An Air Quality Assessment of Alberta Transporation's Proposed Spy Hill Sand and Gravel Operations
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DM Leahey & Associates Limited
Air Quality Specialists
Expert Witness

3036 Second Street S.W.
Calgary, Alberta T2S 1T3
Tel: (403) 243-6969
Fax: (403) 243-6969
Email: dmleahey@shaw.ca

Jacques Whitford
Consulting Engineers
Environmental Scientists
Risk Consultants

Suite 500, 708 – 11th Avenue SW
Calgary, Alberta T2R 0E4
Tel: (403) 263-7113
Fax: (403) 263-7116
www.jacqueswhitford.com

EXECUTIVE SUMMARY

Alberta Transportation (AT) is proposing to develop sand and gravel operation in the Spy Hill area of Northwest Calgary. The proposed operations will be located about 400m north of the University's Agricultural Research Centre, about 1.5 km northeast of the residential communities of Royal Oak and Rocky Ridge, and 60 to 100m east of MD of Rocky View acreage residential properties. Gravel production is expected to begin in 2004 at an annual level of 0.7 million tones. This production level is expected to rise to peak aggregate production levels of about 3.6 million tones by 2022. There will be asphalt production associated with the sand and gravel operation. Asphalt production levels are also expected to reach peak production levels of about 0.85 million tones per annum by 2022.

This report provides an assessment of particulate emissions relating to the 2002 "peak conditions" operating scenario. This 2002 "peak conditions" operating scenario was assessed to determine the acceptability of air quality impacts from the highest anticipated annual emissions from the site during the next 20 years including an extraction phasing location close to an acreage residential area. Beyond 2022, annual operating volumes at the subject site are difficult to predict and may be directly related to the extent that other aggregate operations in the Spy Hill area are nearing depletion.

Maximum acceptable ambient ground-level concentrations of total suspended particulates (TSP) are governed by Alberta's Ambient Air Quality Guidelines. There is a Canadian Wide Standard (CWS) pertaining to the 98^{th} percentile daily average concentration of particulates with diameters of less than 2.5 µm ($PM_{2.5}$). There are no ambient air quality Canadian or provincial guidelines relating to PM_{10}. The United States however has ambient air quality standards for this air pollutant.

AT is proposing a program of applying dust suppressants (i.e. water, oil) to the unpaved roads and of watering and sweeping for the paved roads associated with its operations. Moisture contents of excavated materials are expected to be at the 3.0 percent level. Dust emissions from the paved and unpaved roads and other potential sources (e.g. topsoil/overburden removal and replacement, stock pile handling, conveyors) were estimated from equations obtained from studies conducted in the United States. All other potential sources of dust (*e.g.* crushers, screens, wind erosion) should be negligible because of the nature of the excavated material (i.e. wetness, size, encrustation) and blanketing effects. Emission estimates for the $PM_{2.5}$ associated with diesel engines (*e.g.* pumps, generators, loaders, scrapers, trucks) and Asphalt Plant operations were obtained either from data supplied by manufacturers or from the United States Environmental Protection Agency (USEPA).

Calculations were performed to assess the air quality impact of particulate matter emissions ($PM_{2.5}$, PM_{10}, and TSP) from all potential sources associated with AT's proposed sand and gravel operations through the use of the ISCPRIME dispersion model. This model, developed by the USEPA and accepted by Alberta Environment, allows for the air quality assessment of air emissions from pit and road sources associated with the proposed gravel mine. Meteorological data relating to wind, cloud and temperature, as obtained from the nearby Calgary International Airport were used for plume dispersion calculations. Wind information was modified to allow for effects on air flows of local terrain. Data relating to atmospheric mixing depths was derived from an Environment Canada upper air station at Stony Plain which is located about 260 km north of the proposed gravel pit.

Results of plume dispersion calculations showed that maximum ground-level particulate concentrations were not sensitive to assumed wind rose information. The highest predicted particulate concentrations occurred during the summer production period. All 98 percentile daily average values for fine particulate matter, $PM_{2.5,}$ predicted for areas outside the Gravel Pit, were much less than the Canadian Wide Standard. This was especially true for the residential communities of Royal Oak and Rocky Ridge. All daily and annual average concentrations of PM_{10}, as predicted for the environs of the Gravel Pit, were also less than relevant USEPA standards.

Maximum daily average ground-level concentrations of TSP were predicted to exceed Alberta Environment Guidelines in the near vicinity of the proposed gravel pit. Predicted exceedances usually occurred with an annual frequency of only about five times a year. This is a small level of exceedances compared to the fact that these guidelines are exceeded in all major urban areas of Canada about 10 percent of the time.

It was concluded that particulate air emissions associated with dust generation and diesel exhausts from activities at AT's proposed sand and gravel operations should have no adverse effects on the environment. This conclusion with respect to fine particulates ($PM_{2.5}$) is consistent with results of observational studies conducted at a typical stone crushing plant in the United States.

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1.0 INTRODUCTION

Alberta Transportation (AT) is proposing to develop sand and gravel operations in the Spy Hill region within the northwest portion of the City of Calgary adjacent to the M.D. of Rocky View. An aerial photo of the location of expected operation in 2022 is presented in Figure 1. The Gravel and Backfilled Pits are shown as being in the near vicinity of the University of Calgary's Agricultural Research Centre, the Province of Alberta's Spy Hill Remand Centre and Young Offender's Centre and 60 to 100m east of MD of Rocky View acreage residential properties. Lafarge Canada Inc.'s Spy Hill sand and gravel operations lie about 500m to the northeast of the proposed operations. The residential communities of Royal Oak and Rocky Ridge lie about 1.5 km to the southwest of the proposed development. Sand and gravel production is anticipated to begin in 2004 at a peak daily rate of about 4,000 tonnes (annual average level of about 0.7 million tonnes). It is estimated that peak daily production levels will reach values of about 20,335 tonnes in 2022 (3.6 million tonnes on an annual average basis). (Brown and Associates Planning Group and Russ Gerrish Consulting (2002)) Asphalt production will be associated with the sand and gravel operations with annual production levels reaching values of about 0.85 million tonnes in 2022.

The purpose of this study is to assess the air quality implications with respect to particulate emissions from the proposed sand and gravel operations within the areas shown in Figure 1. (This figure also shows the boundary line of the Gravel Mine area within which proposed operations will occur over about a 50 year period.) The assessment involved an evaluation of the 2022 operating scenario because it includes the highest anticipated annual emissions over about the next 20 years and because it includes an occasion when the gravel pit will be closest to expected community development on the west side of 101st Street NW.

In 2022 the proposed AT sand and gravel operations will involve a peak daily processing of upwards to approximately 32000, 38000, and 20335 tonnes of removal/replacement of top soil and overburden and gravel production respectively. There will be an associated daily asphalt production of about 5000 tonnes from a plant located in the Backfilled Pit (annual average level of about 850,000 tonnes). This production will occasionally be supplemented over short periods of time through operations of a mobile plant. Gravel excavations will begin along the east end of the southern boundary of the AT property and will proceed westward and northward over about a 50 year period. Areas for the Gravel and Backfilled Pits as shown in Figure 1 correspond to the 2022 operating scenario with the gravel pit in the nearest vicinity of MD of Rocky View acreage residential properties which lie to the west of 101st Street NW. Depths of Gravel and Backfilled Pits will be about 32 and 19 m respectively. Operations within the Gravel Pit will include topsoil/overburden removal and replacement, gravel excavations, stockpiling, and crushing operations. Conveyors will be generally used to transport mined and processed gravel within the Gravel Pit and between the Gravel Pit and the asphalt plants, located in the Backfilled area.

The road system associated with AT's proposed sand and gravel operations is also shown in Figure 1. Roads within the Gravel and Backfilled Pits will be respectively watered and oiled for purposes of dust suppression. Trucks will transport gravel to market along 85 Street NW. About 50 % of the trucking will proceed north and the remainder 50 % south along this public paved highway. At the junction of 85th Street N.W. and 144 Ave. NW (Burma Road), the majority of northward bound traffic will proceed east on 144^{th} Avenue. (Finn Transportation Consultants (2003)).

This air quality assessment presents an estimate of particulate emissions from AT's proposed sand and gravel operations as they relate to road dust generation and diesel engine activities. It then compares resulting estimates of ambient particulate concentrations, predicted using plume dispersion model calculations, to regulatory guidelines.

2.0 STUDY SCOPE

Maximum ground-level concentrations of total suspended particulates (TSP), are governed by nationwide objectives. Total suspended particulate denotes what is measured by a high volume sampler. It is often associated with PM_{30} (particulate matter with diameters of less than 30 µm). Up to three objective values have been recommended for TSP by Environment Canada using the categories "desirable," "acceptable" and "tolerable." The desirable objective is the most stringent. The general intent of the objectives is described in Table 2.1. The current Alberta guidelines (Alberta Environment 2000a) for TSP associated with diesel emissions and comparable national ambient air quality objectives are shown in Table 2.2. There are no hourly average guidelines or objectives for TSP. Alberta's guideline for 24-hour maximum concentrations for TSP is more stringent than the corresponding desirable National Ambient Air Quality Objective.

Table 2.1 Description of the Federal Ambient Air Quality Objectives

Objective Description	
Maximum Desirable (most stringent)	Long-term goal for air quality. Provides a basis for anti-degradation policy for unpolluted parts of the country and for continuing development of control technology.
Maximum Acceptable	Provides adequate protection against adverse effects on soil, water, vegetation, materials, animals, visibility, personal comfort and well being.
Maximum Tolerable (least stringent)	Indicates appropriate abatement strategies required without delay to avoid further deterioration to air quality to protect the health of the general population.

Table 2.2 Ambient Air Quality Guidelines for TSP for Alberta and Comparable National Ambient Air Quality Objectives

Parameter	Alberta* µg m^{-3}	National Ambient Air Quality Objective (NAAQO)*	
		Desirable Objective µg m^{-3}	Acceptable Objective µg m^{-3}
1-Hour Maximum	-	-	-
24-Hour Maximum	100	-	120
Annual Mean	60	60	70

*Concentrations given in micrograms per cubic metre at 25 °C, 101 kPa, dry basis

Canada's long-term air quality management goal for particulate matter is to minimize their risks to human health and the environment. As a result a Canada Wide Standard (CWS) has been established for fine particulate matter, $PM_{2.5}$ (particulate matter with diameters of less than 2.5 µ m). It represents a balance between the desire to achieve the best health and environmental protection possible in the relative near- term and the feasibility and costs of reducing pollutant emissions that contribute to elevated $PM_{2.5}$ in ambient air.

The recently established CWS for $PM_{2.5}$ is presented in Table 2.3. It is to be implemented by year 2010. CWS achievement is based on the average results from community-oriented monitoring sites, *i.e.* sites located where people live, work and play rather than at the expected maximum impact points for specific emission sources.

Table 2.3 CWS for $PM_{2.5}$

$PM_{2.5}$	30 µg m^{-3} averaged over a 24-hour period. Achievement will be based on the 98th percentile ambient measurement annually, averaged over 3 consecutive years.

There are currently no guidelines in Canada relating to annual averages of $PM_{2.5}$ or to daily and annual averages of PM_{10}. National Ambient Air Quality Standards in the United States not only stipulate a 98th percentile level for acceptable daily average $PM_{2.5}$ concentrations of 65 µg m^{-3}, but also an annual standard for the three year annual arithmetic mean of 15 µg m^{-3}. There is also a daily average standard for the 99th percentile value for coarse particulate matter (PM_{10}) of 150 µg as averaged over three years. The annual average standard for PM_{10} in the United States is 50 µg m^{-3}.

Ambient concentrations of TSP are no longer regulated by the USEPA.

3.0 EMISSIONS ASSOCIATED WITH ALBERTA TRANSPORTATION'S PROPOSED SPY HILL SAND AND GRAVEL OPERATIONS

Gravel and processing pit operations at the proposed AT facility will generally occur six days a week (Monday to Saturday) for twelve hours a day (07:00am – 07:00pm). Maximum production over the six month summer production period (1 May- 31 October) from the gravel pit, which will have a depth of about 32 m, is anticipated to be about 3,200,000 tonnes. Operations will also proceed on the same schedule during the winter production period (1 November- 30 April) but at a much reduced production level of only about 340,000 tonnes.

Operations at the proposed Gravel and Backfilled Pits involve the excavation, processing and transportation of sand and gravel through the use of diesel driven generators and diesel trucks whose exhausts will be sources of $PM_{2.5}$. Road traffic, conveyor transfer points, handling of storage pile material and topsoil/overburden removal and replacement will be dust sources not only of $PM_{2.5}$ but also of PM_{10} and TSP. Other potential sources of dust such as crushers and screening decks should be of negligible concern because the moisture content of the sand and gravel material is anticipated to be at about 3 percent. They may, therefore, be considered wet and consequently not significant sources of particulate emissions. (Richards and Palm 2000). This is especially true because much of the equipment will be blanketed for purposes of noise control. Stack emissions associated with operations of the asphalt plants will also be a source of fine particulates ($PM_{2.5}$).

Exhaust Emissions

Tables 3.1 and 3.2 present estimates of type and number of diesel equipment/engines that will be involved in Gravel and Backfilled Pit operations during summer and winter production periods respectively. As expected there will be many more engines involved in operations during the more active summer period. A comparison of Tables 3.1 and 3.2 shows that all scraper operations have been assumed to occur during the busy summer season. This is a conservative assumption because the removal and replacement of top soil material and overburden usually occurs in the off-season. (i.e.winter).

Emission factors relating to $PM_{2.5}$ for diesel engines as shown in Table 3.3 (g/bhp.hr) for the loaders and scrapers were supplied by Caterpillar Inc. Emission rates for other equipment, shown in Table 3.3 were obtained from AP-42 emission factors published by the United States Environmental Protection Agency (1998b, 2000a). As may be seen, the emission factor for the generators is greater than for the mobile machines (loader, scraper, tractor and grader).

Table 3.1 Diesel Engines Assumed to be at Alberta Transportation's Proposed Spy Hill Gravel Mine during the Summer Production Season (1 May – 31 October).

Engine	Number
Generator	4
Loader	4
Scraper	4
Tractor	1
Grader	1
Hydraulic Shovel	1

Table 3.2 Diesel Engines Assumed to be at Alberta Transportation's Proposed Spy Hill Gravel Mine during the Winter Production Season (1 November-30 April)

Engine	Number
Generator	1
Loader	2
Hydraulic Shovel	1

Table 3.3 Emission Factors Relating to $PM_{2.5}$ for the Indicated Diesel Engines (g/bhp·hr)

Engine	Brake Horsepower (bhp)	$PM_{2.5}$
Generator	500	1.00
Loader	311	0.29
Scraper	550	0.084
Tractor	850	0.40
Grader	215	0.40
Hydraulic Shovel	1550	0.40

Diesel driven trucks used to transport sand and gravel products will generate $PM_{2.5}$ as a result of their exhausts. They will also generate particulates as a consequence of road dust. During the summer (winter) production season there will be a maximum of about 302 (32) round trips/day for the Tandem Trucks. There will be 227 (24) round trips/day for Truck-Trailer and for the B-Train combinations. (Values shown in brackets refer to the winter production season.) Lengths of roads associated with operations at each pit as evaluated for this study are shown in Table 3.4. The maximum estimated length of the unpaved roads within the gravel pit, which will be watered for dust suppression, is 455 m. The paved industrial road refers to the Scale House access road. The public paved road refers to 85th Street N.W and 144th Avenue NW (Burma Road). Weights of the empty and loaded Tandem

Trucks are 9 and 24 tonnes respectively. Comparable weights for Truck-Trailer and B-Train combinations are 17 and 52 tonnes.

Table 3.4 Road Lengths (m) Associated with Operations at Alberta's Transportation's Spy Hill Gravel Mine.

Road Type	Road Length (m)
Paved:	
Industrial	200
Public	11,530
Unpaved:	
Industrial (Oiled)	1,330
Industrial (Watered)	455

An exhaust emission factor for on-highway heavy duty diesel engines for $PM_{2.5}$ of 0.09 g/bhp.hr was obtained from the Cummins Engine Company Inc. of Columbus Ohio. This was converted to a value for average weight (loaded and unloaded) Tandem Trucks of 0.13 g/vehicle km travelled through use of conversion factors for heavy-heavy duty trucks as provided by weight by the United States Environmental Protection Agency (USEPA 1998b). The comparable values for the Truck-Trailer and B-Train combination was 0.16 g/vehicle km travelled. It was assumed in the obtaining of conversion factors that the model year for the diesel trucks was 1996. Values for the conversion factor were not sensitive to this assumption as to model year. If, for example, the 1987 model year were assumed, the comparable conversion factor would be only ten percent greater than the value employed for this study.

Dust Emissions

Paved and unpaved roads, and procedures involved in topsoil removal and overburden replacement are major sources of dust emissions.

Road Dust Emissions

The quantity of fine dust emissions, $PM_{2.5}$, from vehicular traffic on paved roads was estimated using an expression provided by the United States Environmental Protection Agency (2000a):

$$E = 1.1\ (sL/2)^{0.65}\ (W/3)^{1.5} \qquad (1)$$

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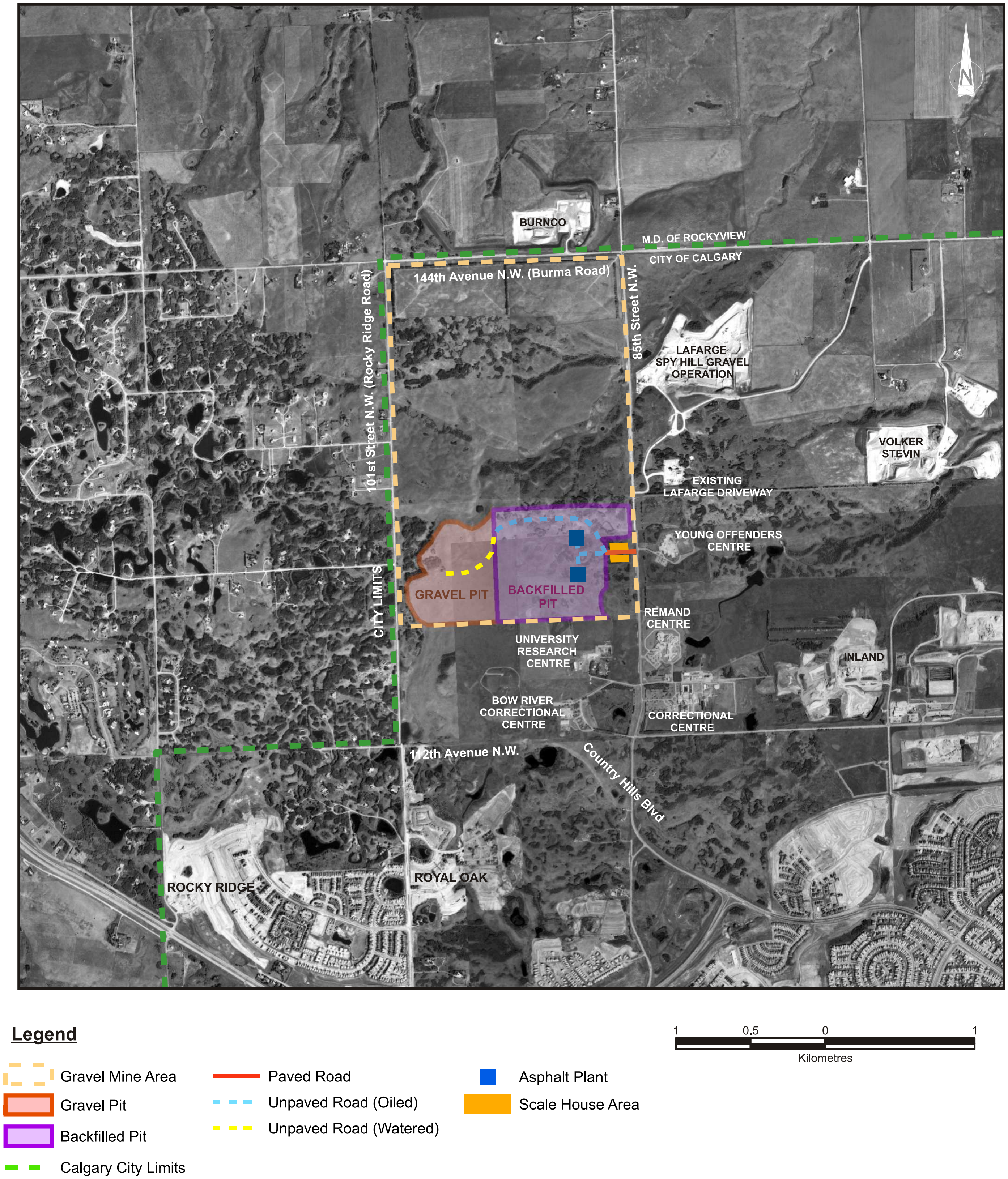


Figure 1 **Aerial Photograph of the Area Surrounding Alberta Transportation's Proposed Spy Hill Sand and Gravel Operations. Expected Locations for the Gravel and Backfilled Pits are Shown for the Year 2022.**

Where E is the $PM_{2.5}$ emission rate for paved roads (g/vehicle km travelled); sL is the road surface silt loading (g/m^2), and W is the mean vehicle weight (tons). Comparable emission values for PM_{10} and total suspended particulates were obtained by multiplying $PM_{2.5}$ emission values by the factors 4.2 and 21.8 respectively as recommended by the United States by the United States Environmental Protection Agency.

The industrial paved Scale House access road will be swept and watered, as required during dry weather, to ensure that road silt loading (sL) will be maintained at levels of less than 1 g/m^2. It was assumed that public paved roads would have a silt load of 0.10g/m^2 which is a maximum observed for heavily travelled public highways (USEPA 2000b). Average weight for the empty and loaded Tandem Trucks is 16.5 tonnes. The comparable value for the Truck Trailer and B-Train combinations is 34.5 tonnes.

For vehicles travelling on unpaved surfaces emission of total suspended particulates TSP, PM_{10} and $PM_{2.5}$ were respectively estimated from equations (2) (3) and (4) as recommended by the United States Environmental Protection Agency (2000a).

$$E = 1381\left(\frac{S}{12}\right)^{0.7}\left(\frac{W}{3}\right)^{0.45}(100 - CE)100 \qquad (2)$$

$$E = 422.8\left(\frac{S}{12}\right)^{0.9}\left(\frac{W}{3}\right)^{0.45}(100 - CE)100 \qquad (3)$$

$$E = 64.8\left(\frac{S}{12}\right)^{0.9}\left(\frac{W}{3}\right)^{0.45}(100 - CE)/100 \qquad (4)$$

Where E = emission rate (grams per vehicle km travelled (g/V KT).
S = surface material silt content (%).
W = mean vehicle weight (tons).
CE = control efficiency (%)

It has been conservatively assumed that CE has a value of 0.0 when the surface moisture content is at 3.0 percent.

It was assumed for purposes of these analyses that dust suppression on unpaved oiled roads, during the summer production period would be accomplished by the maintenance of a minimum ground inventory of 1 litre/square metre of petroleum resin (or equivalent) through necessary oil applications. This application corresponds to a CE for TSP, PM_{10} and $PM_{2.5}$ of 75, 85 and 85 percent respectively. Unpaved roads, that are not oiled, are estimated to have a silt content of 8%. These roads will be watered on a regular basis during dry weather at a frequency sufficient to maintain road moisture content at 6 percent. This corresponds to a *CE* value for watered unpaved roads of 75 percent for all dust particle sizes. (United States Environmental Protection Agency 2000a). It has been further assumed that during the winter production period the effects of freezing, snow cover and melting during Chinook periods will be such as to suppress dust emissions on unpaved roads to 50 percent of that level which might occur under uncontrolled conditions during summer months.

Removal/Replacement of Topsoil or Overburden

There will occasionally be a maximum of about 32,000 and 38,000 tonnes per day of removal/ replacement of topsoil and overburden respectively at the proposed gravel pit. These operations are often conducted during periods of low gravel extraction activities such as the winter season. It has, however, been conservatively assumed, as has been previously mentioned, that the removal/replacement of topsoil and overburden will occur during the summer season when gravel operations and associated dust generation will be greatest. This assumption will tend to overestimate gravel pit dust emissions during the summer season by about 30 %.

The TSP emission factors for topsoil removals by scraper and overburden replacement are 0.029 and 0.006 kg/tonne respectively (USEPA2000b). Estimates for PM_{10} and $PM_{2.5}$ were obtained by assuming that their ratios to TSP would be the same as for unpaved roads.

Conveyor Belt Emissions and Stockpile Handling

Excavated sand and gravel within the Gravel Pit will generally be stockpiled through the use of stackers which employ conveyor belts. It will be removed from the stockpiles through truck loading.

Dust will be generated at conveyor transfer points which are locations where a stream of gravel/sand makes an abrupt change in elevation as it is discharged from one conveyor to another or to a stockpile. Drop heights between conveyors and to stockpiles will be minimized to ensure that they do not exceed values of 0.3m. Potential for dust emissions will be low because drop heights are low (Richards, Brozell, and Palm 2000) and because of the relatively high moisture content of the processed material which is expected to be about 3 %. It was assumed for these reasons that conveyor emissions would be only 0.0065, 0.024 and 0.142 g per tonne of handled material for $PM_{2.5}$, PM_{10} and TSP respectively. The values for $PM_{2.5}$ and PM_{10} emissions were estimated from information supplied by Richards and Palm (2000). The emission value for TSP was estimated assuming that the ratio of TSP to $PM_{2.5}$ would be the same as for unpaved roads.

Dust will be generated at stockpiles at AT's Gravel Pit through the process of material removal. The quantity of $PM_{2.5}$ generated by loader/truck operations associated with removal may be estimated through use of the following equation (USEPA 2000b)

$$E = \frac{0.00018 \left(\frac{U}{2.2}\right)^{1.3}}{\left(\frac{M}{2}\right)^{1.4}} \text{ kg/tonne}$$

Where *E* is the emission factor, *M* moisture content (%) and *U* mean wind speed (m s^{-1}). The total quantity of stockpile material removed under the worst case scenario assumed for the present analyses would be about 20,000 tonnes per day. *M* was assumed to have a value of 3.0 %. Emission rates for PM_{10} and TSP are respectively about 3.2 and 6.7 times greater than the values given in the above equation for $PM_{2.5}$ (USEPA 2000b).

Wind Erosion

Wind erosion of the sand and gravel stockpiles will not create regional air quality problems firstly because these piles tend not to contain the fine particulate matter associated with adverse health effects ; secondly because the stockpiles tend to be encrusted, which makes them relatively impervious to wind disturbances; thirdly because the high wind velocities associated with wind erosions, which are usually in excess of 50 km h^{-1} (USEPA2000a) will quickly dissipate any disturbed material and finally because the high deposition velocities of large diameter particles from the stockpiles will cause them to be deposited within tens of metres of the source. It has been estimated that under high wind speed conditions, for example, that daily wind erosion from a highly disturbed coal stockpile, which is arguably similar to a sand and gravel stockpile, will be typically only about 250 g (USEPA2000a). This amount is very small when compared to other sources of particulate emissions.

Asphalt Plants

There will be a counterflow drum mix asphalt plant with a stack height of about 8 m situated in the Backfilled Pit as shown in Figure 1. Annual production will be at a level of about 850,000 tonnes per year. Production from this plant will be occasionally supplemented by similar production from a mobile plant. Ninety and ten percent of asphalt production will respectively occur during the summer and winter production periods. Particulate stack emissions will be controlled through the use of fabric filters.

Stack emissions of $PM_{2.5}$, PM_{10}, and TSP will be respectively about 3.5, 11.5, and 16.5 g per tonne of production (USEPA 2000c). It was conservatively assumed that two asphalt plants would be continuously operating at similar production levels in the Backfilled Pit. This assumption will tend to overestimate $PM_{2.5,}$ PM_{10} and TSP emissions from the Backfilled Pit (which includes those from diesel engines and dust sources) by about 45%, 25% and 7% respectively.

It was assumed that particulate emissions from the 8m asphalt plant stacks would be entrained within air flows of the 19m deep Backfilled area and would be emitted as part of the associated pit source.

Summary

A summary of emission values of particulates from diesel exhausts for the summer and winter production periods are shown in Tables 3.5 and 3.6 respectively. Estimated emissions are much lower during the winter period because of the lower level of production. Most of the emissions will be from the Gravel Pit which contains the electrical generators and much of the other diesel driven equipment.

Table 3.5 Summary of Particulate Emissions (g s^{-1}) from Diesel Exhausts from the Indicated Sources during the summer production period. (1 May-31 October)

Air Contaminant	Source Area	Emission Rate (g s^{-1})
$PM_{2.5}$	Paved Roads (Industrial)[a]	0.00105
	Paved Roads (Public)	0.02050
	Backfilled Pit[b]	0.00594
	Gravel Pit[c]	0.99700

[a] Road Emissions reported are total emissions from the particular category of road and may be different on sections of the same category of road, depending upon the type and amount of traffic, road maintenance and distance from the industrial site.
[b] Backfilled Pit Area Emissions include diesel exhaust emission from Trucks travelling on Unpaved Roads (oiled).
[c] Gravel Pit Area Emissions include emission from Loaders, Generators, Tractors, Scrapers, Grader, Packer, Hydraulic Shovel and Trucks travelling on Unpaved Roads (watered) inside the pit.

Table 3.6 Summary of Air Contaminant Emission Values (g s^{-1}) from Diesel Exhausts for the Indicated Sources (1 November-30 April)

Air Contaminant	Source Area	Emission Rate (g s^{-1})
$PM_{2.5}$	Paved Roads (Industrial)[a]	0.000117
	Paved Roads (Public)	0.00227
	Backfilled Pit[b]	0.00065
	Gravel Pit[c]	0.36100

[a] Road Emissions reported are total emissions from the particular category of road and may be different on sections of the same category of road, depending upon the type and amount of traffic, road maintenance and distance from the industrial site.
[b] Backfilled Pit Area Emissions include diesel exhaust emission from Trucks travelling on Unpaved Roads (oiled).
[c] Gravel Pit Area Emissions include emission from Loaders, Generator, Hydraulic Shovel and Trucks travelling on Unpaved Roads (watered) inside the pit.

Tables 3.7 and 3.8 present estimates of particulates from the various dust sources: paved roads, Gravel Pit and Backfilled Pit. Emissions assigned to the Gravel Pit in this Table include emissions from topsoil/overburden removal by scrapers and dust from conveyor belt activity. The largest sources of particulate emissions during the summer and winter production periods tend to be the Gravel and Backfilled Pits respectively. Emissions from these sources, as has been previously explained, have been conservatively estimated through assumptions relating to limiting scraper activities to summer months and to the continuous presence of two operating asphalt plants.

Table 3.7 Summary of Air Contaminant Emission Values (g s^{-1}) Associated with Dust Sources from the Indicated Sources (1 May-31 October)

Air Contaminant	Source Area	Emission Rate (g s^{-1})
$PM_{2.5}$	Paved Roads (Industrial)[a]	0.162
	Paved Roads (Public)	0.705
	Backfilled Pit[b]	1.520
	Gravel Pit[c]	1.580
PM_{10}	Paved Roads (Industrial)[a]	0.678
	Paved Roads (Public)	2.950
	Backfilled Pit[b]	7.420
	Gravel Pit[c]	9.070
TSP	Paved Roads (Industrial)[a]	3.540
	Paved Roads (Public)	15.400
	Backfilled Pit[b]	32.200
	Gravel Pit[c]	33.500

[a] Road Emissions reported are total emissions from the particular category of road and may be different on sections of the same category of road, depending upon the type and amount of traffic, road maintenance and distance from the industrial site.
[b] Backfilled Pit Area Emissions include emission from Conveyor Transfer Points, Asphalt Plants and dust emissions due to Trucks travelling on Unpaved Roads (oiled).
[c] Gravel Pit Area Emissions include emission from Topsoil/Overburden removal, Scraper, Handling Active Storage Piles and dust emissions due to Trucks travelling on Unpaved Roads (watered) inside the pit.

Table 3.8 Summary of Air Contaminant Emission Values (g s^{-1}) Associated with Dust Sources from the Indicated Sources (1 November-30 April)

Air Contaminant	Source Area	Emission Rate (g s^{-1})
$PM_{2.5}$	Paved Roads (Industrial)[a]	0.018
	Paved Roads (Public)	0.078
	Backfilled Pit[b]	0.361
	Gravel Pit[c]	0.119
PM_{10}	Paved Roads (Industrial)[a]	0.075
	Paved Roads (Public)	0.326
	Backfilled Pit[b]	2.070
	Gravel Pit[c]	0.748
TSP	Paved Roads (Industrial)[a]	0.391
	Paved Roads (Public)	1.700
	Backfilled Pit[b]	6.740
	Gravel Pit[c]	2.610

[a] Road Emissions reported are total emissions from the particular category of road and may be different on sections of the same category of road, depending upon the type and amount of traffic, road maintenance and distance from the industrial site.
[b] Backfilled Pit Area Emissions include emission from Conveyor Transfer Points, Asphalt Plants and dust emissions due to Trucks travelling on Unpaved Roads (oiled).
[c] Gravel Pit Area Emissions include emission from Handling Active Storage Piles and dust emissions due to Trucks travelling on Unpaved Roads (watered) inside the pit.

4.0 PLUME DISPERSION MODELLING APPROACH TO PREDICTING AIR QUALITY CHANGES

Plume dispersion model calculations were performed in order to estimate ground-level air quality changes that might be attributable to emissions of $PM_{2.5}$, PM_{10}, and TSP associated with operations at AT's proposed sand and gravel operations.

Air emissions from the proposed sand and gravel pits will be primarily from excavation and road sources. Ground-level concentrations of air emissions from these sources, have been estimated through use of the ISCPRIME plume dispersion model which was developed for the United States Environmental Protection Agency. Recommended by Alberta Environment, this model is universally known, widely accepted, and well documented. It is constantly being reviewed and updated by USEPA as better data and correlations are obtained.

Plume dispersion calculations were performed using three grid systems. The first grid system comprised the entire study area with 250 m spacing. The second grid, used for evaluations of $PM_{2.5}$ concentrations, was comprised of receptors with 50 m spacing extending 250 m along both sides of all roads and along the edges of the Gravel and Backfilled Pits. The third grid, used for evaluations of PM_{10} and TSP, was similar to the second grid except that it was comprised of receptors with 100 m spacing extending 100 m along both sides of the road.

Dispersion meteorology data relating to wind speeds, wind directions, atmospheric stability and mixing heights were needed to estimate hourly average concentrations of the particulate emissions.The area surrounding the proposed sand and gravel operations was assumed to be characterized by a roughness length of 0.30 m with Monin-Obukhov lengths being dependent on Pasquill stability classes in the manner proposed by Golden (Seinfeld and Pandis 1998). Five years of meteorological data were used to predict maximum daily concentration averages. More details pertaining to assumptions regarding atmospheric stability conditions, and mixing height distributions are contained in the Appendix.

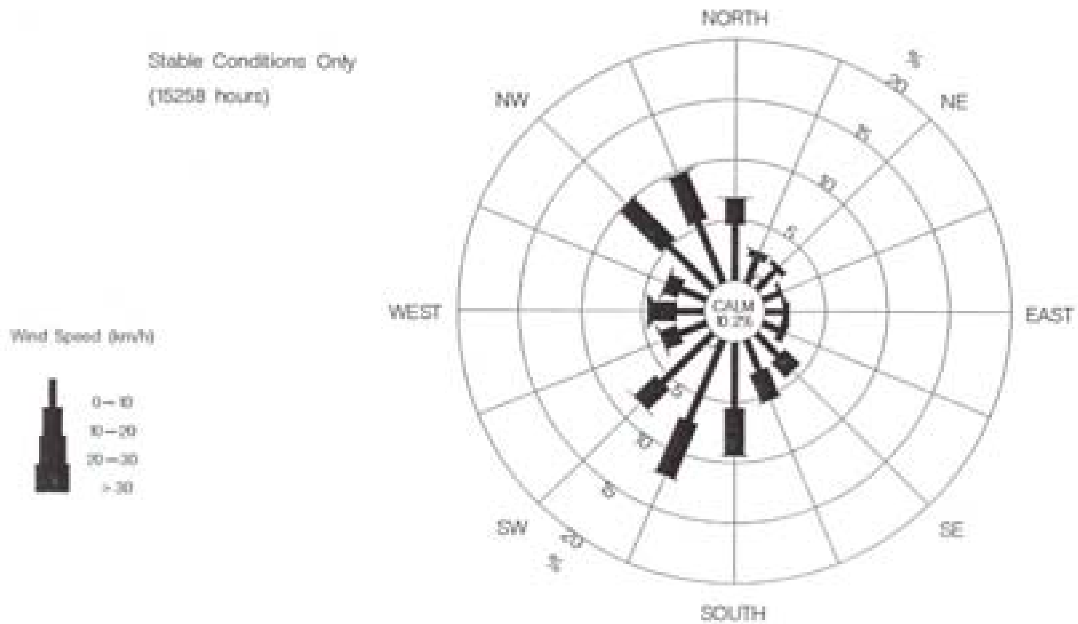
The proposed sand and gravel operations will be situated in an area on Spy Hill where the slope of the land is such as to channel winds towards an east-north-easterly direction. This is especially true for stable atmospheric conditions which tend to occur at night under clear skies. During these periods cool dense air near the ground will tend to drain down topographical gradients in an east-north-easterly direction into local valleys.

Figure 2 shows wind roses obtained from data collected over a five year period (1 November 1996 to 31 October 2000) at the Calgary International Airport, which lies about 20 km east of the study area, for stable conditions only and for all atmospheric conditions. Wind roses are a convenient means of presenting wind velocity data. The total length of a "barb" indicates the frequency of all winds **from** a given direction. The frequency of wind speed classes is given by the thickness of the barb. Thus for example Figure 2 shows that at Calgary International Airport NW winds occurred 10 percent of the time under stable atmospheric conditions, while NW winds with speeds between 10 and 20 km h^{-1} occurred about 5 percent of the time under these conditions.

The wind rose for stable atmospheric conditions as shown in Figure 2 demonstrates a tendency for NNW and SSW winds. These reflect the local drainage influences at the Airport site of the Ghost River Valley and Nose Hill. There is no tendency for the east-north-east drainage patterns that would be expected at AT's Spy Hill site because of down slope influences. (Such a drainage pattern would be shown in a wind rose, which shows the frequency of winds **from** a given direction, by a tendency for the occurrence of west-south-westerly winds).

Winds from the Calgary International Airport for stable atmospheric conditions were subjectively adjusted such that the indicated air flow would be more representative of conditions expected at the AT's Spy Hill site. Results of the modification as shown in Figure 3 demonstrate a greater tendency for west-south –west wind flows than does the unmodified wind rose. Wind data from both the modified wind rose and the unmodified wind rose (as obtained from the Calgary International Airport) have been separately employed to evaluate emissions associated with AT's proposed sand and gravel operations.

Deposition calculations were performed for dust particles assuming that TSP was fractionated between PM_{30}, PM_{10} and $PM_{2.5}$, in the manner presented in Table 4.1. (These fractions are consistent with emissions presented in previous tables). Values shown in brackets refer to the winter production period. The highest fraction of TSP emissions to be $PM_{2.5}$ occurs in the Gravel Pit because of diesel exhaust emissions from associated electrical generators. (PM_{30} relates to particulates with diameters of less than 30µm; PM_{10} relates to particulates with diameters of less than 10µm etc.). Deposition velocities for PM_{30}, PM_{10} and $PM_{2.5}$ as incorporated into ISCPRIME modeling calculations are respectively 7.21, 0.80 and 0.05 cm s^{-1}.



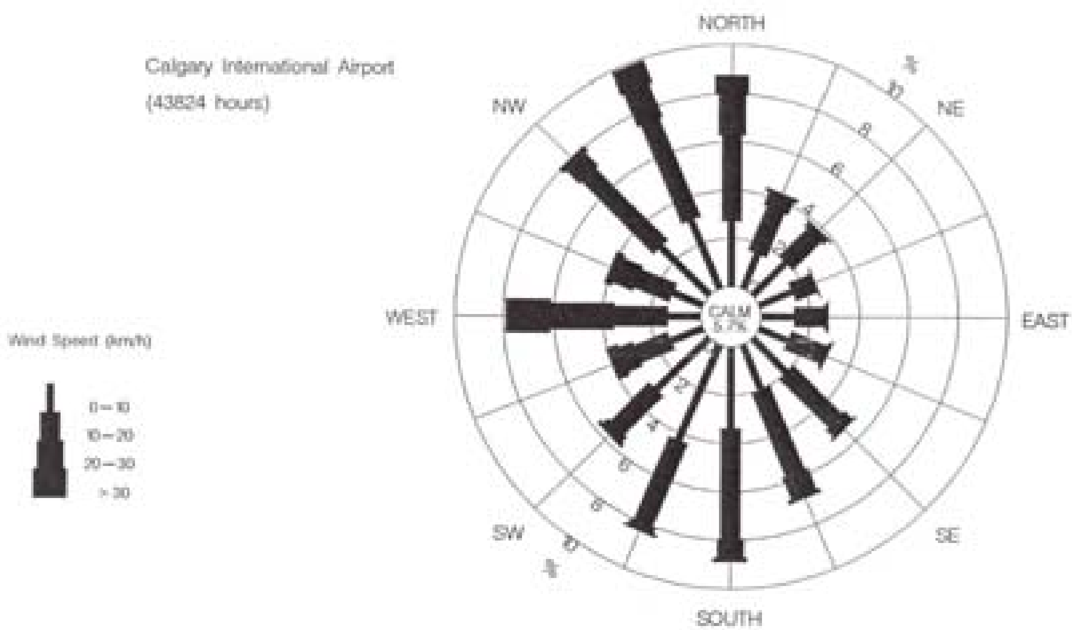


Figure 2 Wind roses obtained from unmodified wind data collected at the Calgary International Airport (1 January 1998 — 31 December 2002) for stable conditions only and for all stability conditions.

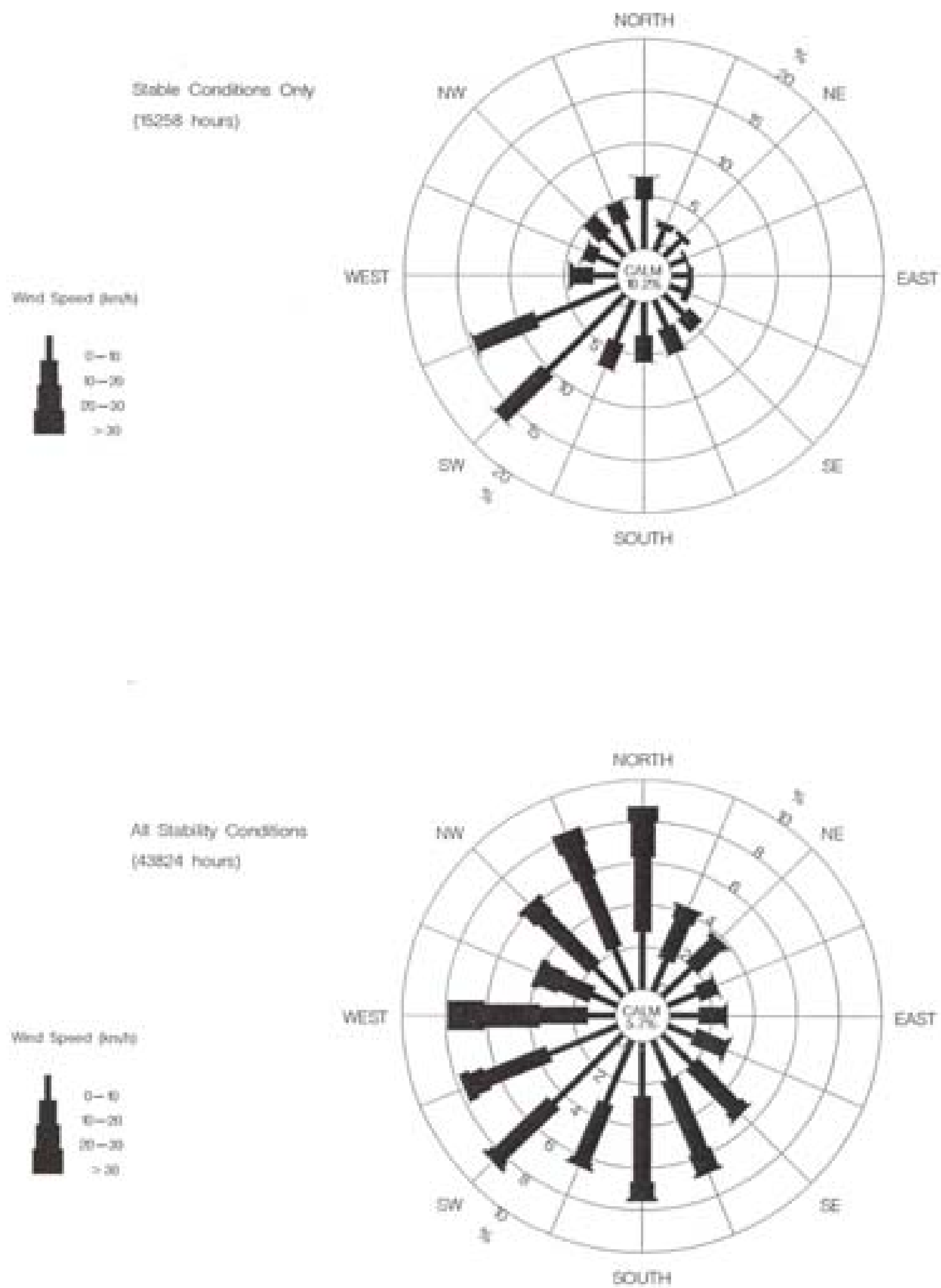


Figure 3 Wind roses obtained from modified wind data collected at the Calgary International Airport (1 January 1998 — 31 December 2002) for stable conditions only and for all stability conditions.

Table 4.1 Assumed Mass Fractions of Total Suspended Particulates based on Particle Diameters (μm)

Source Area	Particle Diameter (μm)		
	2.5	10	30
Paved Roads (Industrial)	0.05	0.15	0.80
Paved Roads (Public)	0.05	0.15	0.80
Backfilled Pit	0.05	0.18	0.77
Gravel Pit	0.07 (0.16)	0.22 (0.21)	0.71 (0.63)
Active Storage Piles	0.15	0.32	0.53

5.0 EVALUATION OF PLUME DISPERSION MODELLING CALCULATIONS

Ground-level ambient pollutant concentrations associated with emissions that might result from operations at AT's proposed sand and gravel operations were estimated through use of plume dispersion calculations. Results were obtained using the dispersion meteorological data as presented in Figures 2 and 3 and in the Appendix.

Fine Particulate Matter ($PM_{2.5}$)

Emissions of $PM_{2.5}$ resulting from road dust are qualitatively different from those associated with diesel fuels. Constituents of mineral particles emitted as road dust are mainly crustal elements. They are therefore similar to particles emitted from agricultural operations and natural wind-blown sources. Diesel-related $PM_{2.5}$ particles are comprised of the products of incomplete combustion which includes VOCs and PAHs. The difference between particles originating from dust and diesel exhausts may be important from a human health perspective. Estimates were therefore made for ambient $PM_{2.5}$ concentrations associated with emissions from all sources (the combination of emissions from diesel and dust sources) and from diesel sources alone.

Figure 4 presents 98th percentile daily average values of $PM_{2.5}$, for a three year period, resulting from all sources associated with the proposed Spy Hill sand and gravel operations as predicted using unmodified winds. An examination of this Figure shows that values in excess of the Canadian Wide Standard (CWS) of 30 μg/m^3 occur only within the Gravel Pit, where occupational health standards rather than the CWS apply. All predicted concentrations outside the immediate area of the Gravel Pit are much less than the CWS of 30 μg/m^3. This is especially true for the communities of Royal Oak and Rocky Ridge where predicted 98th percentile values tend to be less than 3 μg/m^3. Predicted 98th percentile concentrations for Rocky View acreage residential properties are only about 10μg m^{-3}.

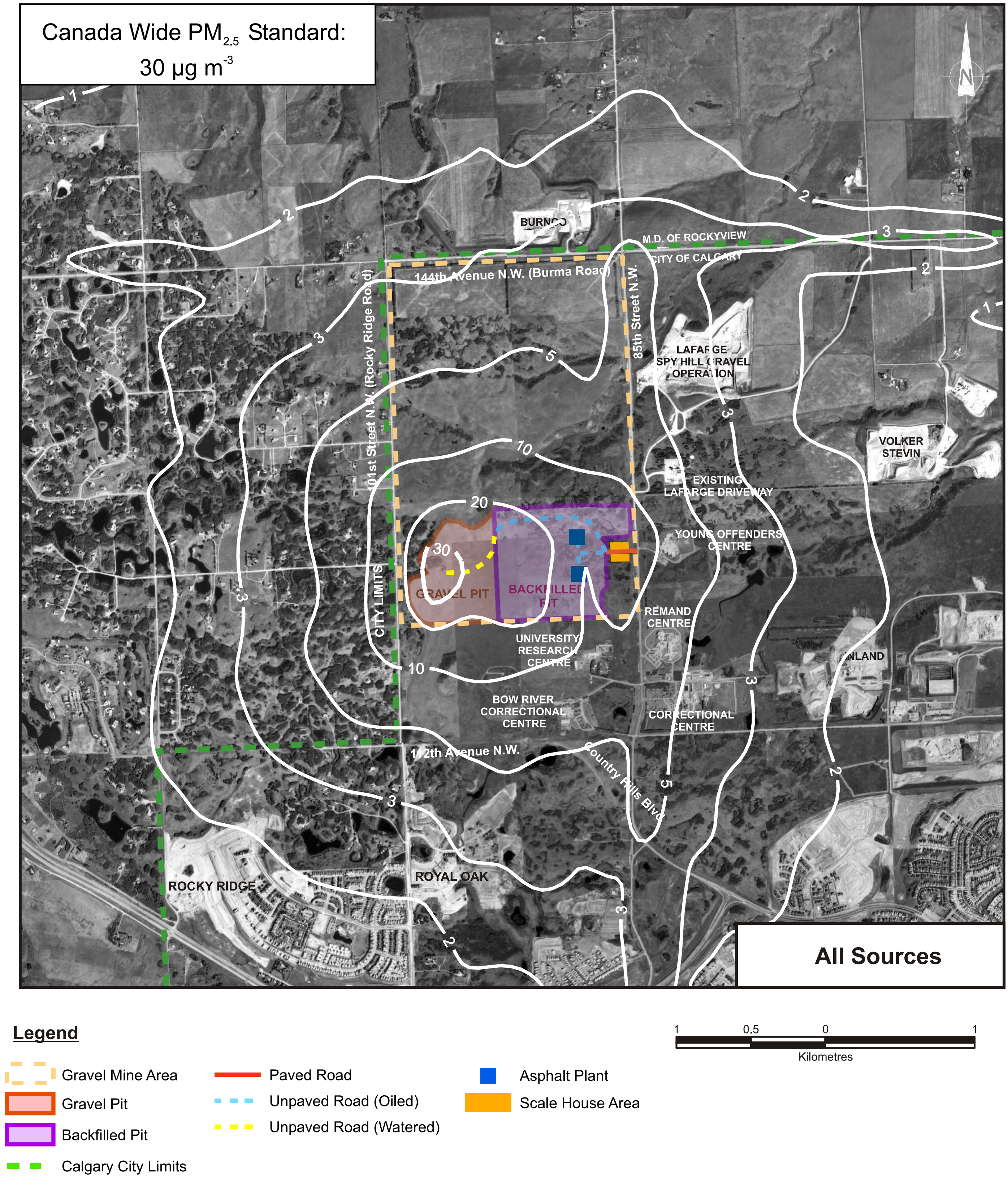


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Figure 4 Isopleths of 98th Percentile Daily Average Ground-Level PM$_{2.5}$ Concentrations (µg/m^3) Associated with the Proposed Spy Hill Sand and Gravel Operations as Predicted Using Unmodified Winds.

Results of plume dispersion calculations showed that maximum predicted ambient daily average particulate concentrations tended to be insensitive to assumed wind distributions. This is illustrated in Figures 4 and 5 which respectively present isopleths of 98th percentile values of daily average $PM_{2.5}$ concentrations associated with the proposed Spy Hill sand and gravel operations using unmodified and modified wind rose information. A comparison of the two Figures shows that they are virtually identical. The only apparent difference is the slightly larger concentrations predicted for the Scale House area through use of the modified winds. The fact that use of the two different wind roses resulted in essentially the same predictions of 98th percentile values might have been anticipated. Firstly because the occurrence of the largest daily average values at a given location tends to be associated with particular meteorological conditions which are likely to occur at least once in any five year climatological record and secondly because the difference in the unmodified and modified winds lay in the assumed occurrences of stable atmospheric wind conditions. These conditions usually occur during night time, when the Gravel Pit will tend not to be operating, and their occurrence should therefore have only a minimal effect on ground-level particulate concentrations.

Figures 6, 7, and 8 respectively show isopleths of maximum daily average $PM_{2.5}$ concentrations as predicted using modified winds for the entire year, summer production period (May to October) and the winter production period (November to April). A comparison of the three Figures shows that the highest concentrations predicted on an annual basis coincides with those predicted for the summer period. Maximum concentrations predicted for the winter period are less than 50 % of those predicted for the summer period.

Figure 9 is similar to Figure 4 except that it shows predicted 98th percentile $PM_{2.5}$ concentrations resulting only from diesel sources. Maximum predicted values, beyond the immediate area of the Gravel Pit are less than 5 $\mu g/m^3$ and thus well within the CWS of 30 $\mu g/m^3$.

Figures 10 and 11 respectively present maximum isopleths of predicted annual averages for $PM_{2.5}$ resulting from all sources and from diesel sources alone. All predicted values are much less than USEPA's standard of 15 $\mu g/m^3$. This is especially true for concentrations associated with diesel emissions.

Particulate Matter (PM_{10})

Maximum predicted daily and annual average concentrations of PM_{10} are respectively presented in Figures 12 and 13. The highest daily and annual average concentrations tend to be predicted in the region of the Gravel Pit. Average maximum daily and annual PM_{10} concentrations predicted for the residential areas located south-west of the proposed gravel pit are respectively about 12 and 1 $\mu g\ m^{-3}$. All predicted daily and annual average concentrations, beyond the immediate area of the Gravel and Backfilled Pits, tend to be much less than USEPA's respective proposed national ambient air quality standards for PM_{10} of 150 and 50 $\mu g\ m^{-3}$.

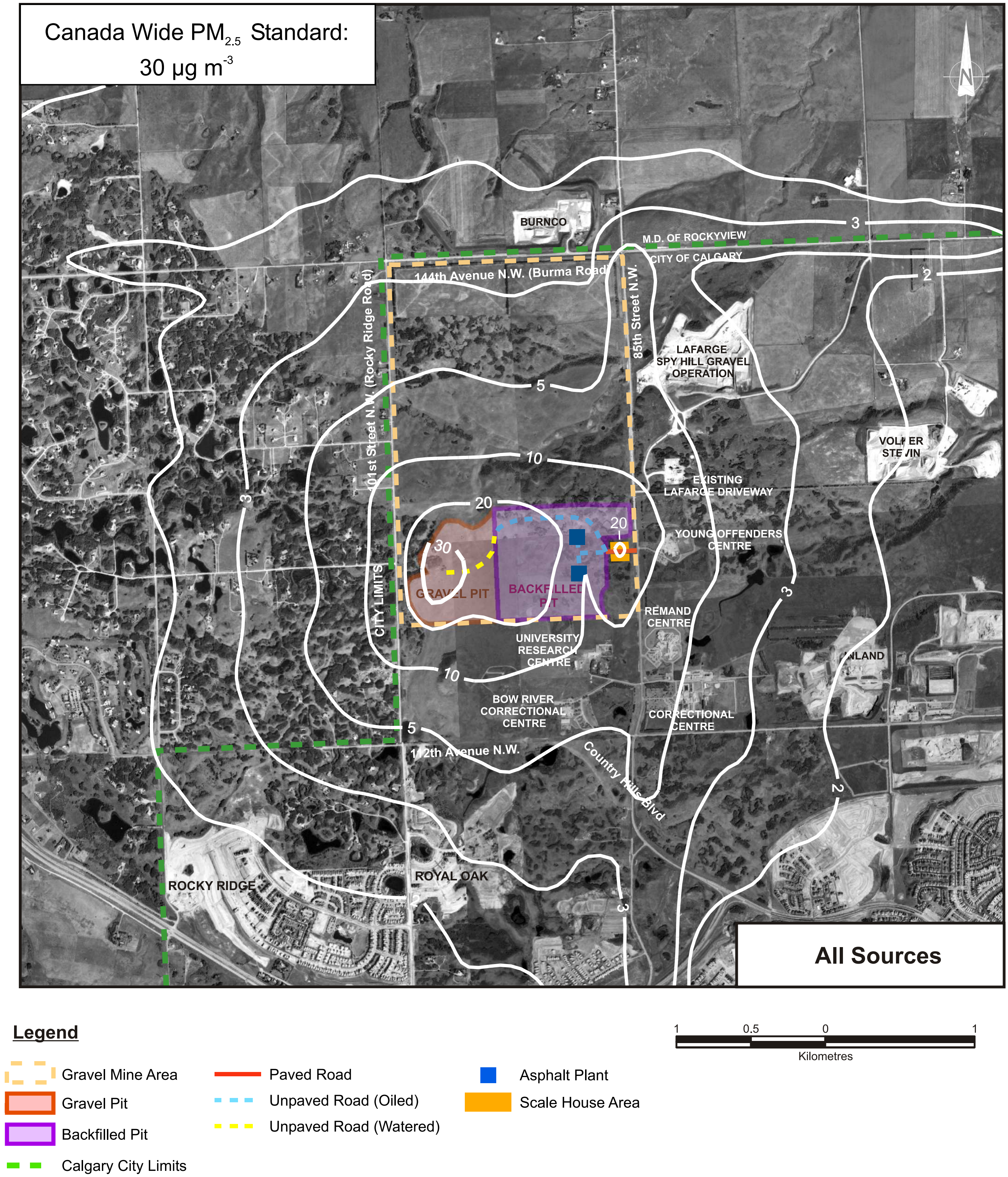

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Figure 5 **Isopleths of 98th Percentile Daily Average Ground-Level $PM_{2.5}$ Concentrations ($\mu g/m^3$) Associated with the Proposed Spy Hill Sand and Gravel Operations as Predicted Using Modified Winds.**

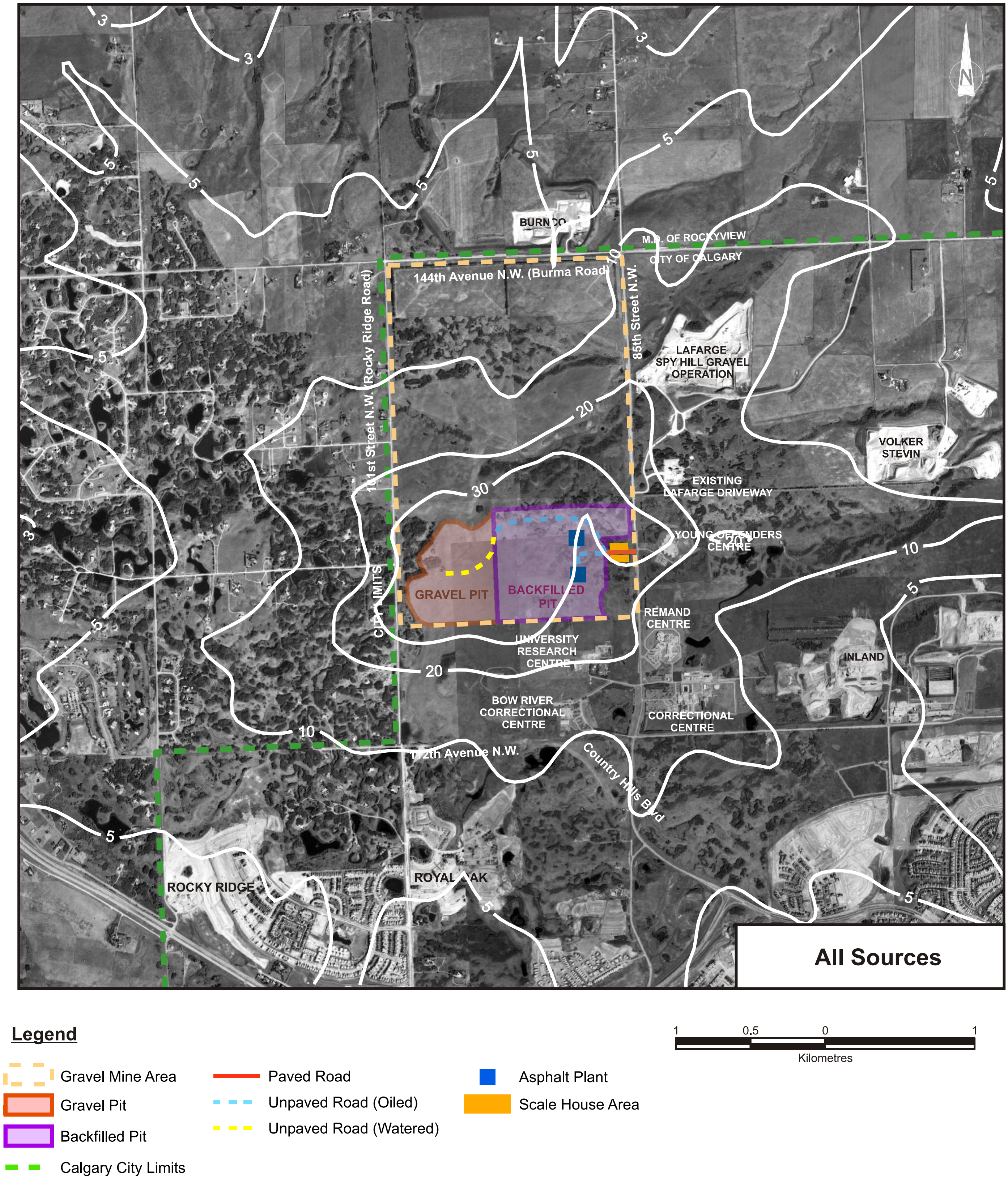

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Figure 6 **Isopleths of Maximum Predicted Daily Average Ground-Level $PM_{2.5}$ Concentrations ($\mu g/m^3$) Associated with the Proposed Spy Hill Sand and Gravel Operations.**

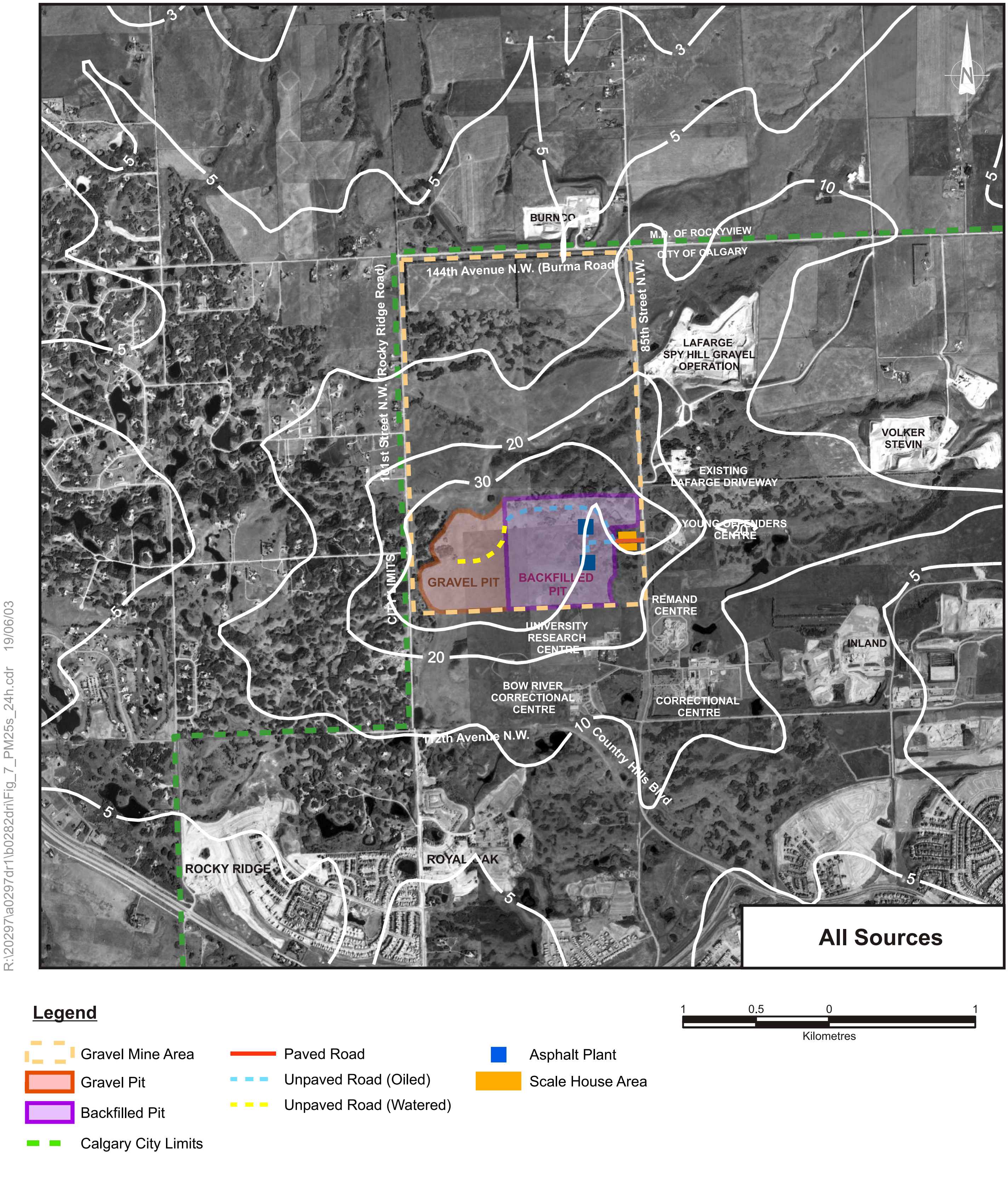

Figure 7 Isopleths of Maximum Predicted Daily Average Ground-Level $PM_{2.5}$ Concentrations (µg/m^3) Associated with the Proposed Spy Hill Sand and Gravel Operations (May to October).

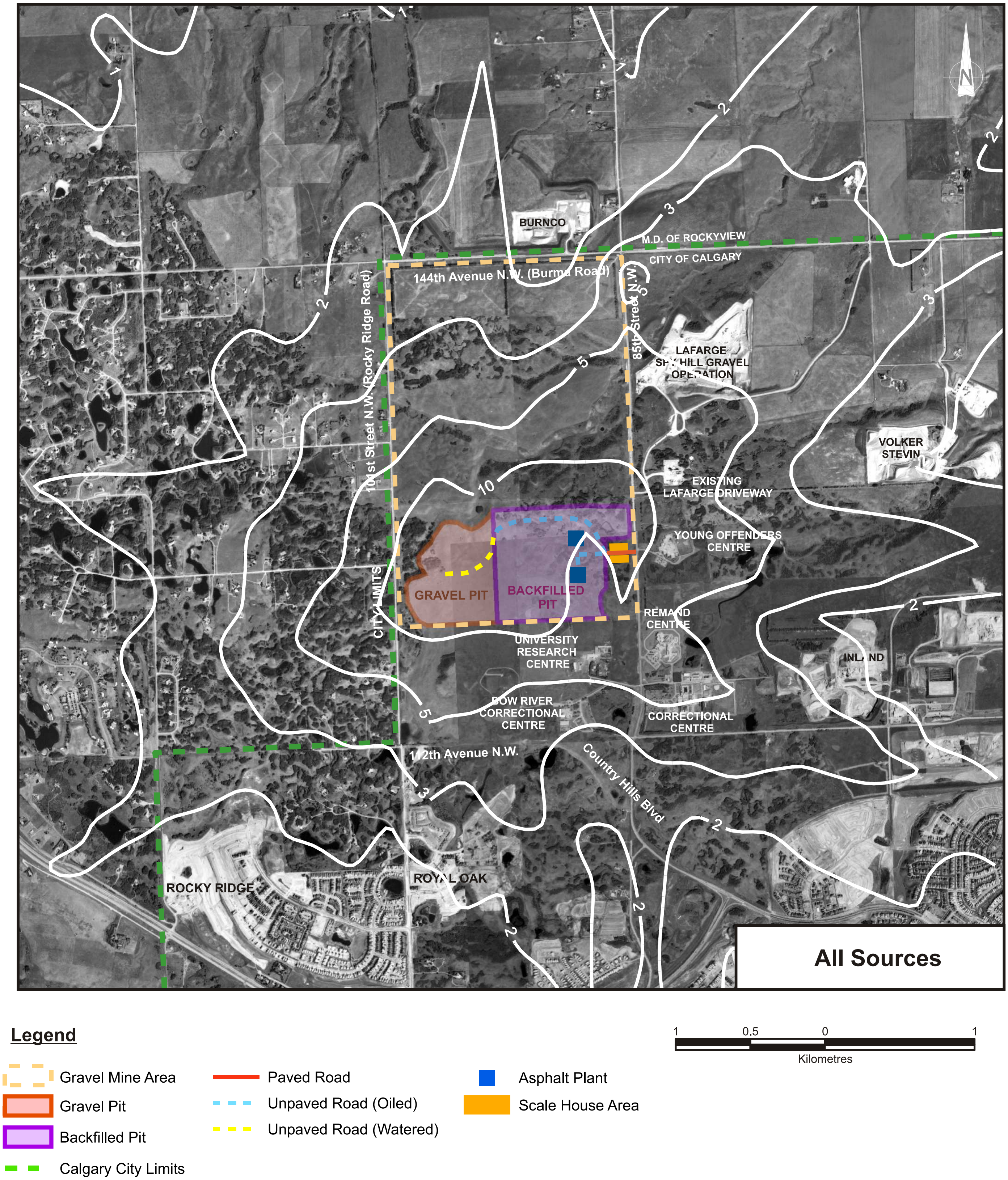

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Figure 8 Isopleths of Maximum Predicted Daily Average Ground-Level $PM_{2.5}$ Concentrations ($\mu g/m^3$) Associated with the Proposed Spy Hill Sand and Gravel Operations (November to April).

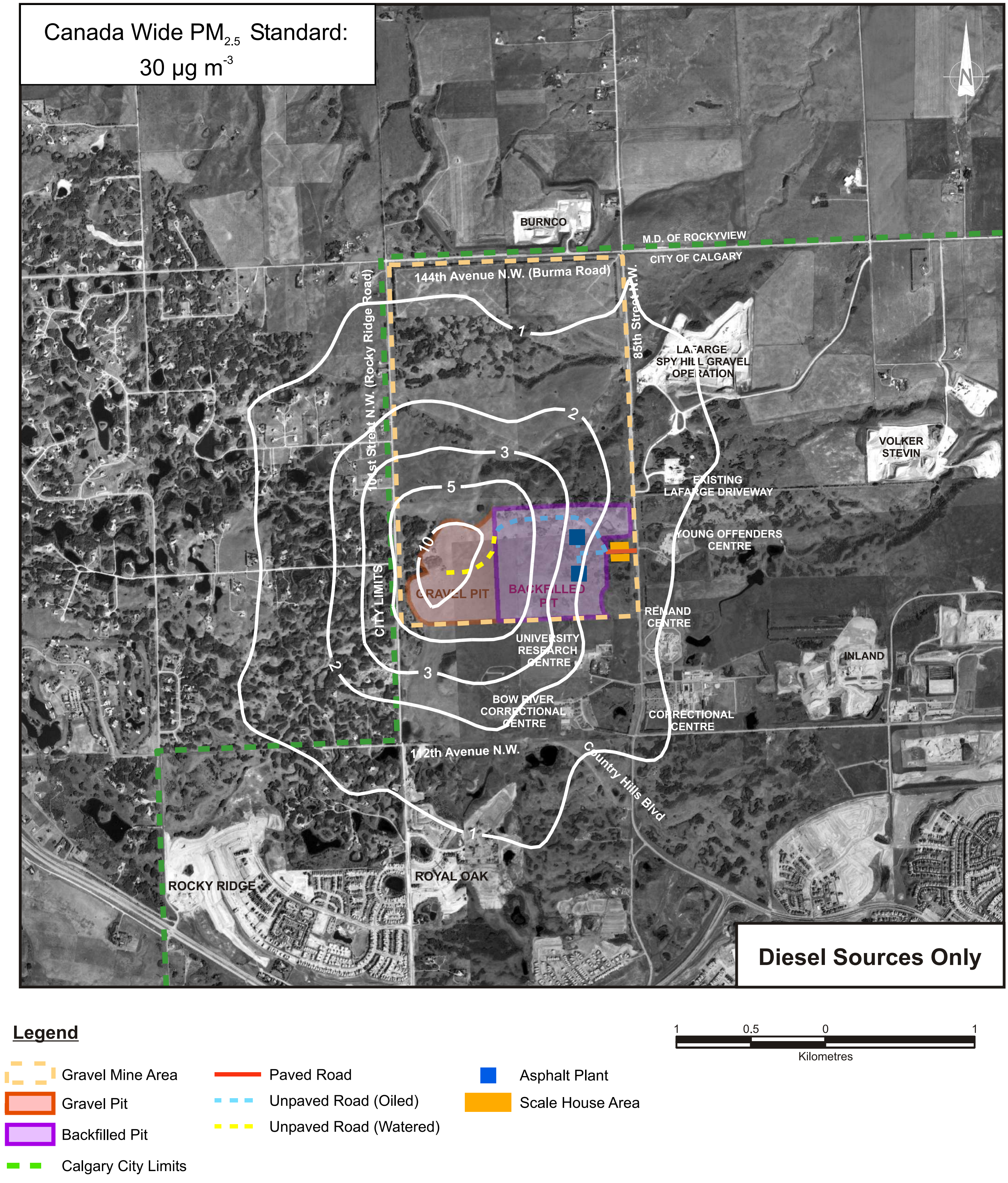

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Figure 9 **Isopleths of Predicted 98th Percentile Daily Average Ground-Level $PM_{2.5}$ Concentrations ($\mu g/m^3$) Associated with the Proposed Spy Hill Sand and Gravel Operations (Diesel Sources Only).**

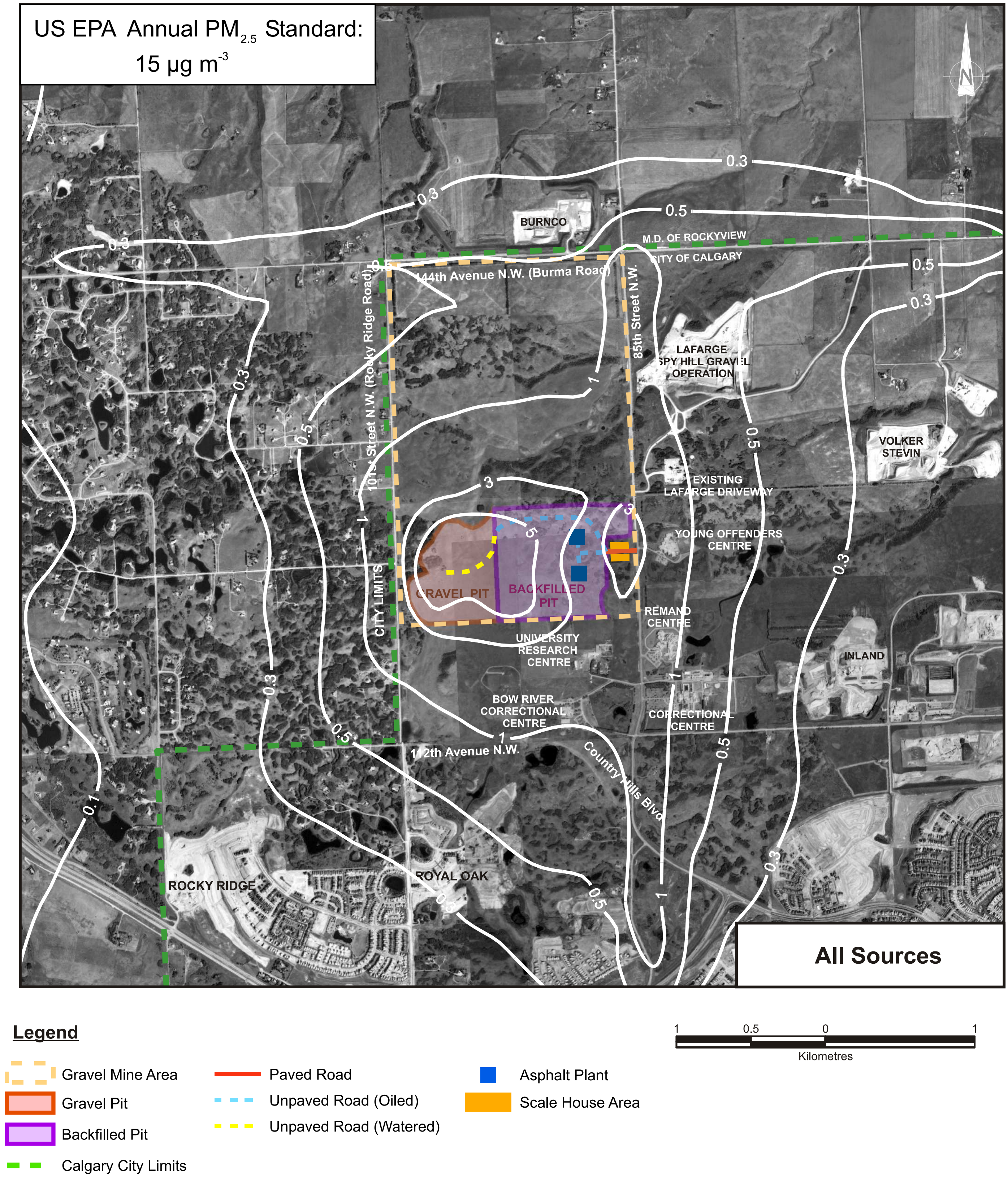

Figure 10 **Isopleths of Maximum Predicted Annual Average Ground-Level $PM_{2.5}$ Concentrations ($\mu g/m^3$) Associated with the Proposed Spy Hill Sand and Gravel Operations.**

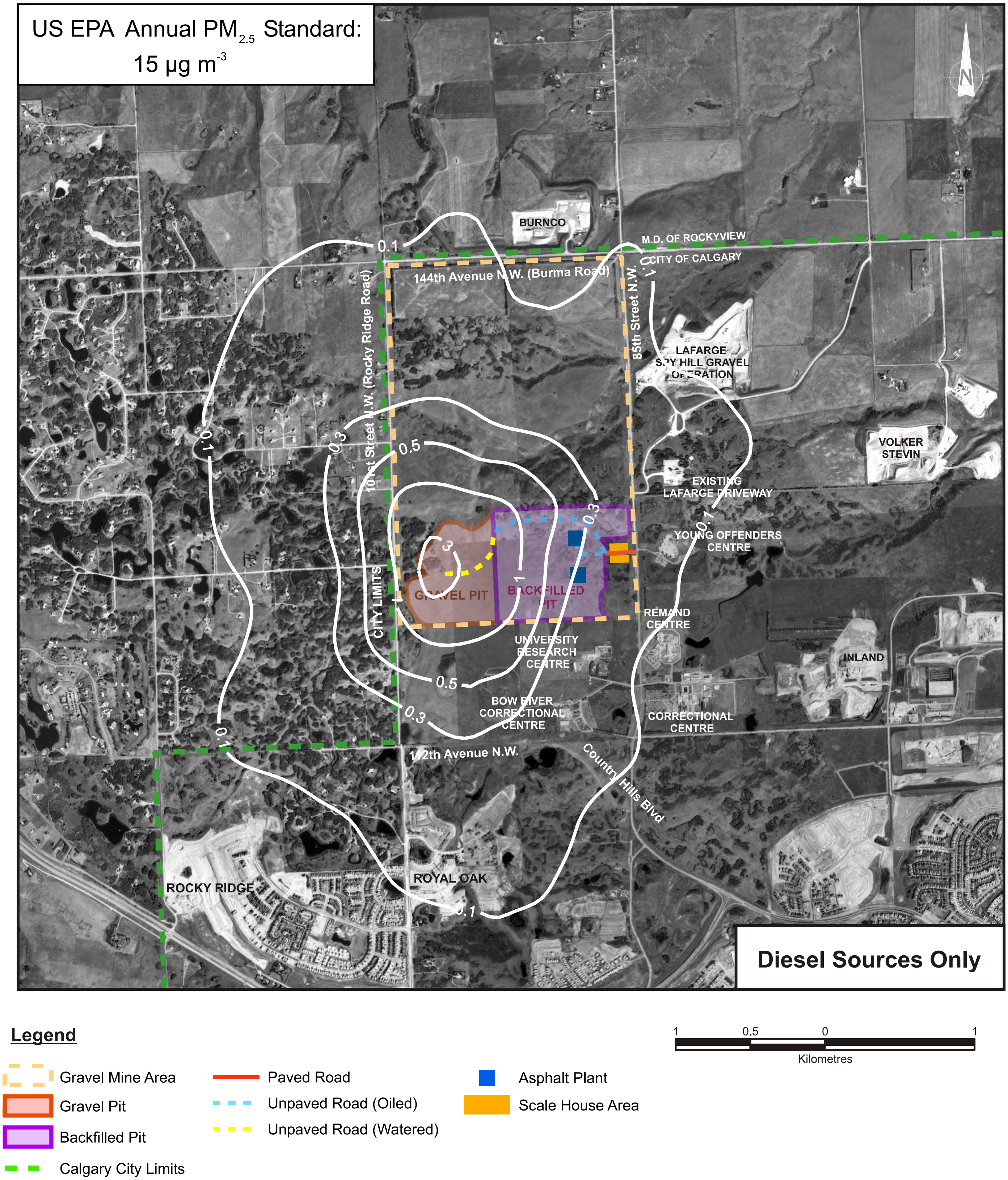

Figure 11 **Isopleths of Maximum Predicted Annual Average Ground-Level $PM_{2.5}$ Concentrations (µg/m^3) Associated with the Proposed Spy Hill Sand and Gravel Operations (Diesel Sources Only).**

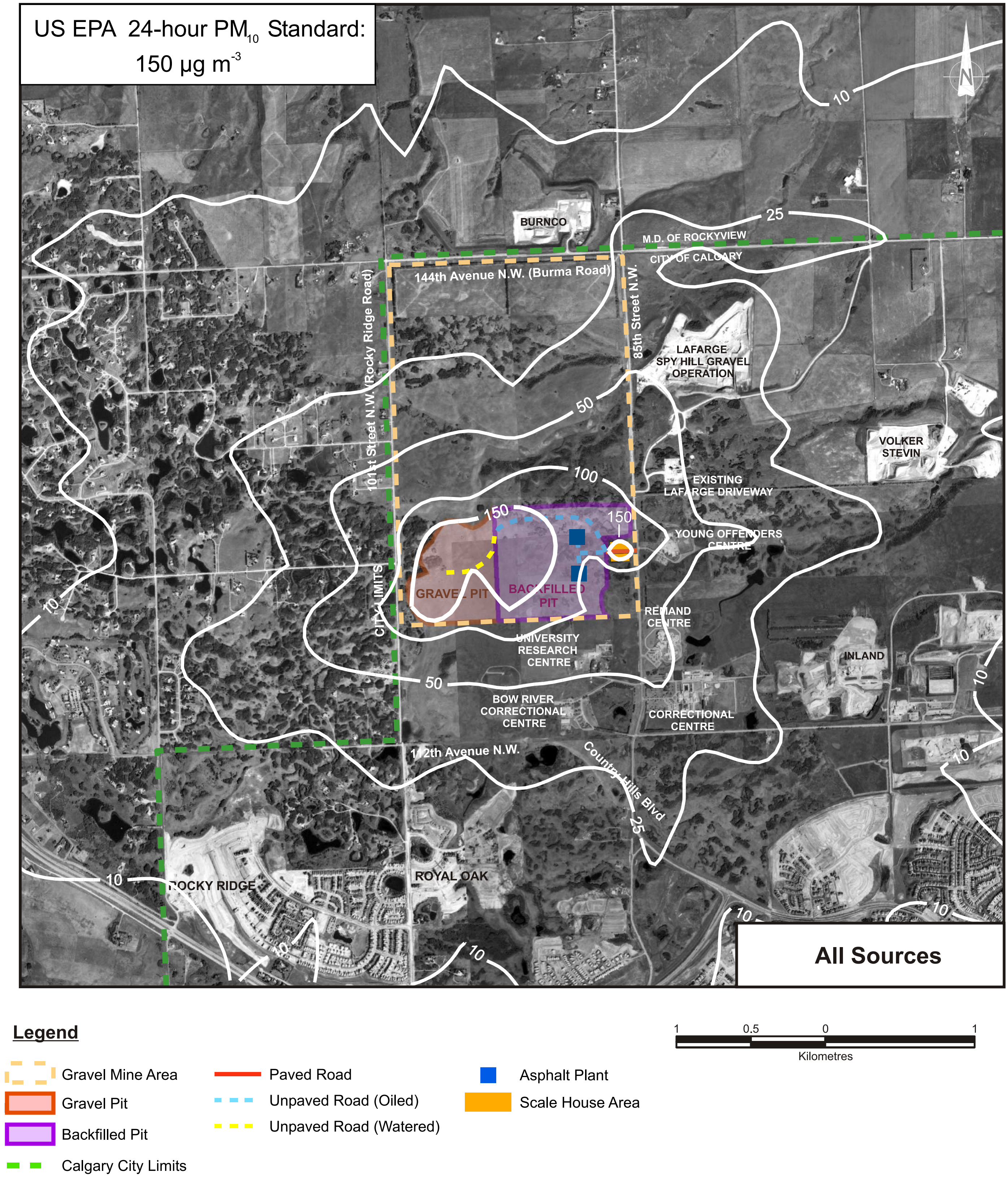

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Figure 12 **Isopleths of Maximum Predicted Daily Average Ground-Level PM_{10} Concentrations ($\mu g/m^3$) Associated with the Proposed Spy Hill Sand and Gravel Operations**

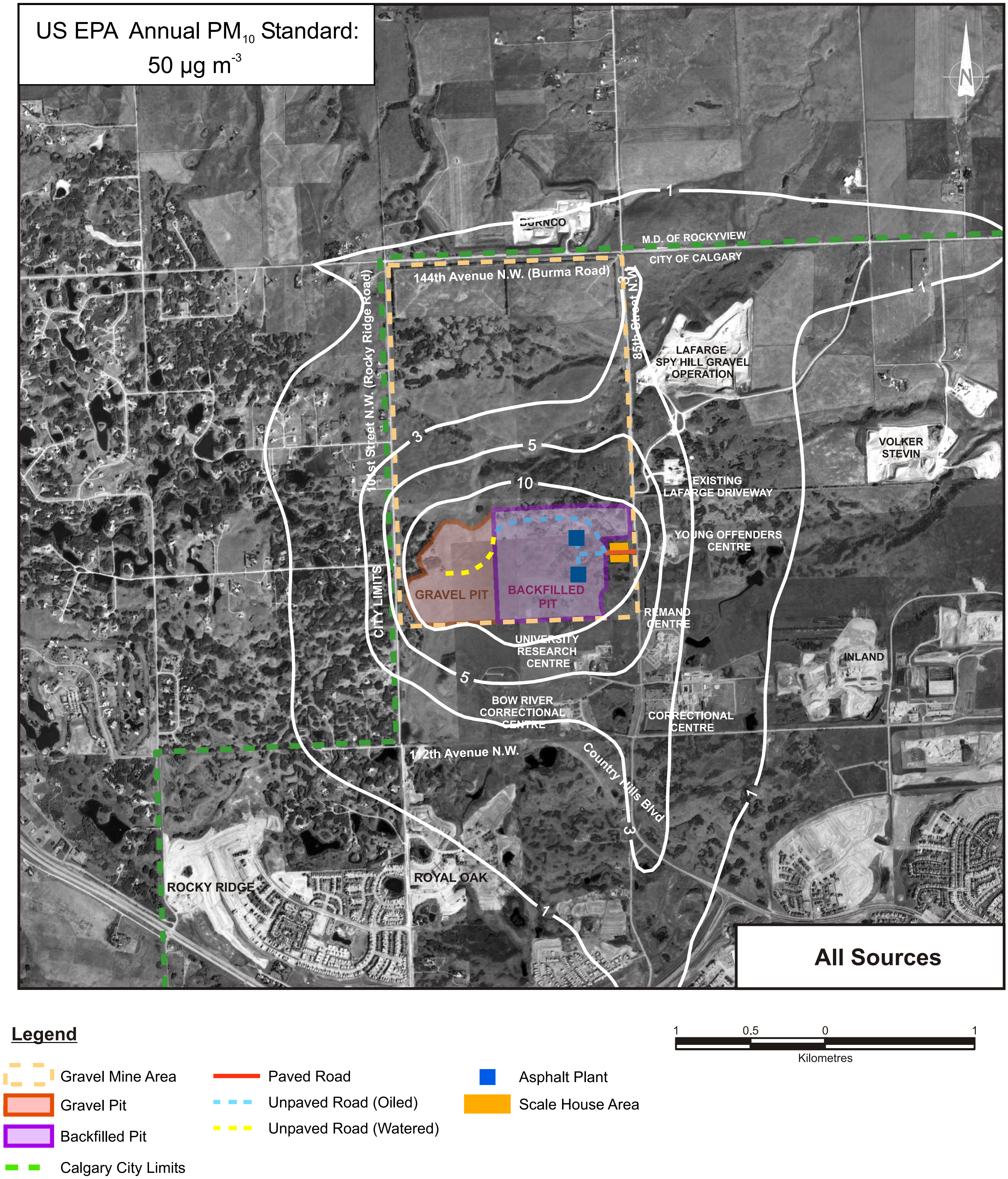

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Figure 13 **Isopleths of Maximum Predicted Annual Average Ground-Level PM_{10} Concentrations (µg/m^3) Associated with the Proposed Spy Hill Sand and Gravel Operations.**

Total Suspended Particulates (TSP)

Figure 14 presents isopleths of predicted maximum daily average concentrations of TSP. Alberta's ambient air quality guideline of 100 μg/m^3 is exceeded in the vicinity of the Gravel and Backfilled Pits. (It should be noted that this guideline is not applicable within AT's property fence line where less stringent standards apply for the working environment.)

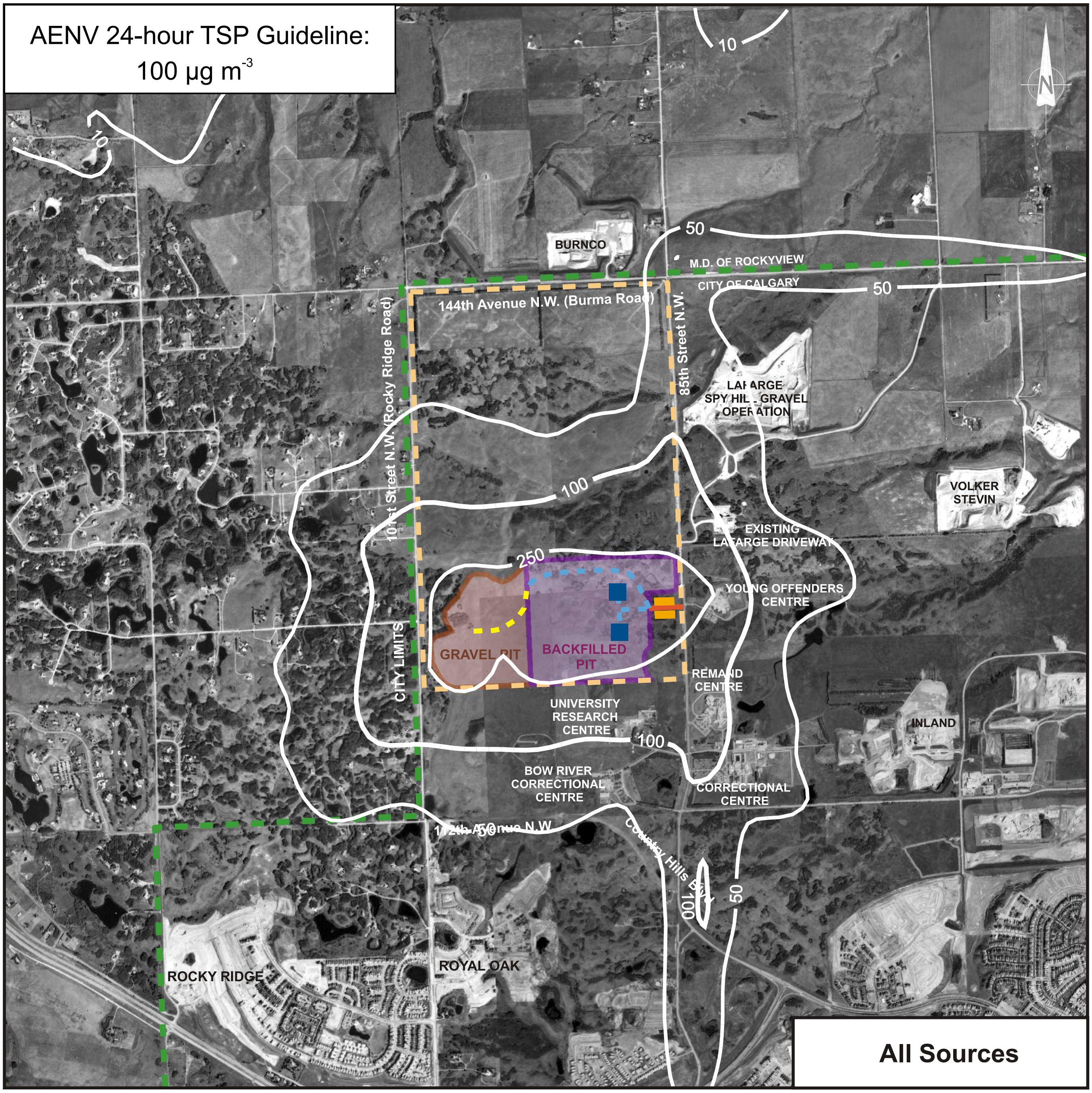
Figure 15 shows the annual predicted frequency of exceedances of Alberta's ambient air quality guideline for locations within the vicinity of the proposed Spy Hill sand and gravel operations. As shown, the guideline, at locations adjacent to the proposed gravel mining area, should be generally exceeded only about 5 times a year. This is a small level of exceedances compared to the 10 percent of the time that the guideline of 100 μg m^{-3} is exceeded at the 19 cross-Canada locations which comprise the observational network for the National Air Pollution Surveillance Network (NAPS) (Brook *et al* 1997). The USEPA no longer regulates TSP.

Figure 16 presents isopleths of predicted annual average ground-level TSP concentrations associated with operations of the proposed Spy Hill sand and gravel operations. All values outside the proposed Gravel mining area are less than Alberta's ambient air quality guideline of 60 μg/m^3.

6.0 CONCLUSIONS

Alberta Transportation is proposing a sand and gravel operation in the Spy Hill area of Northwestern Calgary. The proposed Gravel Pit and associated Asphalt Plants are in the near vicinity of the University of Calgary's Research Centre and the City of Calgary's Remand and Young Offender's Centres and acreage residential properties lying within the MD of Rocky View. Anticipated maximum annual levels of gravel and asphalt production in 2022 are expected to be about 3.6 and 0.85 million tonnes respectively. Ninety and ten percent of the production will respectively occur during the summer (May to October) and winter (November to April) production periods. The Gravel Pit will have a depth of about 32m.

Operations associated with the proposed sand and gravel operations will generate particulate matter which includes fine particulates ($PM_{2.5}$), larger particulates (PM_{10}) and total suspended particulates (TSP). Sources of particulate matter include removal/replacement of topsoil and overburden, stockpile handling, road traffic and asphalt plant stack emissions. Diesel exhausts from trucks and heavy equipment (*i.e.* loaders, scrapers, electrical generators), will also be sources of fine particulate matter. Alberta Environment has ambient air quality guidelines relating to daily and annual averages of TSP. Daily average concentrations of $PM_{2.5}$ are regulated by a Canadian Wide Standard (CWS).There are no standards in Canada relating to PM_{10}. There are, however, ambient standards established for this atmospheric pollutant in the United States.



Legend

- Gravel Mine Area
- Gravel Pit
- Backfilled Pit
- Calgary City Limits
- Paved Road
- Unpaved Road (Oiled)
- Unpaved Road (Watered)
- Asphalt Plant
- Scale House Area

1 0.5 0 1
Kilometres

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Figure 14 **Isopleths of Maximum Predicted Daily Average Ground-Level TSP Concentrations ($\mu g/m^3$) Associated with the Proposed Spy Hill Sand and Gravel Operations.**

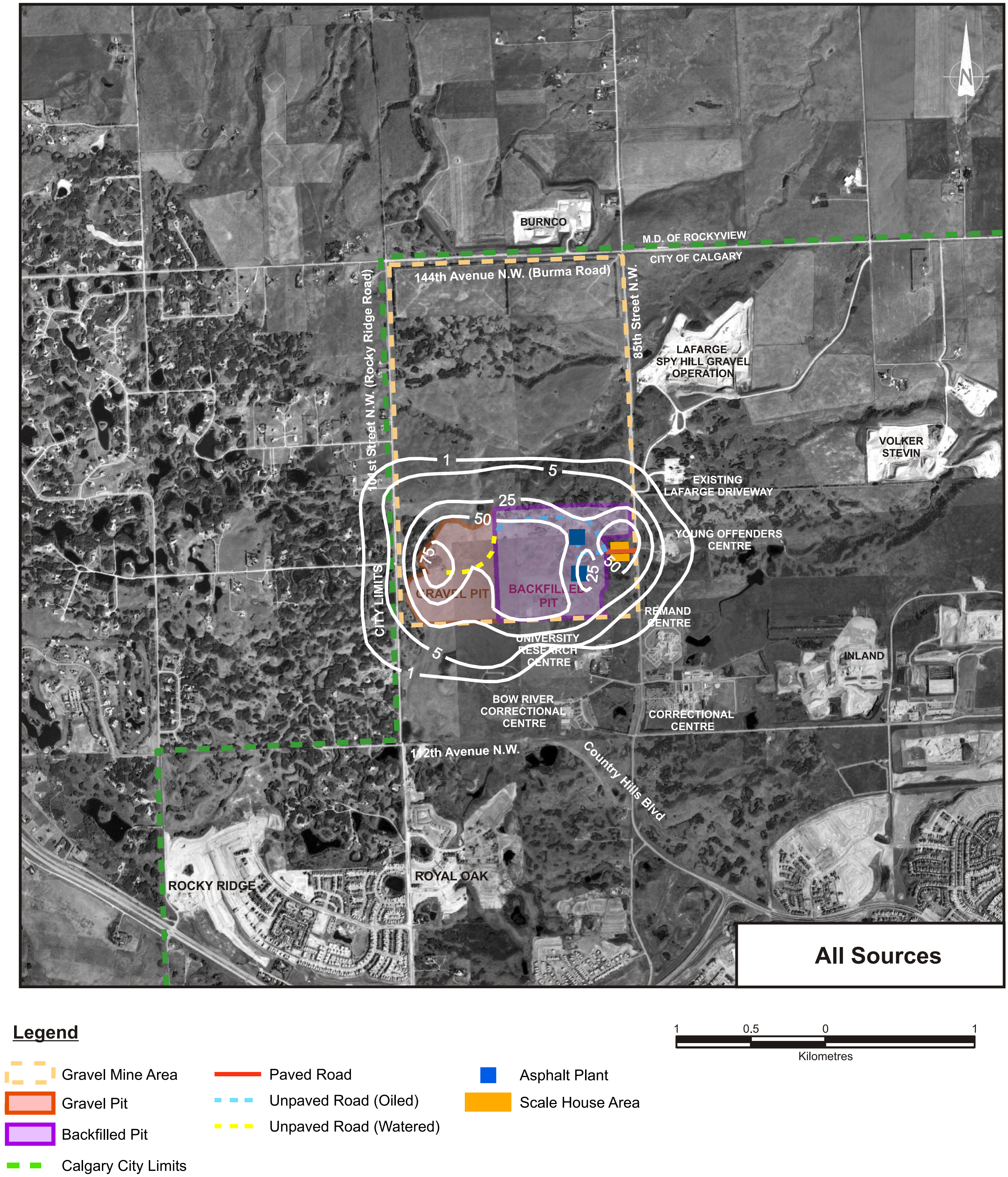

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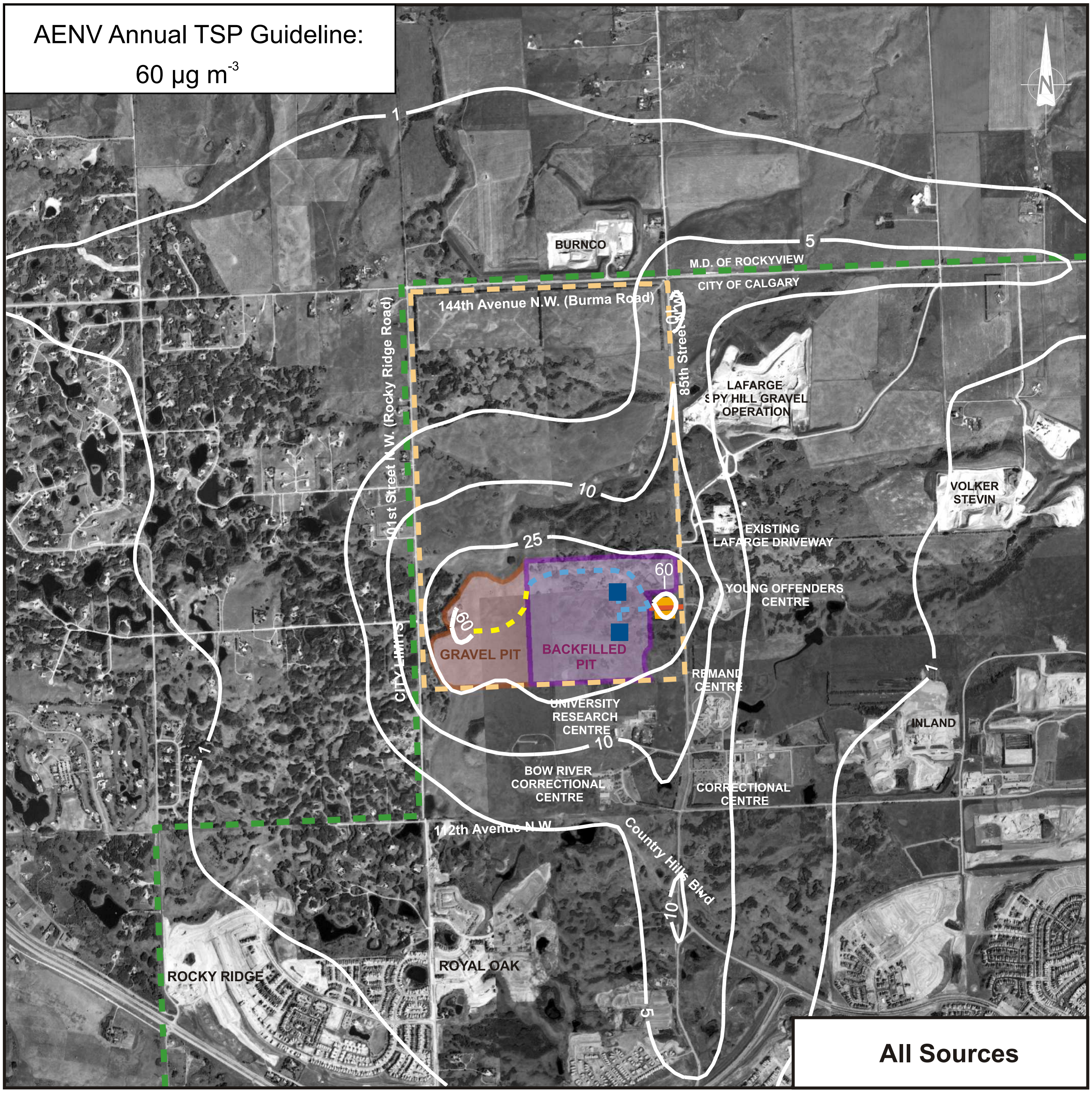
Figure 15 **Isopleths of Annual Predicted Frequency of Exceedances (days/year) of Alberta Environment's Ambient Air Quality Guideline for Maximum Daily Average TSP Concentrations.**



Legend

- Gravel Mine Area
- Gravel Pit
- Backfilled Pit
- Calgary City Limits
- Paved Road
- Unpaved Road (Oiled)
- Unpaved Road (Watered)
- Asphalt Plant
- Scale House Area

1 0.5 0 1
Kilometres

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Figure 16 **Isopleths of Maximum Predicted Annual Average Ground-Level TSP Concentrations (µg/m^3) Associated with the Proposed Spy Hill Sand and Gravel Operations.**

Sand and gravel as excavated from the Spy Hill Gravel Pit is expected to have a moisture content of about 3 % and as a result may be considered to be wet. Material handling will in consequence have a limited potential for dust emission. Blanketing of crushers and screens for purposes of noise reduction will also reduce the potential for dust generation from processing operations. Alberta Transportation will, for purposes of dust suppression, institute a regular program for watering/oiling unpaved roads and for the sweeping and watering of paved roads on its premises.

Plume dispersion calculations have shown that ambient concentrations of $PM_{2.5}$ in the residential communities of Royal Oak and Rocky Ridge, and within Rocky View acreage residential properties resulting from a combination of emissions from roads plus diesel exhausts from the proposed operations, will remain below values stipulated in the Canadian Wide Standard. Actual ambient concentrations should be even less than these estimated values because of the conservative assumptions relating to scraper operations and asphalt emissions which tend to overestimate particulate emissions within the Gravel and Backfilled Pits during the summer production season. Operations at Alberta Transportation's proposed gravel pit with respect to ambient $PM_{2.5}$ concentrations should therefore not be of concern. This conclusion is consistent with results of observational studies conducted in the United States which demonstrated the near-negligible impact of stone crushing operations on ambient $PM_{2.5}$ levels (Hayden e*t al* 1998).

There are currently no federal or provincial ambient air guidelines in Canada relating to PM_{10}. Additional calculations demonstrated however that maximum PM_{10} concentrations in the residential areas and residential acreages adjacent to the proposed operations, occurring as the result of dust generation from AT property, should remain much below daily and annual ambient average concentrations standards proposed by the United States Environmental Protection Agency (USEPA).

Predicted maximum daily average concentrations of TSP exceeded Alberta Environment's guideline of $100 \mu g\ m^{-3}$ within the near vicinity of the gravel pit, processing area and associated roads. Predicted frequencies of exceedances of the daily average guideline at nearby residences are very small, however, when compared to the frequency of exceedances which occur routinely because of wind blown dust resulting from agricultural activities, traffic on unpaved municipal roads etc. The USEPA no longer regulates ambient concentrations of TSP.

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APPENDIX A

Information Relating to Atmospheric Stability and Mixing Heights

Atmospheric Stability

Atmospheric dispersion is a function of atmospheric stability, which may be broadly classified as being stable, unstable or neutral. Stable atmospheres occur at night under clear or partially cloudy skies. As the earth cools due to long-wave radiational heat loss, air in contact with the ground also cools and becomes colder and more dense than the air aloft. This dense air tends to remain near the ground and upward air motions are discouraged. The atmosphere is said to be stable. Unstable atmospheres occur during the day as the earth becomes heated due to solar radiation. Air next to the ground becomes warmer and lighter than the air aloft and tends to rise. The atmosphere is said to be unstable. Neutral atmospheres occur during transitional periods between stable and unstable atmospheric situations, under overcast sky conditions, and during periods characterized by wind speeds of greater than 22 km per hour.

Pasquill (1961) devised a classification scheme that considers six atmospheric stability categories ranging from extremely unstable to moderately stable. The classification scheme allows for the identification of the pertinent category through the use of cloud and wind information. Table A.1 shows the frequency of each stability category in the Calgary region as derived using wind speed and cloud data obtained from the Calgary International Airport

Extremely unstable atmospheric conditions, which are associated with strong solar heating, seldom occur in Alberta. Neutral atmospheric stabilities, which are associated with cloudy skies and/or strong winds, are the most common of the categories. Stable atmospheres, which occur at night under clear skies and low winds are least common during the spring and summer seasons when day-light periods are longest.

Table A.1 Seasonal Atmospheric Stability Frequencies for the Calgary International Airport

Pasquill Stability Category	Frequency (%)			
	Winter	Spring	Summer	Autumn
Extremely Unstable	0.0	0.14	1.20	0.13
Moderately Unstable	1.48	5.76	11.63	3.60
Slightly Unstable	9.13	13.28	16.81	12.00
Neutral	45.39	53.70	41.91	44.35
Slight Stable	18.88	13.61	13.37	17.61
Moderately Stable	25.14	13.51	15.08	22.32

Mixing Height

Strong solar heating or strong winds can create a two-layered atmosphere. The lower layer is well-mixed and is characterized by either neutral or unstable conditions; the upper layer is characterized by stable conditions (temperature inversion). The thickness of this lower, well-mixed layer is called the mixing height. Vertical motions in the upper stable layer are dampened, and this effectively prevents the transfer of air between the two layers.

Mixing height varies from several metres to several thousand metres, depending upon the wind speed and the intensity of solar radiation reaching the earth's surface. Mean mixing heights are much larger in summer than in winter. Maximum mixing heights usually occur during mid-afternoon hours and minimum heights at night.

Diurnal variations in median estimated seasonal mixing heights, as calculated by the method recommended by Benkley and Shulman (1979), are shown in Figure A.1. Maximum mixing heights, which occurred during mid-afternoon hours, for spring, summer and autumn seasons were about 1,600 1,400 and 400 m, respectively. Mixing heights tend to remain more constant during winter days with maximum values of about 600 m.

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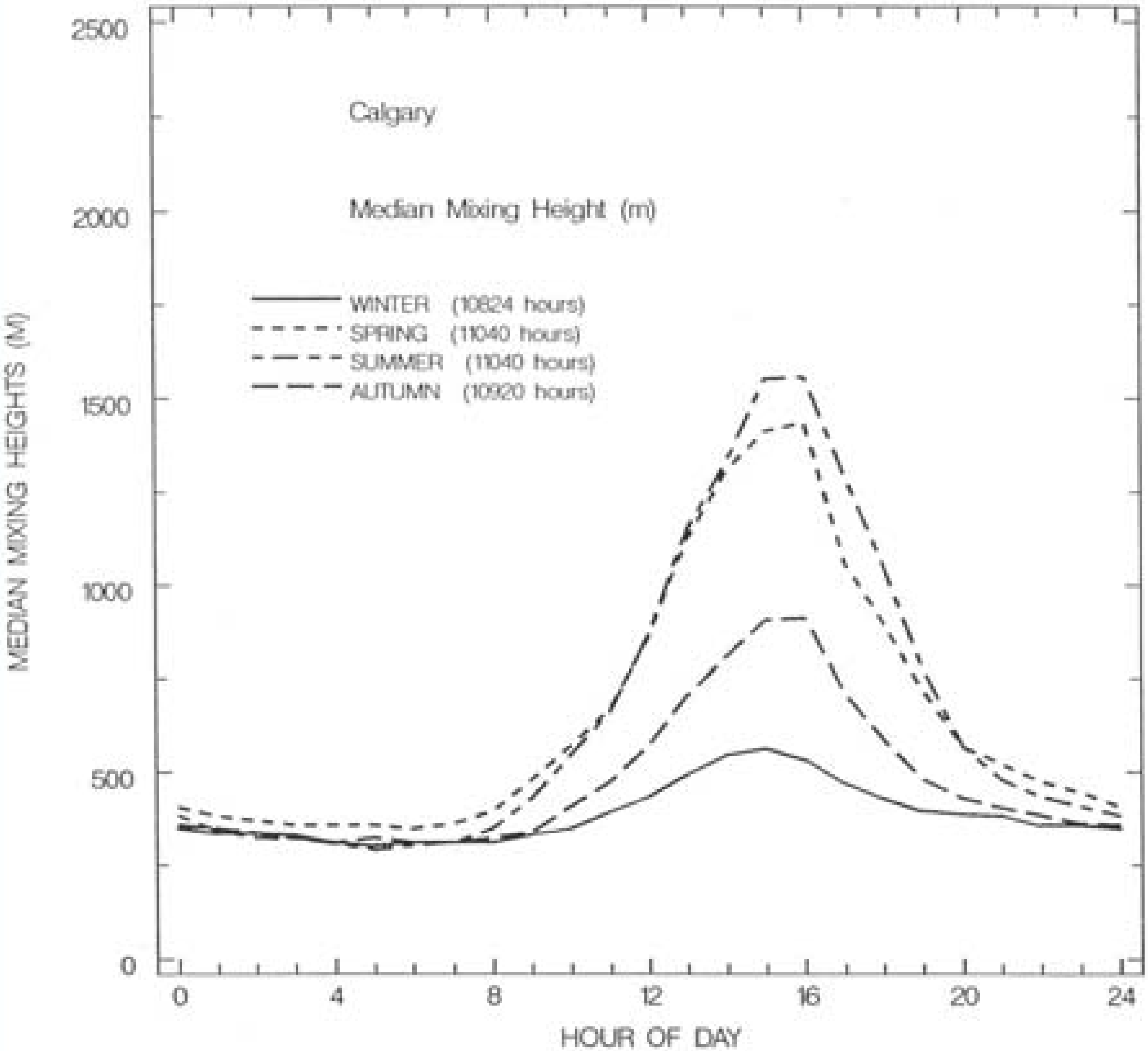

Figure A.1 Seasonal medians of hourly average mixing height (m) as a function of hour of day for the Calgary Region, obtained from data observed at the Calgary International Airport and Stony Plain monitoring stations during the period 1 January 1998 to 31 December 2002.