriction that has the greatest effect on the locomotive's ability to operate normally.

When "reset" is pressed, the most recent FAULT message is displayed. The locomotive engineers may choose to view older faults or reset the one displayed. As an active FAULT is reset, the system will display the highest priority SUMMARY message of the remaining active faults. Once all faults have been reset, the display will change to indicate: "Ready – Work Report Stored." Maintenance staff use the faults recorded in the locomotive fault log history to troubleshoot and maintain locomotives.

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15 CN Form 8960 was introduced in early 2005. Some training was provided for crews on the contents and application of this document.

Six-axle locomotives have six traction motors, three per truck, one per axle each operating independently of each other. Subsequent to the accident, an inspection of both remote consist locomotives was performed by CN maintenance staff. This inspection revealed high traction motor current and flashover damage that indicate that both locomotives experienced significant electrical fault conditions. High current faults occur for the thermal protection of the traction motor, and flashover faults occur due to shorting across the armature during "plugging state" when remote locomotives are commanded to go in the opposite direction from lead locomotives.[16] To protect the locomotives from further damage, each locomotive is provided with control and protection circuits designed to prevent the locomotive from developing horsepower when serious faults are detected. Faults reset automatically once; the next occurrence within a 200-minute window requires a manual reset. Alarms are given for each fault, and no more alarms were given after all the traction motors isolated themselves within 11 to 14 minutes after departing North Vancouver.

CN Form 8960, Section C3, provides basic troubleshooting for overheated support bearing, ground relay, wheel slip, locked wheels and slipped pinion faults but there are no instructions regarding action to be taken in the event of traction motor current or flashover faults and alarms. The accompanying SUMMARY message does not always give specific information regarding the reason for the fault, that is, flashover or high current such as when locomotives are pulling in opposite directions.

Although railway training material and operating manuals do not provide specific direction regarding action to be taken in the event of traction motor current or flashover faults and alarms, a traction motor flashover will cause an electrical fault (ground) to occur such that the ground relay protective circuit will be tripped. When this happens, Section C3 of CN Form 8960 states that a TL2 alarm sounds and the engine stops loading. The ground relay is either manually or automatically reset, but after three automatic resets, a manual reset is required. If the problem persists, and all traction motor cut-out combinations do not clear the fault, the locomotive must be isolated and a Mechanical Service representative (MSREP) contacted.

An MSREP is available 24 hours per day, seven days per week to assist in troubleshooting problems and provide diagnostic information to locomotive engineers. Section A1.10 of CN Form 8960 states that all locomotive failures, faults or defects must always be reported by the locomotive engineer in the following manner:

- initiate radio or telephone contact with the MSREP;
- record information on Locomotive Engineer's Report Form 538D; and
- inform the inbound Locomotive Reliability Centre supervisor when terminating at the Locomotive Reliability Centre facility.

16 The orientation of the controlling remote locomotive relative to the controlling lead locomotive determines how the direction control circuits are set up on the controlling remote locomotive during DP setup. Section H1.3.1 (7) of CN's *Locomotive Engineer Operating Manual*, Form 8960, states "Important!!! Set the direction on the controlling remote locomotive as either SAME DIR'N as lead locomotive or OPPS'T DIR'N to lead locomotive." This is required to ensure that the remote locomotives load in the same direction as the lead locomotives.

1.10 BC Rail/Canadian National Derailment History for the Squamish Subdivision

There were four BCR main-track derailments on the Squamish Subdivision between January 2000 and 31 March 2004. None of these derailments were investigated by the TSB because the railway was under provincial jurisdiction. Investigations were conducted by BCR and reviewed by the regulator, the British Columbia Safety Authority. Appendix D gives a summary of these derailments and the conclusions of the British Columbia Safety Authority.

In addition to the derailment that is the subject of this investigation report, three similar CN derailments occurred on the Squamish Subdivision in late 2005. The TSB did not conduct formal investigations into these accidents; however, investigators were deployed and preliminary assessments were conducted. Some of the preliminary results of the railway internal investigations into these derailments are also included in Appendix D.

1.11 Canadian National Emergency Response and Remediation

The rail traffic control centre, NOC, Senior Regional Officers and CN Police were advised within minutes of the incident, and outside agencies were quickly alerted as required by CN's Dangerous Goods Emergency Response Plan (DGERP) incident notification process. CN initiated its DGERP, which specifies the framework and procedures in place within CN's Canadian operations to respond safely and efficiently to the release of dangerous goods. The plan serves as the Emergency Response Assistance Plan (ERAP) filed with TC.

The DGERP is linked with CN's Environmental Emergency Response Plan, which ensures compliance with federal and provincial legislation. The DGERP details the incident notification process, the response management system and CN's incident command system (ICS) organization, which facilitates the rapid mobilization and efficient and effective use of resources. Wrecking operations were coordinated by CN at an incident command post (ICP) established at the Garibaldi Siding, Mile 59.7 of the Squamish Subdivision, three miles north of the derailment site.

CN managed the incident response from the ICP until the early afternoon when the extent of the spill and threat to life and the environment became known. An emergency operations centre (EOC) under Unified Command (UC) was then set up to manage this incident. The EOC was set up in the Squamish Emergency Program Office in Squamish. The EOC operated under the command of the British Columbia Ministry of Environment. CN and all federal, provincial and municipal responders were invited to participate. The UC structure facilitated and coordinated the involvement of the various responding agencies, blending them together to create an integrated response team with common objectives and strategies (see Appendix E for a complete list of responding agencies).

CN is working closely with federal, provincial and local agencies in the development, implementation and funding of comprehensive remediation and long-term restoration plans for the river (see Cheakamus Ecosystem Recovery Plan, 2006 Final Report, in Appendix F).

1.11.1 Provincial Emergency Program

The province of British Columbia has adopted a coordinated emergency management system called the British Columbia Emergency Response Management System (BCERMS) focused on providing for the safety and health of responders, saving lives, protecting property and preserving the province's infrastructure and economy.

The Provincial Emergency Program (PEP) is a branch of the Ministry of Public Safety and Solicitor General. The program's mandate encompasses educating the public about prevention and personal emergency preparedness, as well as providing support to local government emergency planning and response. Additionally, the program has resources to help facilitate local government recovery planning.

During large-scale emergencies, the emergency management structure is activated when a British Columbia community or any significant infrastructure is threatened by an emergency that may overwhelm a local authority's ability to respond.

The provincial emergency management structure encompasses the participation and cooperation of provincial ministries, crown corporations, volunteer groups, local and federal government, major utilities, First Nations and key industry groups. There are a core staff of about 60 people in EOCs in Surrey, Kamloops, Nelson, Prince George, and Terrace. In addition, there are over 120 trained staff from across the government who are available for deployment to help manage the EOCs.

CN notified the PEP very soon after the train derailment, activating the BCERMS. In British Columbia, the line of "first response" to emergencies is the responsibility of local government municipalities and regional districts. Municipalities and regional districts, under legislation, are responsible for having a current, integrated local emergency plan in place and maintain an emergency management organization that can be activated as an EOC. This structure contributed to the response effectiveness. The District of Squamish played a key role in the derailment response, providing an EOC (UC) facility, resources and support.

Under the Squamish Emergency Program (SEP), the District of Squamish has an Emergency Measures Bylaw that provides authorities and directs the Emergency Operations Control Group during emergencies. The Community Emergency Plan is a reference used as a guide by management staff and responders as they respond to emergencies.

2.0 Analysis

2.1 Introduction

The condition of the track and rolling stock were not considered contributory to this accident. The curvature, grade and position of the derailed cars are characteristic of an event involving high in-train draft forces. Therefore, the analysis will focus on the in-train forces (train dynamics), train operating practices, train marshalling and distributed power.

2.2 The Accident

As the train traversed the sharp left-hand curve on the ascending grade at the derailment location, high lateral forces developed on the low rail as draft forces stretched the train. Although flange and top of rail lubrication worked to reduce the lateral curving forces, a high L/V ratio resulted due to the relatively low offsetting vertical force exerted by the light weight of the empty centre beam flat cars. With the elastic fasteners, steel ties and good ballast on the curve resisting rail rollover, the wheels climbed the rail and the train derailed as it stringlined to the inside of the left-hand curve.

Due to the combination of steep ascending grade, sharp curvature, trailing tonnage and the long-short car coupling on train A471, high longitudinal forces created by excessive locomotive tractive effort concentrated on the train head end resulted in high lateral forces being developed with high L/V ratio on the derailed cars.

2.3 Distributed Power

There are economic benefits for railways to operate long trains as more tonnage can be handled with fewer crews and locomotives. Trains can be longer with DP and can be safer than long, conventional trains provided they are properly set up and operated according to established rules and practices. There are no restrictions for DP trains in either BCR or CN operating instructions other than prohibiting empty log cars and cars exceeding 80 feet in length with a gross weight of 50 tons or less within five cars on either side of the working remote or helper units.

The download data indicate that the controlling head-end master locomotive BCOL 4607 and the controlling slave locomotive BCOL 4621 were loading[17] in the same reverser direction (both forward or both reverse) although the locomotives were facing in opposite directions. If the intention was to maintain the orientation of these locomotives when they were deployed to train A471, the download data should have indicated the controlling remote unit load in the reverse direction when the head-end controlling unit loaded in the forward direction. Also, the controlling remote unit should have loaded in the forward direction whenever the head-end controlling unit loaded in the reverse direction.

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17 The term loading refers to the amperage (power) distributed to the locomotive traction motors from the main alternator that is driven by the diesel engine.

Section H1.3.1 (7) of CN's *Locomotive Engineer Operating Manual*, Form 8960, states "Important!!! Set the direction on the controlling remote locomotive as either SAME DIR'N as lead locomotive or OPPS'T DIRN'N to lead locomotive." LER data indicate that a movement test was done as part of the setup, but it was either not done properly or misinterpreted, resulting in the head-end and remote locomotives setup to pull in opposite directions. This caused the traction motors on the remote locomotives to isolate and fail-safe to an inoperative state. A manual reset then became necessary for the remote locomotives to load properly, which required the train to stop and the locomotive engineer to physically perform the reset on the controlling slave remote. Given that the route from North Vancouver to Squamish is characterized by light grades and modest curvature, train performance may not be noticeably affected with inoperative DP over this segment of the trip. Thus, the crew handling the train may not have realized the need to perform the task of manually resetting the fault condition that existed on the remote locomotive. This resulted in the remote locomotives not being available for the remainder of the trip north of Squamish.

Because the initial setup of the remote locomotives directional feature was not done properly, these locomotives went into protect mode and this power was not available. Therefore, train A471 became a conventional train subject to conventional train restrictions.

2.4 Locomotive Faults and Alarms

On a BCR GE Dash 8 locomotive, there are 584 different faults that will activate a TL2 alarm. A serious condition conveys no sense of urgency as TL2 alarms sound the same for all faults. Given the high number and frequency of faults that can activate a TL2 alarm, many of which may indicate somewhat transient or often non-critical information, locomotive engineers can be presented with a constant stream of non-distinguishable TL2 alarms. Equally, however, they may make several trips (tours of duty) without ever encountering a single alarm condition.

In order to ensure that a locomotive engineer can discern important events from background noise, it is essential that faults and alarms be presented at a rate and in a manner that can be easily assimilated by an operator. In the absence of specific details on the faults and their effect on locomotive operation, it is difficult for locomotive engineers to determine the specific fault or appropriate action when alarms occur.

The investigation determined that the traction motor current and flashover fault TL2 alarms that occurred shortly after leaving North Vancouver were silenced automatically by the locomotive computer. In the circumstances, once the remote locomotives attempted to load in the opposite direction twice, they went into protection mode and the audible alarm automatically silenced. There is no record that the North Vancouver–to–Squamish crew completed Form 538D or that the MSREP was contacted.

Since train performance did not appear to be affected by the faults and alarms (the additional power of the remote locomotives was only required north of Squamish), the crew may not have been aware of the full extent of the problem they had experienced. In this instance, the remote locomotives became inoperative when they reverted to a fail-safe and protected state in response to being improperly set up. This prevented recurrence of the alarms, but no direct indication of the inoperative state of the remote locomotives was relayed to either crew. In fact, while the remote locomotives were not loading, they did respond to throttle commands.[18] Had both locomotive consists been marshalled with a GE Dash 9 in the lead position, it would have been possible for a locomotive engineer to confirm the operational status of the remote locomotives after the TL2 alarms occurred.

The inoperative state of the remote locomotives had serious implications for train handling and the continued safe operation of the train north of Squamish. Train A47151 left North Vancouver with four operable locomotives, three of which were online delivering 11 800 HP with 18 driving axles. To compensate for the lack of remote locomotive power and to maintain speed up the grade, the lead locomotive was brought online, adding 4400 HP and six driving axles to the head end. If the train were to stall ascending the 2 per cent grade, it would require significant time and effort to resume operation. For instance, it may have been necessary to provide an additional engine and crew to double the hill.

The prospect of stalling at this location presented the locomotive engineer with potential consequences that made the risk of adding head-end horsepower not unreasonable. The conductor, who was making only his second trip on the Squamish Subdivision in 19 months and second trip on the road in 11 years, did not challenge the locomotive engineer's decision to bring another head-end locomotive online. This action resulted in train A471 exceeding powered axle and horsepower restrictions for conventional trains.

2.5 *Train Tonnage and Marshalling Restrictions*

CN's and BCR's trailing tonnage restrictions applied behind empty cars more than 80 feet in length. Following the box car and the three short 44-foot loaded tank cars were six empty centre beam flat cars between 79 feet 7 inches and 80 feet 6 inches in length. These cars for all intents and purposes are 80 feet or longer. The trailing tonnage and coupling restrictions apply to cars more than 80 feet in length, which excludes many of the centre beam flat cars. Given the intent of the instruction to limit high drawbar force on long, empty centre beam flat cars operating through high curvature, the restrictions were inadequate to capture all empty cars close to 80 feet in length, increasing the risk of derailment due to excessive trailing tonnage behind these types of cars.

This occurrence was the first of four similar derailments involving long, empty DP trains that occurred on the Squamish Subdivision between 05 August and 05 December 2005. While the contributing factors differed, the common feature of all four derailments was derailed trains stringlined to the low rail, or inside of sharp curves. The stringlining occurred due to high lateral forces creating a high L/V ratio, wheel lift and derailment (see Appendix D).

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18 Newer locomotives equipped with modern state-of-the-art Locotrol systems transmit information to the DP lead locomotive related to loading (amperage or tractive effort). Although BCR had purchased 10 Dash 9 locomotives with these newer systems, the controlling remote locomotive did not have this feature.

2.5.1 *Long Distributed Power Train Operation*

Operation of long DP trains on the former BCR territory is particularly challenging with some of the most severe grades and curves found in mountain operations. *Railway Safety Management System Regulations* require a risk assessment to be done by a railway before a significant operational change. BCR recognized that the topography could be unforgiving of even minor errors in train handling and developed comprehensive operating practices and locomotive engineer training and qualification programs accordingly.[19] Since BCR had operated DP trains in the past according to train handling instructions approved by the former provincial regulator, the British Columbia Safety Authority, CN did not consider resuming operation of DP trains a significant operational change requiring a formal risk assessment.

When CN acquired BCR, the organization was restructured to improve productivity and CN planned to use long DP trains. The number of northbound trains was reduced and the operation of long, single DP train operations was resumed in the spring of 2005. Operational staff reductions and retirements led to a shortage of train crews and loss of corporate operational knowledge and experience. The road foremen positions were eliminated and replaced with a trainmaster, a CN employee with no operational experience on the BCR territory. The CN trainmaster was to be trained by the last BCR road foreman, but due to a shortage of train crews, many supervisors including the foreman were called upon to run trains, taking them away from their mentoring and supervisory duties.

Although the locomotive engineer operating train A471 was qualified to operate DP trains between Squamish and Prince George and had done so for a number of years up until the time BCR stopped operating DP trains in June 2003, he and other locomotive engineers did not receive any formal training when CN resumed long DP train operations. In addition, with the transition back to long DP train operations, mechanical staff at North Vancouver and Prince George were no longer tasked with setting up the remote control consist independently from locomotive engineers. This task now became the joint responsibility of locomotive engineers with the assistance of a mechanical department electrician. The locomotive engineers were not provided with formal training on the proper setup of the remote locomotives.

Although CN had prepared a Safety Integration Plan and provided informal training in DP setup and operations, in the absence of a formal risk assessment, CN resumed long DP train operations without adequate consideration of the value of retaining and using local knowledge and experience in the operation of long DP trains. This resulted in a lack of training and proper supervision that contributed to this derailment.

Although damage to the environment and wildlife in the Cheakamus River was extensive, the multi-agency response to the incident was well coordinated and effective.

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19 Every locomotive engineer and some conductors new to the North Vancouver–to–Prince George route received six months' orientation, familiarization and practical training by the locomotive road foremen. Refresher training provided to improve train handling performance using the Locomotive Engineer Guide and the Freight Car Air Brake System reference manual.

3.0 Conclusions

3.1 Findings as to Causes and Contributing Factors

1. The train derailed on a 1.97 per cent ascending grade when it stringlined to the inside of the 12-degree 20-minute left-hand curve over the Cheakamus River Bridge.

2. The combination of excessive locomotive tractive effort and trailing tonnage, along with long-short car coupling, produced high lateral forces and a correspondingly high lateral/vertical (L/V) ratio and wheel lift, causing the train to stringline the curve.

3. The distributed power (DP) locomotives were set up incorrectly in North Vancouver, resulting in significant electrical faults when the remote locomotive consist was brought online, and the activation of protection circuits preventing them from developing horsepower.

4. Although Train Line 2 (TL2) alarms were generated by the faults in the remote consist, they did not result in the first crew (North Vancouver to Squamish) identifying the problem or initiating any action.

5. Because the train had been marshalled with earlier-model locomotives (GEF-40 Dash 8s) leading the head end and also controlling the remote consist, no direct indication of the inoperative state of the remote locomotives was provided to either crew. Deployment of two of the four available GEF-44 Dash 9s in these positions would have provided this indication.

6. With the DP locomotives unavailable, train A471 became a conventional train and subject to conventional train restrictions, which were not applied.

7. Bringing the lead locomotive online resulted in additional horsepower and driving axles exceeding powered axle and horsepower restrictions for conventional trains.

8. Canadian National (CN) had prepared a Safety Integration Plan and provided informal training in DP setup and operations. However, in the absence of a formal risk assessment, CN resumed long DP train operations without adequate consideration of the value of retaining and using local knowledge and experience in the operation of long DP trains. This resulted in a lack of training and proper supervision that contributed to this derailment.

3.2 Findings as to Risk

1. The General Operating Instructions (GOIs) restrictions in effect at the time were inadequate to capture all empty cars close to 80 feet in length, increasing the risk of derailment due to excessive trailing tonnage behind these types of cars.

2. In the absence of specific details on locomotive faults identified by TL2 alarms, and their effect on locomotive operation, it is difficult for locomotive engineers to determine the appropriate action when alarms occur.

3.3 *Other Findings*

1. This occurrence was the first of four similar derailments involving long, empty DP trains that occurred on the Squamish Subdivision between 05 August and 05 December 2005. While circumstances differed, the common feature of all four derailments was derailed trains stringlined to the low rail, or inside of sharp curves. The stringlining occurred due to high lateral forces creating a high L/V ratio, wheel lift and derailment.

2. The multi-agency response to the incident was well coordinated and effective.

4.0 Safety Action

4.1 Action Taken

4.1.1 Regulatory Action

Following the 05 August 2005 derailment, the TSB issued Rail Safety Advisory (RSA) 09/05 to Transport Canada (TC) on 07 October 2005. The RSA stated that, in consideration of the safety-critical nature of operating instructions, and the recent acquisition of this territory by Canadian National (CN), TC might wish to review and assess CN's equipment handling, train length and tonnage instructions to ensure that they are adequate for safe train operation over the sharp curvature and steep grades on the former BC Rail (BCR) territory. TC responded to the RSA on 08 December 2005 and to circumstances identified as a result of the three subsequent derailments on the Squamish Subdivision. TC's December 8 response discussed the Notices and Orders issued below:

> In response to the October 24th CN derailment at Mile 54 on the Squamish Subdivision (R05V0206), Transport Canada issued CN a Notice and Order on October 27th restricting northward conventional trains handling only empty cars to a maximum of 12 driving axles on steep ascending grades in the Squamish area. In response to the November 3rd CN derailment at Mile 15 on the Squamish Subdivision, Transport Canada issued another Notice and Order to CN on November 3rd to limit the length of its conventional trains to a maximum of 12 driving axles and 80 cars while operating northbound between Squamish and Clinton, B.C. CN Operating Bulletin No. 92 dated November 1 revised conventional train handling instructions on ascending grades between Cheakamus and Mons, Pemberton and Birken and Fountain and Kelly Lake to include this restriction. In addition:
>
> - tonnage was limited to 2700 tons trailing any empty car 76 feet or more in length;
> - a maximum number of 18 driving axles on trains handling loaded and empty cars provided tonnage of empty cars not exceed 4200 tons and the trailing tonnage inclusive of non-driving locomotives does not exceed 4600 tons; and
> - a conventional freight train was defined as one either without Distributed/Remote Power, or trains with such power within the make-up of the train but not operative, or which has become inoperative en-route.

The TC Notice and Order also required CN to provide TC with a detailed analysis of its distributed power (DP) train operations in the Squamish area and a comprehensive risk assessment of any changes CN has made to BCR's operating instructions. This analysis and assessment was to focus on train length, equipment, track conditions and speed. This assessment was done by a consultant (Rail Sciences) for CN and presented to TC on 22 November 2005.

CN provided new training for four supervisors who prepared a revised DP training module for use in the ALERT (Advanced Locomotive Engineer Refresher Training) program. All locomotive engineers on this territory received this training. In addition, the four mechanical staff at Vancouver were retrained in DP setup.

CN Operating Bulletin 100 was issued on 21 November 2005 following the 04 November 2005 derailment at Mile 15.5. This bulletin contained the same conventional train handling instructions as Operating Bulletin 92 except that the provision for 18 driving axles on trains handling loaded and empty cars was removed.

TC issued another Notice and Order dated 07 December 2005 following the derailment on the Squamish Subdivision at Mile 57.9 on December 5. This order limited the length of all CN freight trains, including those using DP, to a maximum of 80 cars, 6400 feet in length and 3200 tons while operating northbound between Squamish and Clinton, British Columbia. The order also restricted all freight trains to a maximum of 12 locomotive driving axles.

CN Operating Bulletin 103 covering DP–equipped northward trains on the Squamish and Lillooet subdivisions was issued on 10 December 2005 following the fourth Squamish Subdivision derailment on December 5 at Mile 57.9. It stated the following:

- trains restricted to a maximum of 99 cars and a total of 6000 tons with loads marshalled as close as possible to the head end of the train;
- long empty cars in excess of 76 feet must be marshalled in the last half of the train;
- no more than 3750 tons may be trailing any empty car that is 76 feet or more in length;
- all trains to be operated with a maximum of three working locomotives (2 head-end and 1 remote) with the single remote locomotive marshalled at least 2/3 deep in the train from the first rail car with the first 5 cars on either side of the working remote locomotive not to be greater than 76 feet in length;
- prior to departure from North Vancouver, the locomotive engineer will be provided with confirmation that DP is available and working on the train, and indication of the marshalled position of the remote locomotive within the train;
- a running test must be performed prior to departure to ensure the remote locomotive is responding properly;

- remote consist must not be placed in "isolate" mode in areas where a "COM loss" between the lead and remote locomotives is known to occur such as the tunnels at Horseshoe Bay and Seaton; and

- employees must monitor and ensure that communication is restored and verify that the remote consist is responding to commands from the lead locomotive.

CN Operating Bulletin 104 was issued on 10 December 2005 providing instructions for trains in a high throttle position experiencing an imminent and/or unrecoverable stall situation.

On 14 December 2005, TC revoked the Notice and Order issued on December 7 and issued a new Notice and Order that contained conditions for all northward freight trains operating between North Vancouver and Lillooet on the Squamish Subdivision. The order, in effect for a 60-day trial period, contained the following conditions for all northward freight trains operating between North Vancouver and Lillooet on the Squamish Subdivision in addition to instructions currently in place:

1. Operating Instructions to be issued new or revised as mutually required.

2. CN Officers to accompany all trains over the territory.

3. Operating Crews to receive ongoing mentoring and hands on training.

4. Trains will be provided with a form of exclusive occupancy to reduce stops.

5. Trains will operate with distributed power with a maximum of 99 rail cars.

6. Distributed power working consist will be 2X1 (2 head end locomotives and 1 remote).

7. CN to provide Transport Canada daily a copy of the origin list of all train 471's operated.

8. CN to provide Transport Canada event recorder data of each train 471 as timely as possible.

9. CN to provide notification to Transport Canada of planned operation of train 471, 24 hours prior to operation so a Railway Safety Inspector can monitor for compliance.

On 06 March 2006, TC revoked the Notice and Order issued to CN on 14 December 2005. This action followed completion of CN's 60-day trial period on the line on 11 February 2006 during which time there were no incidents. A new Notice and Order was issued to CN increasing the length of its DP northbound trains from 99 cars to a maximum of 114 cars in the Squamish area. The length of conventional trains operating northbound in the Squamish area remained restricted to 80 cars. CN issued Operating Bulletin 17 incorporating these operational changes.

As of April 2007, the Notice and Order issued on 06 March 2006 was still in effect. TC is satisfied that the conditions contained in the Notice and Order appear to adequately address current operations throughout this territory. Railway Safety inspectors from the TC Surface Pacific Region, as part of their compliance activities, continue to monitor the railway's operations to ensure that the levels of compliance are maintained. One of the conditions contained in the Notice and Order requires that any operating instructions, whether new or revised, be agreed upon by both TC and the railway.

4.2 Safety Concerns

This investigation revealed significant safety issues related to train operations and the use of technology. The first area of concern is with respect to the priority given to marshalling the locomotives with the safest technology in the lead position. The second area of concern relates to the need for human performance assessment of alarms to ensure that crews understand the priority that should be given to the many alarms in the cab.

4.2.1 Prioritize Use of the Safest Technology

In this accident, the remote locomotives became inoperative when they reverted to a fail-safe and protected state in response to being improperly set up. This prevented recurrence of the alarms, but no direct indication of the inoperative state of the remote locomotives was relayed to either crew.

The lead locomotive consist comprised both General Electric (GE) Dash 8 and GE Dash 9 locomotives. However, the consist was marshalled with an older Dash 8 locomotive in the lead position of the train. The Operator Interface Module (OIM) on the Dash 8s does not display the actual power output or "loading status" of the remote power whereas the more current Dash 9 would display this information.

When the DP failed, had the Dash 9s been marshalled in the lead positions, an indication of a problem would have shown on the tractive effort display, thus providing the crew with the opportunity to take corrective action.

The Board is concerned that the railways do not require trains to be marshalled so the safest technology is available to the locomotive engineer.

4.2.2 *Locomotive Alarm Systems*

On a BCR GE Dash 8 locomotive, there are 584 different faults that will activate a Train Line 2 (TL2) alarm. A serious condition conveys no sense of urgency because TL2 alarms sound the same for all faults. Given the high number and frequency of faults that can activate a TL2 alarm, many of which may indicate somewhat transient or often non-critical information, locomotive engineers can on occasion be presented with a constant stream of non-distinguishable TL2 alarms.

In order to ensure that a locomotive engineer can discern important events from background noise, it is essential that faults and alarms be presented at a rate and in a manner that can be easily assimilated by an operator. In the absence of specific details on the faults and their effect on locomotive operation, it is difficult for locomotive engineers to determine the appropriate action when alarms occur.

The Board is concerned that locomotive engineers may not be able to differentiate between the many alarms in the cab and as a consequence may not always effectively prioritize the alarms and take corrective action.

The Board is of the opinion that railways would benefit from working with human factors specialists and locomotive manufacturers to design alarms that will clearly identify the nature of the fault.

This report concludes the Transportation Safety Board's investigation into this occurrence. Consequently, the Board authorized the release of this report on 30 May 2007.

Visit the Transportation Safety Board's Web site (www.tsb.gc.ca) for information about the Transportation Safety Board and its products and services. There you will also find links to other safety organizations and related sites.

Appendix A – Fish Kill Assessment

Note: Details were taken from the report "Assessment of the CN Rail Caustic Soda Spill, August 5th, 2005 on the Cheakamus River," authored for the British Columbia Ministry of Environment and the federal Department of Fisheries and Oceans (DFO) by Instream Fisheries Research Inc.

Virtually all the free-swimming fish occupying the Cheakamus River at the time of the spill were killed. Those surviving the events were either still within the gravel as developing embryos residing in tributary streams, in back channels or had not yet entered the river from the ocean during their annual spawning or feeding migrations. A total of 4710 dead fish were collected between 05 August and 08 August 2005 from a number of locations throughout the Cheakamus and Squamish rivers downstream of their confluence. Experienced fisheries technicians and biologists from the Tenderfoot Hatchery facility (DFO) assisted volunteers in species identification, bio-sampling, categorization of age class (adult or juvenile), measurement of fork length and weight. Data were recorded and archived at the British Columbia Ministry of Environment laboratory facilities in Abbotsford.

Although the total number of fish collected is insignificant compared to the true number of fish that were killed by the caustic soda spill, the assessment report indicates that the number of fish killed can be estimated as greater than 500 000 from 10 different species and encompassing all age classes of fish present in the river at the time of the spill. The most severely affected were rearing juvenile steelhead/rainbow trout, with a mortality rate of approximately 90 per cent in four age classes, as well as multiple age classes of coho and chinook juveniles. Among adult salmon, already low returns of pink salmon were further reduced in abundance, as any spawning adults present in the river at the time of the spill were likely killed. A total of 40 to 50 per cent of the entire 2005 chinook adult salmon spawning run was lost as this proportion of the return was estimated to be in the Cheakamus River at the time of the caustic soda release.

Following the fish kill assessment, data were collected on survivors in both the main river channel and in back waters and natural and restoration channels. These data were compared with historic information that has routinely been collected and reported as part of studies on the ecology and species community of the fish resource by B.C. Hydro, Squamish Nation and regulatory agencies. Results indicate a variety of impacts, with limited survivorship of resident fish, juvenile salmonids and returned adult salmon of the 2005 brood year.

The fish kill and survivorship data indicate that multiple brood years of the majority of salmonid and all non-salmonid species will be depressed in the future. Pink salmon are slightly less affected with one of two brood years affected while chum salmon were largely unaffected as all life stages were in the ocean at the time of the incident.

Cheakamus Ecosystem Recovery Technical Committee, Cheakamus Ecosystem Recovery Plan (Appendix F) Species Impact Assessment conducted by Instream Fisheries Research Inc. for the British Columbia Ministry of Environment and the Department of Fisheries and Oceans

Chinook Salmon – A portion of the adult run was in the river at the time of the incident. It was estimated that 50 per cent of the 2005 chinook adult population was affected. It was also estimated that 90 per cent of parr juveniles from the 2004 brood year, present in the river at the time of the spill, were affected. However, the majority of chinook juveniles migrate out of the Cheakamus River during the spring as fry of the year, and it was estimated that 0 per cent of the fry juveniles from the 2004 brood year were affected.

Pink Salmon – An estimated 3 to 10 per cent of the 2005 pink salmon adult population was affected. It is estimated that no pink parr or fry juveniles were affected.

Coho Salmon – It was estimated that no adults from the 2005 brood year were affected as a result of this accident. Effects were less severe in off-channel habitats and some of the constructed side channels, which are estimated to provide 50 per cent of the annual smolt production for coho salmon and it was estimated that the spill would reduce the 2006 smolt production by 50 per cent, which is expected to affect returns in 2006 and 2007. These juveniles represent mostly fish from the 2004 brood year, with a small percentage from the 2003 brood year.

Chum Salmon – It is estimated that adverse impacts occurred to the 2005 adult chum salmon population and no juveniles were affected because the spill occurred well in advance of the chum salmon spawning and migration period.

Rainbow and Steelhead Trout – The spill occurred well in advance of the reported steelhead spawning and migration period, and it was estimated that no adult steelhead were affected as a result of the spill. It was estimated that 90 per cent of adult and juvenile rainbow (including juvenile steelhead) present in the river at the time of the spill were affected.

Cutthroat Trout, Char, Sculpins– It is estimated that 90 per cent of the adult, parr and fry population present in the river at the time of the spill were affected.

Lamprey – The magnitude of the impact on lamprey was potentially large, based on the number of mortalities recorded; however, historic and post-spill survivorship sampling efforts in the Cheakamus River did not target lamprey, and comparable density information regarding abundance was not available to estimate the level of impact. Recent sampling efforts targeted at lamprey indicate that a considerable number of lamprey from a variety of age classes likely survived the effects of the spill.

Stickleback – No attempt was made to estimate the impact of the spill on this species. Sticklebacks tend to reside in backwater areas, which largely protected them from the main effects of the spill.

Benthic Invertebrates – Sampling in the Cheakamus River after the spill documented benthic community structure upstream and downstream of the spill site. Initial observations and post-spill survival assessment of juvenile fish to monitor ongoing feeding indicated that benthic invertebrates survived in some abundance.

Following the fish impact assessment, Canadian National (CN), in cooperation with other groups studying the Cheakamus River, began assessing the actual facts on fish populations in the mainstream, side channels and in natural and restoration channels. These data are being collected over the next 10 years and compared to historical data previously collected by groups including B.C. Hydro, regulatory agencies and Squamish Nation.

The fish impact assessment and actual measured population estimates will be assessed over the coming years to determine actual long-term effects to fish population recovery as a result of the derailment and spill.

Appendix B – Train Operating Practices

The Association of American Railroads (AAR), formed in 1934, includes Canadian National (CN) and other major freight railroads in the United States, Canada and Mexico. The AAR develops standards for its members and is involved in programs to improve the efficiency, safety and service of the railway industry. The Transportation Technology Center, Inc. (TTCI) is an AAR subsidiary that helps ensure that railroads remain on the cutting edge of transportation technology. The November 1979 AAR report *Track Train Dynamics to Improve Freight Train Performance*, AAR-R-185, provides guidelines for optimum train handling, train make-up, and track considerations.

Appendix C – Trains 471, 470, 576 and 570

The locomotives and crews for train 471 are dependent on the operation of three other trains – 470, 576 and 570.

Train 471

Northbound train 471 originates daily in North Vancouver and terminates in Prince George, a distance of 462.4 miles over the Squamish, Lillooet and Prince George subdivisions. The scheduled departure time is 0215 with a total run time of 28 hours. The schedule allows for work at Squamish, Mons, Lillooet, Koster, Exeter, Williams Lake, Gibraltar, Quesnel, and Prince George. The train hauls mostly empty box cars, wood chip gondola cars and bulkhead centre beam flat cars with some mixed freight including dangerous commodities. Canadian National's (CN) train service plan (TSP) specifies a maximum length of 7600 feet for the train between Squamish and Lillooet.

Train 470

Southbound train 470 originates daily in Prince George with a scheduled departure time of 0245 and terminates in North Vancouver. The total run time allotted to this train is 31 hours and 45 minutes. The schedule allows for work at Quesnel, Dragon, Gibraltar, Williams Lake, Exeter, Koster, Lillooet, Darcy, and North Vancouver. The train handles mostly forest products with some mixed freight and dangerous commodities. The TSP for train 470 specifies a maximum length of 6900 feet for the train from Prince George through to North Vancouver. Train 470 will set out tonnage account of grade at Darcy and reduce more tonnage at Squamish if required. Train 470 sets out the remote power at Mons for train 576. The remaining power takes train 470 into North Vancouver where the locomotive engineer and an electrician set the consist for distributed power (DP) operation. The first crew on this train is from Prince George with crew change locations online at Williams Lake, Lillooet and Squamish. On arrival at North Vancouver, the crew goes off duty and is taken by taxi back to Squamish.

The locomotives for train 470 are cycled from train 471 at Prince George.

Train 576

The train crew for the train 576 switcher is ordered daily for 0800 at Squamish. The crew travels north by taxi to Mons to get on the power set off by train 470. The power is then taken north to Darcy. At Darcy, the cars that were set off by train 470 are lifted and hauled south to Squamish. This crew will also perform other switching duties as required. The crew goes off duty at Squamish and leaves their train for the crew on train 570.

Train 570

The train crew for the train 570 switcher is ordered daily for 1700 at Squamish. The crew takes the power and train that was left at Squamish by train 576 and proceeds south to North Vancouver performing online switching as required. On arrival at North Vancouver, the train terminates and the crew turns on train 471.

Train crew 471 is the crew from train 570 from Squamish (if unavailable, train 471 will be crewed from the Vancouver spareboard). Crew change locations are Squamish, Lillooet and Williams Lake.

The locomotives for train 471 come from trains 470 and 570. The train crew on train 470 takes the power to the shop track in North Vancouver and sets it up for DP operation. The locomotives from train 570 (generally two) are added to the power that train 470 brought in (other than the DP set) to complete train 471's locomotive consist.

Appendix D – BC Rail and Canadian National Main-Track Derailments on the Squamish Subdivision

Main-Track Derailments on the Squamish Subdivision Between January 2000 and 31 March 2004 under BC Rail

- On 16 April 2000, three empty cars derailed when a northbound train set out 38 loads of pulp onto 15 loaded air dumps in the north end of Porteau Siding. The three empty derailed cars were marshalled between the locomotives and the 38 cars of pulp. The cause was determined to be wheel climb on an empty centre beam flat car due to excessive buff force during car setout.

- On 18 November 2000, eight empty cars derailed on a northbound train at Mile 86.05. The 3597-ton train had 15 loads and 65 empties pulled by three locomotives on the head end and a remote locomotive located 40th in the consist. The cause of the derailment was determined to be train stringlining/wheel lift over the low rail of a 12-degree curve precipitated by an undesired emergency brake application (UDE) at the end of the train. The retarding force of the braking south half of the train, coupled with the pulling force of the still advancing head end/heavier loaded half of the train on a descending grade resulted in stringlining. The cause or source of the UDE was undetermined.

- On 05 December 2000, 17 cars loaded with sulphur derailed on a southbound train at Mile 131.5 due to narrow wheel gauge due to improper mounting and wide track gauge.

- On 27 August 2001, five empty centre beam flat cars derailed on a southbound train at Mile 156 while entering Lillooet Yard. The 3617-ton train had six loads and 84 empties pulled by two locomotives on the head end and a remote locomotive located 57th in the consist. The cause of the derailment was train stringlining/wheel lift over the low rail of a 12-degree 20-minute curve precipitated by a UDE at the end of the train. The retarding force of 74 empty cars plus the remote locomotive in emergency to the south of the derailed consist, combined with the pulling force of the two lead locomotives, caused the stringlining.

Main-Track Derailments on the Squamish Subdivision under Canadian National in the Fall of 2005

- On 24 October 2005, conventional train A47151-24 derailed 10 empty 79- to 80-foot centre beam flat cars to the inside of a 12-degree left-hand curve on a 2.08 per cent ascending grade at Mile 53.9. The train comprised five head-end locomotives, no loads and 122 empties. It was 8114 feet long and weighed 3983 tons. The derailed cars had stringlined to the inside of the curve. The railway's internal investigation determined that, initially, locomotives 3, 4 and 5 were online generating 12 400 horsepower (HP) on 18 driving axles. While proceeding up the grade, the train stalled. The third locomotive was isolated due to a power cut-out and the lead locomotive was brought online. With 12 000 HP and 18 driving axles, two attempts were made to lift[20] the train before it derailed. The trailing tonnage behind the first 80-foot empty car was 3922 tons, which exceeded the trailing tonnage limit of 2700 tons specified in the railway's General Operating Instructions.

- On 03 November 2005, distributed power train A47151-03 derailed nine empty wood chip gondola cars in two locations in the train around Mile 15. The train comprised four head-end locomotives (two online generating 8800 HP on 12 axles) and two operating remote locomotives in positions 87 and 88, nine loaded cars of pulp, 122 empty wood chip gondola cars and centre beam bulkhead flat cars. It was 8388 feet long and weighed 4913 tons. The cars derailed in a stringline fashion to the low rail, or inside of an 11-degree 50-minute right-hand curve and a 12-degree left-hand curve following a UDE while travelling at 25.4 mph on a 0.12 per cent to 0.56 per cent descending grade. Although the cause of the UDE was never determined, excessive in-train forces following the UDE was determined by the railway to be the most likely cause of the derailment. The trailing tonnage behind three long, empty centre beam flat cars in positions 16, 17 and 18 may also have played a role in this derailment.

- On 05 December 2005, distributed power train A47151-05 derailed two empty wood chip gondola cars and five empty centre beam flat cars, five cars behind the remote locomotives. The train was travelling through 12-degree left-hand and 10-degree 10-minute right-hand reversing curves on a 1.98 per cent ascending grade at Mile 57.9. The locomotive consist comprised four head-end locomotives and two operating remote locomotives in positions 69 and 70. The train comprised two loaded tank cars and 125 empty wood chip gondola cars, box cars and centre beam flat cars. It was 9166 feet long and weighed 5010 tons. The railway's internal investigation determined that, while reducing speed for a track foreman ahead, a UDE occurred and the train came to a stop. It is unknown whether this UDE caused the derailment, but the train line[21] remained intact. Brake pipe pressure was twice restored to the train to release the brakes. Two attempts were made to lift the train; however, in both cases, the train brakes had not fully released at the rear. Due to the high longitudinal force generated by the pulling of the locomotives, the empty cars derailed in a stringline fashion through the reverse curves.

20 Commence movement of the entire train from a stationary position.

21 Continuous piping throughout a train used for the charging, application and release of the air brake system.

Appendix E – Responding Agencies

The following agencies responded to this occurrence:

British Columbia Ministry of Environment
Transport Canada – Dangerous Goods
Transport Canada – Surface
Transportation Safety Board of Canada
Provincial Emergency Program
Canadian National
Environment Canada
Royal Canadian Mounted Police
District of Squamish (Squamish Emergency Program)
Vancouver Coastal Health Authority
Department of Fisheries and Oceans
Squamish First Nations
CEDA-Reactor Ltd.
Conservation Officer Service
Emergency Management British Columbia
Ministry of Public Safety and Solicitor General
Nexen Chemicals
Public Safety Canada
Quantum
Triton Environmental Consultants Limited
Squamish-Lillooet Regional District

Appendix F – Remediation Plan

After the spill, the Cheakamus Ecosystem Restoration Technical Committee (CERTC) was formed. It consisted of regulatory agencies, local governments, Squamish Nation and Canadian National (CN), with jurisdiction or directly affected by the caustic soda spill into the Cheakamus River. The CERTC mandate was to complete a comprehensive impact assessment, identify and recommend restoration strategies based on input from experienced professionals, external specialists, interested parties and the public for species affected, and to accelerate the return of the Cheakamus ecosystem to a pre-spill state as fast as reasonably possible. The Cheakamus Ecosystem Restoration Steering Committee (CERSC) was formed to review and approve programs recommended by the technical committee. Members of the steering committee include CN, the District of Squamish, the Department of Fisheries and Oceans, the British Columbia Ministry of Environment and Squamish Nation.

The Cheakamus Ecosystem Recovery Plan final report prepared for CN by Triton Environmental Consultants Limited was issued in November 2006. The report developed a restoration plan for the Cheakamus River to address the environmental and biological impacts contained in the assessment report prepared by Instream Fisheries Research Inc. Longer term ecosystem damage such as lingering toxicity due to, for example, birds feeding on fish carcasses and to habitat damage was also considered in the remediation plan.

CN has committed to restoring the river to pre-spill conditions:

- 17 August 2005 – CN will donate $250 000 to the Pacific Salmon Foundation to help start work on the salmon recovery plan for the Squamish River Watershed.

- 15 September 2005 – CN will pay $81 000 to help in the recovery of the Cheakamus River chinook and pink salmon.

- 08 February 2006 – CN agreed to pay $1.25 million over five years to restore the Cheakamus River and rebuild fish stocks.

Appendix G – Glossary

AAR	Association of American Railroads
AEI	automatic equipment identification
ALERT	Advanced Locomotive Engineer Refresher Training
BCERMS	British Columbia Emergency Response Management System
BCR	BC Rail
CERSC	Cheakamus Ecosystem Restoration Steering Committee
CERTC	Cheakamus Ecosystem Restoration Technical Committee
CN	Canadian National
DFO	Department of Fisheries and Oceans
DGERP	Dangerous Goods Emergency Response Plan
DID	diagnostic information display
DP	distributed power
EOC	emergency operations centre
ERAP	Emergency Response Assistance Plan
GE	General Electric
GOIs	General Operating Instructions
HP	horsepower
ICP	incident command post
ICS	incident command system
kg	kilograms
km	kilometres
LER	locomotive event recorder
L	lateral
m	metres
mph	miles per hour
MSREP	Mechanical Service representative
NaOH	sodium hydroxide
NOC	Network Operations Centre
OIM	Operator Interface Module
PEP	Provincial Emergency Program
pH	measure of acidity or alkalinity of a solution
RCMP	Royal Canadian Mounted Police
RSA	Rail Safety Advisory
RTC	rail traffic controller
SEP	Squamish Emergency Program
SMS	safety management system
TC	Transport Canada
TL2	Train Line 2 (alarm)
TSB	Transportation Safety Board of Canada
TSP	train service plan
TTCI	Transportation Technology Center, Inc.
UC	Unified Command
UDE	undesired emergency brake application
V	vertical
VCHA	Vancouver Coastal Health Authority
°C	degrees Celsius