Connacher Oil and Gas Limited




Hydrology Assessment for Great Divide SAGD Expansion Project

Final Report

March, 2010

nhc northwest hydraulic consultants

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HYDROLOGY ASSESSMENT FOR GREAT DIVIDE SAGD EXPANSION PROJECT FINAL REPORT

Prepared for:

Connacher Oil and Gas Limited
900, 332 – 6 Avenue SW
Calgary, AB, T2P 0B2

Prepared by:

northwest hydraulic consultants ltd
9819 – 12 Ave SW

Edmonton, AB, T6X 0E3

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nhc

Leaders in water resource technology

March 24, 2010

Millennium EMS Solutions Ltd.
208, 4207-98 Street
Edmonton, Alberta
T6E 5R7

Attention: **Mr. Dane McCoy**

Dear Sir:

Subject: **Connacher Oil and Gas Limited**
Great Divide SAGD Expansion Project
Hydrology Assessment

Northwest Hydraulic Consultants (NHC) is pleased to provide the following report detailing the hydrology assessment for the Connacher Oil and Gas Limited - Great Divide SAGD Expansion Project. The report contains an assessment of the baseline climate and streamflow characteristics, assesses the potential impacts of development according to Environmental Impact Assessment methodologies and identifies reasonable and effective mitigation measures to deal with local disturbances. If you have any questions, please give me a call in our Edmonton office at (780) 436-5868.

Sincerely,

northwest hydraulic consultants ltd

Gary Van Der Vinne, M.Sc., P.Eng.
Principal

northwest
hydraulic
consultants

9819–12th Ave SW
Edmonton, AB
Canada T6X 0E3
Tel 780.436.5868
Fax 780.436.1645
www.nhcweb.com

CREDITS AND ACKNOWLEDGEMENTS

This project was carried out by Salem Bouhaire, Ph.D., E.I.T., Tony Ye, M. Eng. and Bill Rozeboom, M.B.A., P.Eng. under the guidance and supervision of Gary Van Der Vinne, M.Sc., P.Eng.. Site data was collected by James Snyder, E.I.T., Jay Lonsdale, and Thomas Tang. Climate data used in this report was obtained from Environment Canada's National Climate Data and Information Archive. Streamflow data was obtained from Environment Canada's Water Survey Canada Archived Hydrometric Data. Mapping information was obtained from the National Topographic Service's National Topographic Database (NTDB) and Alberta Sustainable Resource Development through the AltaLis digital mapping service. Digital elevation data was obtained from Geobase.

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EXECUTIVE SUMMARY

The regional and local baseline surface water hydrology for the Great Divide SAGD Expansion Project was described and mapped and historical climate, streamflow and lake level data were evaluated. Local water levels, streamflows, and snow depths were measured during the 2007 field season. Flow regimes were evaluated from the regional data and from an HSPF hydrologic model calibrated to the local measurements.

The hydrology evaluation assessed a baseline development case consisting of existing and approved developments and an application development case reflecting the combined buildout of three proposed expansion phases. Compared to pre-development conditions, baseline developments were found to increase annual runoff volumes by up to 1.4%, and the application development would increase annual runoff volumes by up to 2.2%. There will be no perceptible change on either annual peak flows or the timing of runoff hydrographs. The greatest impacts are associated with rainfall events during dry summer periods, when peak flows and runoff volumes under the application case are increased by up to about 5% above pre-development conditions.. Annual minimum monthly flow may be up to 5% less than for pre-development conditions but this effect is mostly due to baseline development.

The effect of the development on water levels and corresponding surface areas was found to be small. Peak water levels and surface areas in streams are not anticipated to change; however, minimum water levels and surface areas may be up to 2% lower due to reduced minimum flows. There will be no perceptible change in the annual range of water levels and surfaces areas of lakes but late summer water levels may be up to 20 mm higher and low-water surface areas up to 1.0% greater during dry years.

Channel morphology and sediment concentrations will not change due to the application development case because changes to the flow regime are small, and because road and utility corridor stream crossings will be designed to minimize the disturbance to the channels.

The effects of the project will be mitigated by design and by reclamation. The surface disturbances will be set back from channels and designed to discharge unconcentrated runoff into undisturbed vegetated areas, rather than to drain directly to existing channels. Stream crossings will be designed and constructed to minimize the impact on the streams. Reclamation activities will be initiated when feasible. Upon project completion, the entire project disturbance will be reclaimed and the landscape restored to be similar to the pre-existing conditions.

Runoff volumes from the plant site runoff ponds will be monitored to determine how much runoff is pumped into the natural environment. Sediment monitoring will be carried out during the construction of stream channel crossings to ensure that sediment from construction sites do not adversely impact the downstream channels.

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1 INTRODUCTION

Connacher Oil and Gas Limited (Connacher) is proposing to expand a Stream Assisted Gravity Drainage (SAGD) Project on their Great Divide Oil Sands leases. Two phases of this project have been approved to date, the Great Divide project on the west side of Hwy 63 and the Algar Project in the northeast portion of the lease.

This report presents the baseline water surface hydrology in the vicinity of the lease and addresses the impacts of the existing and approved developments and proposed SAGD Expansion Project on the hydrologic regime. Included in this evaluation is an assessment of the regional meteorological and hydrologic characteristics, the local hydrography, a brief description of the development plan, and an assessment of the impacts of the development on the water levels, streamflows and channel characteristics of the affected watersheds.

2 BASELINE SETTING

2.1 LOCATION

The Project is located about 70 km southwest of Fort McMurray along Hwy 63 northeast of Mariana Lakes. The Project is located in Twp 81-83, Rge 11-12, west of the 4^{th} Meridian.

Figure 1 shows the location of the Project relative to the hydrography, climate and hydrometric stations, and other geographic features in north-eastern Alberta. The Project is located in the headwaters of two major streams – the Christina River and the Horse River.

The Project lies within an area of Lower Boreal Highlands which drain into the surrounding lower Central Mixedwood Subregion. Both the Lower Boreal Highlands and Central Mixedwood Subregions are part of the Boreal Forest Natural Region of Alberta. The bedrock geology in this area consists of shales and sandstones of the La Biche Group. The soils are composed of grey wooded loams and muskeg. The vegetation in the well drained areas is predominantly Jackpine and White Spruce while the vegetation in the poorly drained muskeg areas consists of Sphagnum Moss and Black Spruce.

2.1.1 REGIONAL STUDY AREA

The Regional Study Area (RSA) for surface water hydrology is defined as the area in which flows and water levels could be affected by development within the lease. The boundary of the RSA is shown in Figure 2. The RSA is composed of four watersheds, Watersheds A and B draining into the Horse River basin and Watersheds C and D draining into the Christina River. Watershed A drains into Little Horse Creek while Watershed B drains directly into the mainstem of the Horse River. Watershed C drains into the mainstem of the Christina River while Watershed D, drains a major tributary of the Christina River. The RSA is limited to these four watersheds because potential impacts to the streams downstream of these watersheds are anticipated to be negligible.

2.1.2 LOCAL STUDY AREA

The Local Study Area (LSA) for surface water hydrology is defined as the lease area and surrounding areas which may be affected by direct runoff from the Project. The boundary of the LSA is shown in Figure 3 along with the boundaries of the smaller scale watersheds within the lease.

2.1.3 PROJECT AREA

The Project Area for surface water hydrology is defined as the block of oil sands leases held by Connacher in the Great Divide area and covers an area of about 153 km^2. The boundary of the Project Area is shown in Figures 2 and 3.

2.2 REGIONAL CLIMATE

Climate is a major driver of the hydrologic regime. The magnitude of the winter snow pack and the severity of summer rain events along with the variations in air temperature contribute to the magnitude and variability of spring and summer runoff events. Climate also influences vegetation characteristics which in turn affect the runoff coefficients and the evapotranspiration rates of the area.

A long term climate station operated by Environment Canada (EC) is located at the Fort McMurray airport about 70 km north of the Project (Figure 1). The elevation of this station is 369 m. This station provides the only long term continuous climate record for the area. This station measures air temperatures, precipitation, wind, atmospheric pressure, hours of bright sunshine, and humidity. Much of the data extends as far back as 1944.

Air temperature and precipitation are also available for the Conklin LO station from 1954 to present. This station is located in the Christina River basin about 65 km southwest of the lease at an elevation of 671 m. This station provides data which is representative of typical elevations in the Christina River basin and other river basins in the region. Data is only available from May to September of each year.

Air temperature and precipitation are also available for the Algar LO station from 1959 to present. This station is located on the GDOC lease so it provides data which is representative of conditions on the lease; however, data is only available from May to September of each year. The elevation of this station is 780 m.

2.2.1 AIR TEMPERATURE

Air temperature is a significant climatic variable which controls the relative amount of rain and snow within the total annual precipitation and which affects the rate and timing of snowmelt in the spring. The monthly maximum, mean, and minimum temperatures for Fort McMurray Airport, Conklin LO and Algar LO for the climate normal period between 1961 and 1990 are shown in Figure 4 and summarized in Table 1. This period was selected for comparison because the updated EC climate normals from 1971 to 2000 are not available for Algar LO. The normal air temperatures at Fort McMurray for the 1971 to 2000 period are typically within 1°C of the 1961 to 1999 temperatures.

Table 1 Summary of monthly temperature characteristics for the climate normal period 1961-1990.

Month	Monthly Average Temperatures								
	Ft McMurray (Elevation 369 m)			Conklin LO (Elevation 671 m)			Algar LO (Elevation 780 m)		
	Max. (°C)	Mean (°C)	Min (°C)	Max. (°C)	Mean (°C)	Min (°C)	Max. (°C)	Mean (°C)	Min (°C)
Jan	-15	-20	-25						
Feb	-9	-15	-21						
Mar	-1	-8	-15						
Apr	9	3	-4						
May	17	10	3	16	10	4	14	8	3
Jun	22	15	8	19	14	8	18	13	8
Jul	23	17	10	21	16	10	20	15	10
Aug	22	15	9	20	15	9	19	14	8
Sep	15	9	3						
Oct	8	3	-2						
Nov	-5	-9	-14						
Dec	-13	-17	-22						
Annual	6	0	-6						

Extreme monthly average temperatures at Fort McMurray range from a maximum of 23°C in July to a minimum of -25°C in January. The mean daily air temperature drops below freezing in November and rises above freezing in April.

Summer air temperatures at the Algar LO station tend to be lower than at Fort McMurray. Maximum monthly temperatures at Algar LO are about 3°C lower, mean temperatures are 1.7°C lower, but minimum temperatures are virtually the same as Fort McMurray temperatures. Temperatures at Conklin LO tend to be between those at Fort McMurray and Algar LO. The air temperatures tend to decrease with increasing elevation.

2.2.2 PRECIPITATION

Precipitation is the most important climate variable that affects the hydrologic cycle. Winter snowfall influences the magnitude and duration of the spring snowmelt flows, while intense summer rainfall events produce summer peak flows. Antecedent precipitation conditions affect both the degree of saturation in the near-surface zone of the watersheds and the subsequent volume of runoff. Regional precipitation produced from the movement of large air masses can be altered by local topographic effects. Generally greater precipitation occurs at higher elevations and along the slopes of uplands where air masses are forced upwards.

These higher elevations also generally experience more of the total precipitation as snowfall rather than rain due to the lower temperatures which occur at higher elevations.

The long term precipitation record (1944-2009) at the Fort McMurray station provides the best description of the historical variation in precipitation even though it may not represent the local topographical effects. The variation in annual precipitation at Fort McMurray is shown in Figure 5. The mean annual precipitation at this station is 436 mm. The maximum annual precipitation of 675 mm occurred in 1973 while the minimum annual precipitation of 242 mm occurred in 1998.

Generally all the precipitation between November and March falls as snow due to the below freezing air temperatures during this period. This precipitation accumulates on the ground until April and May, when the snow melts and runoff is produced. The variation in annual winter snowfall is also shown in Figure 5. The mean winter snowfall is 144 cm, but the snowfall has been as much as 297 cm in 1972 and as little as 46 cm in 1949.

Summer precipitation records are available for Algar LO and Conklin LO as well as for Fort McMurray. The average monthly precipitation for the three stations for the climate normal period from 1961-1990 is shown in Figure 6 and listed in Table 2. Both Algar LO and Conklin LO have just over 20% more precipitation than the Fort McMurray station over the May to August period. The greatest monthly precipitation occurs in July, averaging about 79 mm at Fort McMurray and 102 and 103 mm at Conklin LO and Algar LO respectively.

Table 2 Summary of precipitation characteristics for the climate normal period from 1961-1990.

Month	Monthly Mean Precipitation			Daily Extreme Precipitation		
	Ft McMurray (mm)	Conklin LO (mm)	Algar LO (mm)	Ft McMurray (mm)	Conklin LO (mm)	Algar LO (mm)
Jan	20			6		
Feb	16			5		
Mar	17			8		
Apr	23			15		
May	41	49	49	38	55	53
Jun	64	87	82	46	73	45
Jul	79	102	103	52	91	82
Aug	72	70	79	95	73	89
Sep	51		69	61	100	58
Oct	32			29		
Nov	26			15		
Dec	23			8		
Annual	465					

Table 2 also summarizes the extreme daily precipitation data for Fort McMurray, Conklin LO, and Algar LO for the climate normal period from 1961-1990. The extreme daily precipitation of 89 mm reported at Algar LO is slightly lower than the 95 mm reported at Fort McMurray and the 100 mm reported at Conklin LO. There appears to be little effect of elevation on these extreme values.

Rainfall intensity-duration-frequency values for the Fort McMurray station were obtained from Environment Canada and are summarized in Table 3. The 100-year, 24-hour rainfall is 95.9 mm, which is similar to the maximum daily precipitation of 95 mm at the station. A more frequent 2-year, 1-hour rainfall is 12.8 mm. It is believed that the rainfall amounts given in Table 3 are applicable to the lease area as well because the extreme values given in Table 2 for Algar LO are similar to the extreme values for Fort McMurray.

Table 3 Rainfall intensity-duration-frequency statistics for Fort McMurray

Duration	Rainfall (mm)					
	2-year	5-year	10-year	25-year	50-year	100-year
10 minutes	7.0	9.3	10.8	12.7	14.1	15.6
30 minutes	10.6	15	17.9	21.6	24.3	27.0
1 hour	12.8	17.4	20.5	24.4	27.3	30.2
6 hours	24.6	34.5	41.1	49.3	55.5	61.6
12 hours	31.2	44.7	53.7	65.0	73.4	84.7
24 hours	38.6	53.9	64.1	76.9	86.4	95.9

2.2.3 EVAPORATION

Evaporation causes lake levels and soil moisture levels to drop during the open water season. Evaporation can be measured by evaporation pans or estimated by changes in lake levels. Lake evaporation tends to be less than the measured pan or potential evaporation due to the higher humidity over the lake. Evaporation from small ponds may be higher than lake evaporation and may approach the potential evaporation measured by evaporation pans.

Bothe (1981) calculated lake evaporation for Fort McMurray from 1972 to 1980 from air temperatures, solar radiation, atmospheric pressure, and humidity data. The lake evaporation record was extended to the entire temperature record period from 1944 to 2009 using the relationship between Bothe’s monthly lake evaporation and the effective temperature (air temperature plus average solar radiation) shown in Figure 7. The average annual lake evaporation over this period is estimated to be about 540 mm.

Actual evaporation from lakes is limited to the period from May to October when the lakes are ice free. The average lake evaporation is about 490 mm during this ice free period.

Pan evaporation data was collected at Mildred Lake north of Fort McMurray from 1973 to 1983. Figure 8 shows the correlation between the measured pan evaporation at Mildred Lake and the calculated lake evaporation at Fort McMurray. The correlation indicates that lake evaporation is on average about 74% of the pan evaporation, although there is significant month to month variation. Thus the average annual pan or potential evaporation is estimated to be 730 mm.

Evaporation from small lakes and ponds may be higher than the average lake evaporation because these water bodies have less effect on local humidity and the small volumes of water warm up more quickly. Average evaporation from small lakes and ponds may be as high as the average potential evaporation of 660 mm during the ice free period. The mean annual precipitation at Fort McMurray is 436 mm so small ponds with limited drainage areas may dry out during drier years.

Evapotranspiration, the combination of evaporation and transpiration from vegetated land, tends to be lower than lake evaporation due to the limitation of soil moisture availability. The median annual evapotranspiration from the vegetated land in the lease areas is estimated to be about 350 mm, based on the method of estimating evapotranspiration from potential and lake evaporation proposed by Morton (1983).

2.3 REGIONAL HYDROLOGY

The regional hydrological assessment includes an assessment of flows in the streams which drain the regional study area, as well a regional analysis of runoff and flows from gauges in the vicinity of the regional study area. The Horse River and the Christina River provide drainage for the regional study area. The Christina River is presently gauged but there are only a few years of historical data available for the Horse River.

2.3.1 HORSE RIVER FLOWS

The Horse River drains the north-western portion of the Project Area (Figure 1). Water Survey of Canada (WSC) operated a streamflow gauge on the Horse River at Abasands Park (07CC001) from 1930 to 1931 and from 1975 to 1979. The drainage area reported for the WSC gauge is 2130 km^2 but evaluation of the available drainage data indicated the drainage area is actually about 2,300 km^2. The gauge was operated annually for three full years of record. The mean annual flow during these three years is 8.67 m^3/s. The maximum instantaneous peak flow of 97.1 m^3/s occurred in August, 1976.

2.3.2 Christina River Flows

The Christina River drains the south-eastern portion of the Project Area (Figure 1). Water Survey of Canada maintains a streamflow gauge on the Christina River near Chard (07CE002). This gauge has a drainage area of 4860 km^2 and has been active since 1982. The gauge is seasonal so data is only available for the March-October period of each year.

Flow durations for the site are given in Table 4. Daily flows range from a minimum of 0.9 m^3/s in March to a maximum of 177 m^3/s in May. The mean annual flow for the period of record is 19.7 m^3/s.

Table 4 Flow durations for Christina River near Chard

Month	Daily Exceedance Discharge (m^3/s) for Given Duration (% of time)										
	Max	1.0	5.0	10.0	20.0	50.0	80.0	90.0	95.0	99.0	Min
Mar	9.0	6.9	5.3	4.5	3.8	3.1	2.3	1.7	1.4	1.1	0.9
Apr	104	88.0	63.2	32.0	22.2	8.3	4.4	3.3	2.7	2.0	1.9
May	177	134	95.0	82.0	56.8	18.2	9.3	7.6	6.2	4.9	4.1
Jun	174	118	75.4	65.0	46.9	21.7	9.2	6.0	4.5	3.5	3.3
Jul	152	116	77.3	62.9	44.6	20.3	9.9	6.6	4.3	2.8	2.6
Aug	111	99.0	75.2	54.3	30.2	15.9	6.6	4.1	2.4	2.0	1.9
Sep	72.2	67.2	48.4	29.1	20.3	11.0	3.9	3.3	2.9	2.3	2.0
Oct	68.3	56.4	37.7	23.1	16.3	9.3	4.6	3.5	3.2	2.6	2.3
Mar-Oct	177	101	70.0	51.0	29.2	11.6	4.1	3.1	2.5	1.7	0.9

2.3.3 Regional Flow Characteristics

There are eight Water Survey of Canada (WSC) streamflow gauges in the region. The locations of these gauges are shown in Figure 1 and a summary of their characteristics is given in Table 5. All of the gauges listed are currently operating, with discharge data published to the end of 2008. The gauges provide a record of discharges for streams with drainage areas ranging from 165 km^2 for Beaver River near Syncrude (07DA018) to 5570 km^2 for the MacKay River near Fort MacKay (07DB001).

Table 5 Summary of WSC gauges in the region

Stream	Location	Gauge Number	Gauge Type	Period of Record	Drainage Area (km^2)	Mean Annual Flow (m^3/s)	Median Annual Runoff Coefficient
Beaver River	Syncrude	07DA018	Seasonal[1]	1975-2008	165	0.50	0.20
Pony Creek	Chard	07CE003	Seasonal	1982-2008	278	0.80	0.16
Logan River	mouth	07CA012	Seasonal	1984-2008	425	1.35	0.20
House River	Hwy 63	07CB002	Seasonal	1982-2008	781	2.78	0.24
Hanging-stone River	Fort McMurray	07CD004	Seasonal[2]	1965-2008	959	3.39	0.23
Wandering River	Wandering River	07CA006	Seasonal[3]	1971-2008	1120	2.95	0.16
Christina River	Chard	07CE002	Seasonal	1982-2008	4863	13.8	0.18
MacKay River	Fort McMurray	07DB001	Seasonal[4]	1988-2008	5570	13.4	0.15

[1]guage operated annually from 1975 to 1987
[2]gauge operated annually from 1970 to 1987
[3]gauge operated annually from 1971 to 1996
[4]gauge operated annually from 1972 to 1987

The longest period of record available is 44 years for the Hangingstone River at Fort McMurray (07JD002) from 1965 to 2008. The shortest period of record, 25 years, is from 1984 to 2008 for the Logan River near mouth (07CA012). All the gauges are currently operated seasonally from March to October; however, four of the gauges were previously operated annually so some historical winter data is available for these sites. The Hangingstone River at Fort McMurray (07JD002) was operated annually for 18 years from 1970-1987; the Wandering River near Wandering River (07CA006) was operated annually for 26 years from 1971-1996; the Beaver River above Syncrude (07DA018) was operated annually for 13 years from 1975 1987; and the Mackay River near Fort Mackay (07DB001) was operated annually for 16 years from 1972-1987.

Mean annual flows calculated for each of the eight WSC basins are listed in Table 5. The mean annual flow ranged from 0.50 m^3/s for Beaver River to 13.6 m^3/s for Mackay River. The trend of mean annual flow with drainage area shown in Figure 9 indicates that mean annual flow is directly proportional to drainage area.

Annual runoff coefficients were calculated for each of the drainage basins listed in Table 5. Runoff coefficients define the fraction of precipitation which leaves the basin as streamflow. For consistency, the median annual runoff from each basin was calculated from the streamflow for the period from March to October, since winter flow data in only available for portions of the periods of record at some of the gauges. When winter streamflow data is available it is generally about 5% of the total annual flow so the real annual runoff coefficients may be up to 5% greater than the values provided in Table 5.

As presented in Section 2.2.2, annual precipitation records are available for Fort McMurray while at Algar LO precipitation records are only available for May through September. Therefore, a composite precipitation was developed for the runoff analysis from the Fort McMurray record, modified with the average of the two records where both are available since this average is believed to be more representative of the regional precipitation. The use of this composite precipitation for the region will produce slightly higher runoff coefficients than if just Algar summer precipitation is used, since the composite precipitation is typically lower that the Algar precipitation.

The annual runoff coefficients were calculated from composite annual precipitation calculated from November to October to associate the accumulated winter snowfall with the runoff in the following spring and summer. The median annual runoff coefficients for the region range from 0.15 for MacKay River near Fort MacKay to 0.24 at House River, with an average of 0.19. The WSC gauge stations are distributed around the LSA, so the average value is believed to provide a reasonable estimate of local runoff. There is no significant trend in the magnitude of the runoff coefficient with drainage area.

Peak annual maximum instantaneous flows from the historical records of the eight WSC gauges were also evaluated. These flows are summarized in Table 6. Mean annual peak flows ranged from 9.2 m^3/s for Pony Creek to 122 m^3/s for the Mackay River. The mean annual peak flows tend to increase log-linearly with drainage area as shown in Figure 9. Peak flows for 10-year, 25-year and 100-year return periods are presented in Table 6 for each of the gauges.

Flow frequency distributions of the annual peak flows from the gauges normalized by mean annual peak flows are shown in Figure 10. An adopted regional log-normal distribution which fits the general trend of the data is also shown in this figure.

Average minimum monthly flows are also listed in Table 6 for the eight WSC gauges. These minimum monthly flows include winter flows where available. Minimum flows typically occur during the winter months but can also occur during summer dry periods. These minimum flows tend to vary linearly with drainage area as shown in Figure 9 but there is considerable scatter in the data.

Table 6 Summary of regional peak and minimum flows

Stream	Location	Drainage Area (km^2)	Mean Annual Peak Flow (m^3/s)	10-Year Peak Flow (m^3/s)	25-Year Peak Flow (m^3/s)	100-Year Peak Flow (m^3/s)	Average Minimum Monthly Flow[1] (m^3/s)
Beaver River	Syncrude	165	9.80	21.9	33.7	57.3	0.044
Pony Creek	Chard	278	9.06	16.9	22.9	33.2	0.038
Logan River	mouth	425	14.4	28.4	43.8	74.4	0.47
House River	Hwy 63	781	18.5	35.0	46.7	66.4	0.53
Hanging-stone River	Fort McMurray	959	44.7	84.4	114	166	0.21
Wandering River	Wandering River	1,120	28.0	60.8	89.7	145	0.13
Christina River	Chard	4,863	81.6	160	219	321	3.0
MacKay River	Fort McMurray	5,570	122	258	377	598	0.47

[1]winter flow records incomplete

2.3.4 Regional Lake Levels

Water survey of Canada (WSC) reports water levels for gauges at Gregoire Lake (07CE001) and Christina Lake (07CE906), both of which are located in the Christina River basin. Gregoire Lake is located about 50 km northeast of the lease and Christina Lake is about 75 km to the southeast.

The Gregoire Lake water level gauge has been operated since 1969. The drainage area of the lake of 261.5 km^2 is about 10 times its 25.8 km^2 surface area. The mean lake level during this period is 475.47 m. The maximum lake level of 476.29 m occurred in 1970 while the minimum lake level of 475.01 m occurred in 1981. The annual fluctuation in lake level is on average about 0.35 m with a maximum fluctuation of 0.62 m in 1970 and minimum fluctuation of 0.10 m in 1999. The lake was regulated in 1973 with the construction of a weir at the outlet channel so these fluctuations may not be representative of natural lakes and ponds.

The drainage area of Christina Lake of 1265 km^2 is about 60 times its 21.3 km^2 surface area. Water level data from a gauge on Christina Lake is reported by WSC since 2001. The mean lake level during this period is 554.08 m. The maximum lake level of 554.84 m and the minimum lake level of 553.77 m both occurred in 2003. The annual fluctuation in lake level is, on average, about 0.91 m with a maximum of 1.06 m in 2003 and minimum of 0.77 m in 2006. The lake level fluctuated 0.85 m in 2007.

2.4 LOCAL HYDROLOGY

2.4.1 LOCAL HYDROGRAPHY

Figure 11 shows the hydrography in the vicinity of the LSA. Observations in the LSA and at other sites in the region indicate that the stream network obtained from 1:50,000 scale National Topographic Service (NTS) maps provides a reasonable indication of where streams with defined channels occur. The streams with defined channels shown in Figure 11 were derived from these NTS maps with some minor modifications to maintain consistency with Digital Elevation Model (DEM) data obtained from the Geobase database and LIDAR (Light Detection And Ranging) data. Additional hydrography obtained from 1:20,000 scale Alberta Sustainable Resource Development (ASRD) maps are shown on Figure 11 as drainages without defined channels.

Watershed boundaries were determined from the hydrography, DEM, and LIDAR data. Four major watersheds drain the LSA. Watershed A drains into Little Horse Creek, which is a major tributary of the Horse River, while Watershed B drains directly into the mainstem of the Horse River. Watershed C drains into the mainstem of the Christina River while Watershed D drains a major tributary of the Christina River. The major watersheds were subdivided into a number of smaller scale watersheds which drain individual portions of the LSA. The locations of these smaller scale watersheds are shown in Figure 11.

There are eight small unnamed lakes in the RSA, two in Watershed B and six in Watershed C. The locations of these lakes are shown in Figure 11. Lakes UL1 to UL4 fall within the LSA while the others are located outside the LSA. Table 7 lists the surface areas of these lakes. The largest lake, designated UL1, has an area of 27.1 ha while the smallest, UL4, has an area of 3.8 ha. The combined area of UL2 and UL3, which are separated by a short channel, is 39.6 ha.

2.4.2 LOCAL SNOW COURSE DATA

Snow depths and densities were measured at three sites in the lease area on March 25, 2007. The locations of these sites are shown in Figure 12. Five snow tube measurements were taken at each site at 100 to 200 m intervals. A summary of the data is given in Table 8. The snow depth ranged from a minimum of 20 cm to a maximum of 98 cm. The average snow depth was 64 cm. Snow densities ranged from 127 to 286 kg/m^3 and water equivalents ranged from 40 to 260 mm. The average water equivalent was 155 mm. The water equivalent of the cumulative winter snowfall to March 25 at the Fort McMurray Airport was only 70 mm, which is only 45% of the value measured at the site.

Table 7 Summary of lake areas

Lake	Location	Surface Area (ha)	Drainage Area[1] (ha)	Drainage to Surface Area Ratio
UL1	Watershed C2a	27.1	337.1	12.4
UL2	Watershed C1b	13.9	108.3	7.8
UL3	Watershed C1b	25.7	447.5	17.4
UL4	Watershed C1a	3.8	579.0	152
UL5	Watershed C1c	10.1	207.3	20.5
UL6	Watershed C1d	32.1	663.1	20.7
UL7	Watershed B2	12.5	141.0	11.3
UL8	Watershed B	27.4	12,117	443

[1] drainage area includes lake area

Table 8 Snow course data measured March 25, 2007

Location	Easting (m)	Northing (m)	Distance (m)	Snow Depth (cm)	Density (kg/m3)	Water Equivalent (mm)
Site 6	456538	6216862	0	70	229	160
	456526	6216755	108	79	127	100
	456603	6216686	211	70	171	120
	456608	6216492	405	64	219	140
	456607	6216276	621	75	227	170
			Average	72	194	138
Site 4-5	456155	6220789	0	20	200	40
	456050	6220936	181	55	273	150
	455833	6220915	399	60	233	140
	455778	6221069	562	67	239	160
	455778	6221359	852	66	212	140
			Average	54	231	126
Site 2	454196	6224178	0	56	286	160
	454140	6224035	154	52	250	130
	454072	6223877	326	98	265	260
	453947	6223716	529	63	222	140
	453776	6223544	772	94	255	240
			Average	73	256	186
			Average	64	240	155

Snow depths and densities were again measured at three sites on March 18, 2008 near the original three locations. Five snow tube measurements were taken at each site at 50 to 300 m intervals. A summary of the data is given in Table 9. The snow depth ranged from a minimum of 37 cm to a maximum of 78 cm. The average snow depth was 55 cm. Snow densities ranged from 179 to 391 kg/m^3 and water equivalents ranged from 90 to 180 mm. The average water equivalent was 147 mm. The water equivalent of the cumulative winter snowfall to March 18 at the Fort McMurray Airport was only 57 mm, which is only 39% of the value measured at the site.

The ratio of local snow-on-ground to Fort McMurray accumulated winter snowfall is similar for both years for which local data was collected. This data indicates that the water equivalent of the local snow-on-ground is 2.2 to 2.5 times the water equivalent of snowfall reported at the Fort McMurray Airport.

Table 9 Snow course data measured March 18, 2008

Location	Easting (m)	Northing (m)	Distance (m)	Snow Depth (cm)	Density (kg/m^3)	Water Equivalent (mm)
Site 6	458283	6218029	0	53	302	160
	458275	6217964	65	57	246	140
	458274	6217904	125	73	192	140
	458275	6217841	188	68	235	160
	458273	6217779	250	78	179	140
			Average	66	231	148
Site 4-5	455861	6221657	0	46	391	180
	455909	6221657	48	58	310	180
	455967	6221653	106	44	318	140
	456022	6221645	161	63	190	120
	456076	6221660	215	67	209	140
			Average	56	284	152
Site 2	454009	6223412	0	52	327	170
	454158	6223586	229	50	340	170
	454265	6223780	448	37	324	120
	454365	6224043	724	38	237	90
	454415	6224322	996	45	356	160
			Average	44	317	142
			Average	55	277	147

2.4.3 LOCAL WATER LEVEL AND STREAMFLOW DATA

The streams within the LSA range in size from small channels draining the higher areas to larger channels carrying outflow from the lakes. The larger channels downstream of the lakes contain numerous beaver dams. Six sites were selected to monitor water levels within the LSA. The locations of these sites are shown in Figure 12. Sites 1, 2, 5 and 6 were located in streams while Sites 3 and 4 were located on lakes. Site 1 was located in Watershed B, Site 2 was located in Watershed A and Sites 4-6 were located in Watershed C.

An initial site reconnaissance was made in late March and winter flow measurements were made at Sites 5 and 6. Subsequently three scheduled site visits were made to each of the monitoring sites. During the first site visit in May 2007, water level recorders were installed and discharge measurements were taken where possible. In July 2007, measurements were made of discharges and survey channel cross sections and slope profiles. In the final site visit in September 2007, discharges were measured and the water level recorders were removed. A summary of the streamflow data collected at each site is given in Table 10.

Table 10 Summary of 2007 water level and flow data collected at monitoring sites

Site	Watershed	Easting (m)	Northing (m)	Drainage Area (km^2)	Date	Width (m)	Velocity (m/s)	Discharge (m^3/s)	Water Level (m)
1	B3b	449438	6219160	7.16	May 09 Jul 11 Sep 17	1.90 1.51 1.51	0.52 0.19 0.27	0.20 0.015 0.026	99.110 98.933 98.943
2	A1a	454507	6225204	2.85	May 09 Jul 11 Sep 17	0.90 0.96 0.97	0.17 0.02 0.04	0.034 0.001 0.005	99.090 98.810 98.929
4	C1b (UL3)	455458	6221720	4.48	May 09 Jul 11 Sep 18				99.346 99.305 99.315
5	C1b	456760	6220445	9.26	Mar 25 May 02 Jul 12 Sep 18	0.4 3.0 n/a 8.90	0.04 0.10 n/a 0.07	0.007 0.24 n/a 0.46	n/a n/a 99.237 99.445
6	C2a	456418	6217217	15.58	Mar 25 May 02 Jul 11 Sep 18	2.5 2.5 2.88 3.04	0.005 0.49 0.05 0.03	0.004 0.73 0.047 0.027	n/a bankfull 97.996 97.994

Water levels were recorded using Solinst Model 3001 M5 Leveloggers placed in the water at each site. Water levels were referenced to a local benchmark during each site visit using a survey level. Velocities were measured using a Marsh-McBirney Flo-Mate Model 2000 electromagnetic flowmeter or a Price-type flowmeter. The float method was utilized to measure surface velocities when wading the stream was not possible.

Site 1

Site 1 is located on the stream draining Watershed B3b. The drainage area upstream of this site is 716 ha. The channel cross section is quite small, with a bankfull width of about 2.5 m and a bankfull depth of about 0.5 m. The stream is steep at this location, with an average water surface slope at low flow of 0.012.

The water levels measured at Site 1 are shown in Figure 13. The water level at Site 1 dropped 0.2 m from its initial value in early May which left the Levelogger above the water level. After the Levelogger was reset in July the water level remained low until late August when the water level increased by about 0.2 m before dropping again over a period of about 10 days.

Discharges were estimated from the measured water levels using a discharge rating curve established from discharge measurements at the site (Figure 13). The peak discharge during August of 0.20 m^3/s was similar to the discharge measured on May 9 during the spring runoff; however, it is likely that the spring peak discharge was higher than the measured discharge.

Site 2

Site 2 is located on the stream draining Watershed A1a. The drainage area upstream of this site is 285 ha. The channel cross section is quite small, with a bankfull width of about 1.5 m and a bankfull depth of about 0.5 m. The stream is moderately steep at this location, with average water surface slope of 0.0035.

The water levels measured at Site 2 are shown in Figure 14. The water level dropped 0.30 m from its initial value in early May which left the Levelogger above the water level. After the Levelogger was reset in July the water level remained low until late August when the water level increased by about 0.30 m before dropping again over a period of about 10 days.

Discharges were estimated from the measure water levels using a discharge rating curve established from discharge measurements at the site (Figure 14). The August peak discharge estimate of 0.049 m^3/s was greater than the discharge measured on May 9 of 0.034 m^3/s during the spring runoff.

Site 3

Site 3 is located on Lake UL1 in watershed C2a. The drainage area of Lake UL1 is 337 ha, which is about 12 times the surface area of the lake. Lake levels at Site 3 in Lake UL1 were to be monitored during 2007 but this site was abandoned because access was too difficult. The Levelogger could not be installed in the open water of the lake because firm ground could not be found along the shoreline to access the open water. Photographs of Site 3 are shown in Figure 15.

Site 4

Site 4 is located on Lake UL3 in watershed C1b. The drainage area of Lake UL3 is 448 ha, which is 17 times the surface area of UL3 and 11 times the combined surface area of lakes UL2 and UL3.

Lake levels at Site 4 in Lake UL3 were monitored continuously at 30 min intervals from May 9 to Sept 18, 2007. The fluctuations in water level during this period are shown in Figure 16 along with the daily precipitation reported at the Algar LO climate station. The total May-Aug precipitation at Algar LO of 289 mm for 2007 is only slightly below the median value of 304 mm for this period so the lake level changes measured in 2007 are believed to be typical for lakes of this size and drainage area.

The maximum change in water level which occurred during the measurement period was 0.15 m. This increase in water level occurred during the month of August during which time 119 mm of precipitation fell. The increase in water level in Christina Lake during this time period was 0.39 m. The greater increase for Christina Lake is consistent with the higher drainage to lake area ratio of 60 for this lake.

The annual fluctuation in the level of UL3 is believed to be larger than 0.15 m. The Levelogger at this site was installed after the lake level had increased due to snowmelt runoff so the minimum late winter level was not measured.

Site 5

Site 5 is located on the stream draining watershed C1b. The drainage area upstream of this site is 926 ha. The channel cross section at the site has a bankfull width of about 9 m and a bankfull depth of about 1.1 m. The water surface slope of the stream of 0.000025 is quite mild due to the presence of a beaver dam downstream of the site.

The variation in water levels measured at Site 5 is shown in Figure 17. The water level dropped about 0.30 m from its initial value in early May before increasing again in late June. The water level peaked again in late August after a cumulative rise in level of 0.4 m during August.

Insufficient discharge data was collected at Site 5 to establish a rating curve for the site. The discharge measured on May 10 was consistent with discharges at the other sites but the discharge measured on Sept 18 was much higher than the discharges at the other sites.

A late winter discharge measurement was attempted in the stream upstream of Site 5 on March 25, 2007. Water was found in only one of the holes drilled though the ice, so an accurate discharge could not be determined. A velocity of 0.05 m/s was measured under the ice at this location. The discharge is estimated to have been about 0.008 m^3/s, based on the data collected.

Site 6

This site is located on the stream draining watershed C2a. The drainage area upstream of this site is 1558 ha. The channel cross section has a bankfull width of about 5 m and a bankfull depth of about 0.8 m. The stream is moderately steep at this location, with a water surface slope of 0.0018.

The variation in water levels measured at Site 6 is shown in Figure 18. The water level at Site 6 dropped 0.25 m from its initial value in early May and remained low until late August when the water level increased by about 0.30 m before dropping again over a period of about 10 days. The estimated peak discharge during August of 0.49 m^3/s was less than the discharge measured on May 2 of 0.73 m^3/s during the spring runoff.

A late winter discharge measurement was attempted in the stream downstream of Site 6 on March 25, 2007. Water was found in five holes drilled though the ice but the measured velocity of 0.01 m/s was less than instrument error of 0.015 m/s. The discharge is estimated to have been in the order of 0.005 m^3/s.

2.4.4 LOCAL STREAMFLOWS

The mean annual flows for the streams draining the watersheds listed in Table 11 were estimated using the linear relationship between mean annual flow and drainage area established from the regional flow data (Figure 9). The estimated mean annual discharges are quite low, ranging from 0.007 m^3/s for Watershed C1c to 2.57 m^3/s for Watershed C.

Annual peak flows for the watersheds are also given in Table 11 for a range of return periods. These peak flows were estimated from the drainage areas on the basis of the results of the regional peak flow analysis shown in Figures 9 and 10.

Table 11 Summary of drainage areas and estimated flows for local watersheds

Watershed	Drainage Area (km²)	Mean Annual Flow (m³/s)	Mean Annual Peak Flow (m³/s)	10-year Peak Flow (m³/s)	25-year Peak Flow (m³/s)	100-year Peak Flow (m³/s)	Average Minimum Monthly Flow (m³/s)
A1a	7.04	0.019	0.749	1.51	2.15	3.33	0.002
A1b	6.22	0.017	0.683	1.37	1.96	3.04	0.002
A2	43.28	0.119	2.87	5.76	8.23	12.7	0.013
A	109.35	0.300	5.69	11.44	16.34	25.3	0.034
B1	43.02	0.118	2.86	5.74	8.19	12.7	0.013
B2	28.82	0.079	2.12	4.27	6.09	9.44	0.009
B3a	10.63	0.029	1.02	2.04	2.91	4.51	0.003
B3b	19.73	0.054	1.61	3.22	4.61	7.13	0.006
B3c	6.96	0.019	0.743	1.49	2.13	3.30	0.002
B3d	8.03	0.022	0.826	1.66	2.37	3.67	0.002
B3e	12.09	0.033	1.12	2.24	3.21	4.96	0.004
B3f	3.93	0.011	0.486	0.977	1.40	2.16	0.001
B4	15.96	0.044	1.37	2.76	3.94	6.10	0.005
B	243.05	0.668	10.28	20.6	29.5	45.7	0.075
C1a	7.77	0.021	0.805	1.62	2.31	3.58	0.002
C1b	16.09	0.044	1.38	2.77	3.96	6.13	0.005
C1c	2.52	0.007	0.350	0.704	1.01	1.56	0.001
C1d	10.28	0.028	0.991	1.99	2.84	4.40	0.003
C1e	22.76	0.063	1.78	3.58	5.12	7.92	0.007
C2a	22.51	0.062	1.77	3.55	5.08	7.86	0.007
C2b	18.60	0.051	1.54	3.09	4.41	6.83	0.006
C2c	16.98	0.047	1.44	2.89	4.12	6.38	0.005
C3	17.29	0.047	1.46	2.92	4.18	6.47	0.005
C4	60.80	0.167	3.69	7.41	10.6	16.4	0.019
C	935.99	2.57	27.9	56.0	79.9	124	0.290
D1	65.27	0.179	3.89	7.81	11.2	17.3	0.020

For comparison, the 2007 peak flow data measured at the local streamflow sites and from the WSC gauges are shown in Figure 9 along with the mean annual peak flows. The 2007 WSC peak flows are similar to the mean annual values so 2007 appears to be a typical year for annual peak flows. The peak flows measured at the streamflow sites are below the trend established from the WSC data; however, it is possible that the measured flows did not capture the peak flow during snowmelt in early May.

Minimum flows in most of the smaller watersheds are believed to be zero or near zero. Even the two larger streams at Sites 5 and 6 in Watersheds C1b and C2a where winter flow measurements were taken had very little flow in them, even though there were lakes upstream of both these sites. Some of the smallest streams, such as the stream at Site 2 in Watershed A1a, dry out in the summer as well during periods of little or no rain. This indicates that there is very little groundwater inflow to the streams in the LSA.

2.4.5 STREAMFLOW AND WATER LEVEL SIMULATIONS

Local streamflow hydrographs were simulated with the Hydrologic Simulation Program – FORTRAN (HSPF) in preparation to assess project impacts on the timing and magnitude of peak flows. The HSPF model simulates basin runoff processes including winter snow accumulation, snowmelt, summer runoff, evaporation and evapotranspiration on a continuous basis, with precipitation, potential evaporation, and temperature as the main inputs. For the present study, the model was configured to run at a one hour time step for the period 1961 through 2007. The first year was used to initialize basin moisture conditions and the results for this year were excluded from subsequent analyses. Precipitation for the model was based on data from Algar LO when available and otherwise from Fort McMurray. Temperature and potential evaporation inputs were based on data from Fort McMurray, with temperatures being adjusted in the model to account for elevation differences. In light of the snow survey results which showed winter snow accumulations at the site which were more than double the accumulated winter precipitation at Fort McMurray, the model was configured with a two times multiplier on the McMurray-derived snowfall amounts.

The HSPF model was calibrated to existing pre-development natural site conditions by adjusting snowmelt and runoff parameters so that the timing, volumes, and peaks of simulated flows were similar to data recorded in the LSA in 2007. Simulation results are presented in Figure 19 together with the unit runoff from the gauged sites in the LSA. The match of simulated and measured flows is quite good for the 2007 open water period for which recorded data are available. The simulation results also show that the spring peak flow was about twice the magnitude of the maximum measured flow.

The HSPF model was used to simulate streamflows in watersheds B3b, C1b and C2a. The three watersheds have quite similar flow durations. The unit flow duration for watershed C2b is given in Table 12. Flows are typically very low or zero in winter while the highest flows tend to occur in May and June.

The HSPF model was also used to simulate lake levels. Year 2007 simulated water levels for Lake UL3 are presented in Figure 20 together with the Site 4 measured water levels at Lake UL3. The simulated water levels match the measured values reasonably well, although the simulated summer peak level is about 0.03 m lower than the measured value. The simulated water levels also indicate that the peak water level in the spring was about 0.15 m higher than the maximum measured water level.

Table 12 Unit flow durations for Watershed C2b

Month	Daily Exceedance Unit Discharge ($m^3/s/km^2$) for Given Duration (% of time)										
	Max	1.0	5.0	10.0	20.0	50.0	80.0	90.0	95.0	99.0	Min
January	0.0005	0.0004	0.0003	0.0002	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000
February	0.0005	0.0004	0.0002	0.0002	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
March	0.0005	0.0003	0.0002	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
April	0.122	0.0528	0.0022	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
May	0.260	0.191	0.126	0.0943	0.0664	0.0181	0.0000	0.0000	0.0000	0.0000	0.0000
June	0.250	0.195	0.165	0.131	0.0711	0.0178	0.0058	0.0026	0.0012	0.0006	0.0003
July	0.145	0.0773	0.0434	0.0287	0.0172	0.0064	0.0022	0.0011	0.0005	0.0003	0.0001
August	0.111	0.0567	0.0241	0.0164	0.0103	0.0040	0.0012	0.0006	0.0004	0.0002	0.0001
September	0.0573	0.0412	0.0276	0.0199	0.0127	0.0047	0.0013	0.0006	0.0004	0.0001	0.0000
October	0.0491	0.0331	0.0161	0.0100	0.0063	0.0025	0.0010	0.0006	0.0004	0.0002	0.0001
November	0.0151	0.0094	0.0039	0.0022	0.0013	0.0005	0.0002	0.0002	0.0001	0.0001	0.0001
December	0.0012	0.0008	0.0004	0.0003	0.0002	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000
Annual	0.260	0.141	0.0518	0.0231	0.0088	0.0005	0.0000	0.0000	0.0000	0.0000	0.0000

Table 13 Water level durations for Lake UL1

Month	Daily Exceedance water level for Given Duration (% of time)										
	Max	1.0	5.0	10.0	20.0	50.0	80.0	90.0	95.0	99.0	Min
January	99.34	99.34	99.34	99.33	99.33	99.33	99.33	99.33	99.33	99.33	99.33
February	99.34	99.34	99.34	99.33	99.33	99.33	99.33	99.33	99.33	99.33	99.32
March	99.34	99.34	99.33	99.33	99.33	99.33	99.32	99.32	99.31	99.31	99.30
April	99.55	99.44	99.33	99.33	99.32	99.31	99.29	99.28	99.28	99.27	99.26
May	99.74	99.65	99.56	99.52	99.47	99.37	99.28	99.26	99.26	99.24	99.22
June	99.71	99.64	99.61	99.57	99.49	99.39	99.35	99.33	99.32	99.29	99.22
July	99.59	99.51	99.44	99.42	99.39	99.35	99.33	99.31	99.28	99.23	99.22
August	99.55	99.46	99.41	99.39	99.37	99.34	99.32	99.29	99.27	99.26	99.24
September	99.47	99.44	99.42	99.40	99.38	99.35	99.33	99.30	99.28	99.24	99.23
October	99.45	99.43	99.39	99.37	99.36	99.34	99.33	99.33	99.31	99.27	99.23
November	99.38	99.37	99.35	99.34	99.34	99.33	99.33	99.33	99.33	99.32	99.31
December	99.35	99.34	99.34	99.34	99.33	99.33	99.33	99.33	99.33	99.33	99.32
Annual	99.74	99.58	99.45	99.40	99.36	99.33	99.33	99.31	99.29	99.26	99.22

3 BASELINE DEVELOPMENT CASE

This section describes the hydrologic impacts of the existing and approved developments in the LSA. The footprints of the developments are described and the impacts identified.

3.1 FOOTPRINT OF EXISTING AND APPROVED DEVELOPMENTS

Existing and approved resource extraction developments within the LSA include the existing Great Divide SAGD project and the approved Algar SAGD project. The locations of these developments are included on Figure 21 which shows the footprint for the proposed expansion project. Other significant existing developments in the LSA include Highway 63 and a cleared utility corridor which runs parallel to the highway on the west side. The Great Divide SAGD project is located in Sections 15-17 and 20-23 of Twp 82, Rge 12, W4. The Algar SAGD project is located in Sections 18 and 19 of Twp 82, Rge 11, W4 and Sections 13, 14, 23 and 24 of Twp 82, Rge 12, W4. The Highway 63 and utility corridors are located in Sections 7, 8, 16, 17, 21, 22, 26, 27, 35, and 36 of Twp 82, Rge 12, W4 and Sections 6 and 7 of Twp 83, Rge 11, W4.

There are other minor sources of disturbances within the LSA such as cutlines for seismic exploration and access for oil and gas extraction. These types of activities are wide spread in the region and any hydrologic effects of such minor disturbances will be reflected in the regional historical streamflow data presented in the baseline hydrology study.

3.1.1 SURFACE DISTURBANCES

Surface disturbances that currently exist include road/utility corridors, plant sites, camps, well pads, water wells, airstrip and borrow pits. Some of these are related to Connacher's activities, some are related to Highway 63 development, and some are from other industrial development in the area. The areas of these disturbances within the LSA are summarized in Table 14 (514.6 ha).

Table 15 summarizes the extent of the spatial disturbances within individual watersheds. 75% of the disturbed area is in the Horse River basin (Watersheds A and B) and 25% is in the Christina River basin The greatest percentage area of disturbance occurs in Watershed B3d, where 7.6% of the land is disturbed. Other watersheds with significant percentages of disturbed area are Watershed C1b, where 6.0% of the land is disturbed, and Watershed B3b, where 5.5% of the land is disturbed. The disturbances in the other watersheds are smaller, ranging from 0.67% to 4.1% of the watershed areas.

Table 14 Summary of disturbed areas from existing development

Disturbance Type	Great Divide SAGD Area (ha)	Algar SAGD Area (ha)	Hwy 63 Area (ha)	Utility Corridor Area (ha)	Total Area (ha)
Road & Utility Corridors	27.5	31.0	75.1	221.9	355.5
Plant Sites	16.9	31.8			48.7
Camps	2.6	11.4			14.0
Well Pads	16.7	14.2			30.9
Water Wells		1.7			1.7
Airstrip	20.3				20.3
Borrow Pits	15.9	27.6			43.5
Total	99.9	117.7	75.1	221.9	514.6

Table 15 Summary of spatial extent of existing development

Water-shed	Drainage Area (ha)	Disturbance Areas								Percent of Drainage Area (%)
		Road & Utility Corridor (ha)	Plant Sites (ha)	Camps (ha)	Well Pads (ha)	Water Wells (ha)	Airstrip (ha)	Borrow Pits (ha)	Total (ha)	
A1a	704.4	25.5							25.5	3.6
A1b	621.6	19.3							19.3	3.1
B1	4301.5	73.9					1.6		75.6	1.8
B3a	1062.8	7.2							7.2	0.67
B3b	1973.4	88.3			3.5		9.0	7.5	108.3	5.5
B3c	696.1	13.1	2.2		13.2			0.0	28.5	4.1
B3d	803.1	34.9	14.7	2.6				8.5	60.7	7.6
B3e	1208.7	11.5							11.5	0.95
B4	1596.5	48.7							48.7	3.0
C1b	1609.0	22.9	25.9	11.4	14.2	1.7		19.7	95.8	6.0
C2a	2250.6	10.2	5.9				9.7	7.9	33.7	1.5

The percentage disturbances in the larger scale watersheds are very small. The percentage disturbance in Watershed A is 0.41%; the percentage disturbance in Watershed B is 1.4%; and the percentage disturbance in Watershed C is 0.14%. It is difficult to measure the effect of this very low intensity scale of development on any hydrologic parameter.

Road and Utility Corridors

The location of the Highway 63 road corridor is shown in Figure 21. A major utility corridor, not shown, runs approximately parallel to the highway on its west side. There are additional access roads and utility corridors for the existing and approved SAGD projects. The highway has an 18 m paved width within a 60 m right-of-way while the main utility corridor is about 170 m wide. The total disturbed area of these road and utility corridors, plus those within the existing and approved SAGD development, is 355.5 ha.

The runoff coefficient from the paved highway surface is believed to be about 0.80 since some the runoff will evaporate or infiltrate into the ground in the ditches. The remaining 70% of the highway right-of-way is non-forested vegetation with a runoff coefficient of about 0.25, slightly higher than the undisturbed value of 0.19; therefore, the effective runoff coefficient for the highway corridor is estimated to be about 0.40.

The runoff coefficient from the gravel road surfaces is believed to be about 0.60. The other half of the utility corridor surface area will be non-forested vegetation with a runoff coefficient of about 0.25; therefore, the effective runoff coefficient for the road and utility corridors is estimated to be about 0.40.

Plant Sites

Plant sites are located in NW 16-82-12-W4 in watersheds B3c and B3d and in N18 and S19 of 82-11-W4 in watersheds C1b and C2a. Runoff from the plant sites may be poorer in quality than the runoff from natural areas so it will be detained and discharged after it has been determined to meet water quality guidelines. The effective runoff coefficient may be as much as 0.6 if runoff is discharged after being treated.

Camp

As shown in Figure 21, camps are located in watersheds B3d and C1b. The camp areas will likely consist of buildings on a porous gravel subgrade so the runoff coefficient for these areas is believed to be about 0.60. This is substantially higher than the natural annual runoff coefficient of 0.19. The water quality of the runoff from the camp is not anticipated to be substantially different from the runoff from the undisturbed site so the runoff is not contained. Thus, the camps contribute to an increase in runoff.

Well Pads

The locations of the well pads are shown by “WP” labels in Figure 21. The total disturbed area of these well pads is 30.9 ha. The well pads are located in three watersheds, with 3.5 ha in Watershed B3b, 13.2 ha in Watershed B3c and 14.2 ha in Watershed C1b.

The well pads are expected to be constructed of gravel so the runoff coefficient for the well pads is believed to be about 0.60. This is substantially higher than the natural annual runoff coefficient of 0.19. The water quality of the runoff from the well pads is not believed to be substantially different from the runoff from the undisturbed site.

Water Supply Well Pads

As shown in Figure 21, Water Supply Well (WSW) Pads for the Algar SAGD project are located in Watershed C1b. These WSW pads have a total area of 1.7 ha. The pads are constructed of compacted clay so the runoff coefficient for the pads is believed to be about 0.60. This is substantially higher than the natural annual runoff coefficient of 0.19. The water quality of the runoff from the pads is not believed to be substantially different from the runoff from the undisturbed site so the runoff will not be contained. Thus, the WSW pads will contribute to an increase in runoff from the watersheds in which they are located.

Airstrip

The airstrip is located in watersheds B1, B3b and C2a (Figure 21) and has a total area of 20.3 ha. The runoff coefficient from the gravel surfaces of the airstrip is believed to be about 0.60. The remaining surface of the airstrip area will be non-forested vegetation with a runoff coefficient of about 0.25. Thus, it is estimated that the effective runoff coefficient for the airstrip area will be about 0.40.

Borrow Pits

Borrow pits were excavated at various locations to supply fill material for the construction of roads and well pads. The locations of these borrow pits are shown in Figure 21. The bottoms of the pits are lower in elevation than the surrounding land so any precipitation falling on a borrow pit area will be contained in the borrow pit where it will either evaporate or seep into the ground. No surface runoff will be generated from these areas.

3.1.2 STREAM DISTURBANCES FROM EXISTING AND APPROVED DEVELOPMENTS

A number of highway culverts were identified in the LSA which correspond to existing drainage patterns across the highway. These culverts are listed in Table 16 and the locations shown in Figure 21. There are 14 culvert, most of which s are located in drainages without defined channels. Three of the highway culverts are located on streams with defined channels, one channel in Watershed A1a in NW 6-83-11-W4 and two channels in Watershed B3b in NE 16-8212-W4 and SE 27-82-12-W4.

In addition to the three highway stream channel crossings, the Great Divide road and utility corridor crosses one stream with a defined channel in Watershed B3b in NE 16-8212-W4. The Algar road and utility corridor does not cross any streams which have defined channels. The channels at these stream crossing locations are generally quite narrow. Measurement Site 1 in NE 16-8212-W4, which is on the same stream as the culvert in Watershed A1a, has a bankfull channel width of 1.5 m. Measurement Site 2 in NW 6-83-11-W4, which is on the same stream as two culverts in Watershed B3b, has a bankfull channel width of about 2.5 m.

Table 16 Summary of existing culverts under Hwy 63 in LSA

Culvert	Material	Diameter (m)	Easting (m)	Northing (m)	Watershed	Classification
1	Steel	0.8	454,490	6,225,250	A1a	Defined Channel
2	Plastic	0.6	453,830	6,223,540	B1	Drainage
3	Steel	0.7	453,210	6,222,930	B1	Drainage
4	Steel	0.7	453,620	6,223,350	B1	Drainage
5	Steel	0.9	452,750	6,222,420	B1	Drainage
6	Steel	0.7	452,750	6,222,420	B1	Drainage
7	Plastic	0.6	451,370	6,221,020	B3b	Defined Channel
8	Steel	0.8	449,930	6,219,550	B3b	Drainage
9	Steel	0.9	449,460	6,219,010	B3b	Defined Channel
10	Steel	0.3	448,590	6,218,190	B3d	Drainage
11	Plastic	0.4	448,170	6,217,790	B3d	Drainage
12	Plastic	0.7	447,820	6,217,410	B3e	Drainage
13	Steel	0.75	447,370	6,216,960	B4	Drainage
14	Steel	0.75	446,480	6,216,070	B4	Drainage

3.1.3 WATER SUPPLY

The existing SAGD projects use water for production of steam that will be injected into the oil bearing formation. This process water is re-circulated and reused as much as possible; however, some of the water is lost in the formation or is taken up in disposing of unwanted by-products. This lost water is replaced from local deep groundwater supplies. No surface water is being used for process water.

3.2 HYDROLOGIC IMPACTS FROM EXISTING AND APPROVED DEVELOPMENTS

The existing and approved developments can affect the hydrology in the local study area (LSA). The affects may include changes in the following:

- Runoff volumes and streamflows
- Water levels and surface areas
- Channel morphology and sediment concentrations

These effects are evaluated in more detail in the following sections.

3.2.1 RUNOFF VOLUMES AND STREAMFLOWS

Surface disturbances from existing and approved developments can cause changes to surface runoff characteristics of the natural environment. Specifically, changes in surface drainage patterns and changes in the runoff coefficients can affect the runoff volumes, peak flow rates, and timing of peak flows in the local streams. Water levels in lakes and wetlands may also be affected.

There are no significant changes in the surface drainage patterns due to the existing and approved SAGD projects; however, the highway construction has caused some minor changes in the drainage in Watershed B. Runoff from small areas of the headwaters of the watershed were diverted into neighbouring drainages within the watershed. There will be no effects on water levels in wetlands since drainage patterns to wetlands were maintained.

The effect of development on runoff volumes in each individual watershed depends on the proportions of the watershed that are used for the road and utility corridor, plant sites, camps, well pads, water wells, airstrip and borrow pits. The borrow pits will tend to reduce runoff volumes and flood peaks because water will not be released from these areas. Road and utility corridors, camps, well pads and water well pads will tend to increase both runoff volumes and flood peaks due to the reduction in vegetation and the addition of less permeable surfaces. The plant sites will tend to reduce the flood peaks because the runoff is detained in water quality ponds before being discharged to the natural environment.

Changes in runoff volumes were estimated assuming a worst case condition of the disturbed areas being directly connected to the drainage networks in the watersheds and that the estimated runoff coefficients for each disturbance type are applicable for all runoff events. These changes in runoff volumes are summarized in Table 17. The greatest changes in runoff volume occur in Watershed B3b and B3c, with increases of 3.5% and 4.9% respectively. Most of the increased runoff volumes occur in Watersheds A and B.

Table 17 Summary of changes in runoff volumes due to changes in runoff coefficients from baseline development

Watershed	Natural Drainage Area (ha)	Mean Annual Flow[1] (m^3/s)	Worst Case Change in Runoff Volume (%)
A1a	704	0.019	1.9%
A1b	622	0.017	1.5%
B1	4302	0.118	0.9%
B3a	1063	0.029	0.2%
B3b	1973	0.054	3.5%
B3c	696	0.019	4.9%
B3d	803	0.022	0.4%
B3e	1209	0.033	0.5%
B4	1596	0.044	1.5%
C1b	1609	0.044	2.4%
C1c	252	0.007	0.0%
C2a	2251	0.062	0.4%
C2b	1860	0.051	0.0%
C2c	1698	0.047	0.0%
C3	1729	0.047	0.0%
C4	6080	0.167	0.0%
D1	6527	0.179	0.0%

[1] March to Oct flows only

HSPF modelling was used to further assess the hydrologic effects of the existing and approved developments relative to pre-development conditions. Simulations of the pre-development condition used the land runoff parameters determined by calibration to measured data from undeveloped basins as presented in Section 2.4.5. Simulations of the existing and approved development condition incorporate modifications to represented existing basin alterations which include Highway 63 and utility corridors along with the Great Divide and Algar SAGD developments. For most types of development footprint, the HSPF runoff parameters were adjusted to reflect the effects of clearing and soil compaction. The effects of clearing were simulated using a 25% reduction in potential evapotranspiration in cleared-but-vegetated areas such as utility corridors. An additional 75% reduction in soil storage capacity was assumed where the land is compacted for gravel roads and well pads. Areas of excavated pits and sumps were assumed to be non-draining and were removed from the watershed contributing areas. The Highway 63 road surface was modelled as impervious surface, routed through the roadside ditch before connecting to the natural drainage network.

Plant site runoff was routed through an assumed holding pond with outflow pumped at a constant discharge rate.

Simulations of the effects of baseline development were carried out for three watersheds, B3b, C1b, and C2a, including flow routing through Lake UL1 contained within Watershed C2a and Lake UL3 contained within Watershed C1b. The effects on runoff volume were greatest for Watershed C1b with an overall average increase of 1.4% over pre-development conditions. Runoff volume increases were smallest in wet years while larger impacts occurred in dry years, when annual flow volumes increase by up to 3.2% above pre-development conditions.

There were no perceptible impacts on either the magnitude of annual peak flows or on the timing of runoff hydrographs due to the baseline development; however, summer peaks flows were slightly greater. The simulated annual peak flows were dominated by snowmelt events. These snowmelt events were less affected by the changes in runoff parameters because evapotranspiration effects are generally not significant during the period of snow accumulation and because the effects of compaction less important when the ground is frozen. Summer peak flows tended to be slightly greater for the baseline development case and were consistent with the runoff volume analysis presented in Table 15.

No significant changes to annual minimum flow rates are anticipated in most streams because they have little or no flow in winter. The simulations indicate that the annual minimum monthly flow rates were less than 0.5% lower for the baseline case than they were for the pre-development case for watersheds C1b and C2a. The effects on low flows are reduced in these watersheds because both these streams have upstream lakes which supply base flow during dry periods. Watershed B3b which does not have any lakes was found to have annual minimum monthly low flows about 5% lower due to the existing development.

3.2.2 Water Levels and Surface Areas

Annual peak water levels and surface areas in the streams are not anticipated to change due to project disturbances because snowmelt-dominated annual peak flows will not change. However, stream minimum water levels and surface areas may be about 2% lower due to reduced minimum flows.

The existing and approved SAGD projects have some disturbed area in the watershed of Lake UL1. The HSPF simulation results showed that the baseline development case may cause late summer monthly average water levels to be up to 8 mm higher than the baseline case, but that such effects were generally restricted to dry years. Correspondingly, annual minimum water levels were up to 5 mm higher than the pre-development case. There were no perceptible effects on maximum water levels.

There is no change in the annual maximum surface area in Lake UL1 because the annual maximum water level range is not anticipated to change. The annual minimum surface area may be up to 5% greater in dry years due to project effects.

3.2.3 CHANNEL MORPHOLOGY AND SEDIMENT CONCENTRATIONS

Sediment concentrations in streams have the potential to increase due to increases in streamflow or from sediment introduced to the stream from disturbances. Sediment concentrations in the streams in the LSA do not appear to have increased due to changes in the surface runoff characteristics. The changes in the flow regime due to surface disturbances are very small and would not have a perceptible impact the sediment concentrations significantly.

4 APPLICATION DEVELOPMENT CASE

This section describes the assessment of potential hydrologic impacts of the Great Divide SAGD Expansion Project on the local environment. The project footprint is described, the potential impacts identified and their severity assessed.

4.1 PROJECT FOOTPRINT

The development of the proposed project will produce surface disturbances as well as potential stream disturbances. Figure 21 shows the layout of the Project. It is located in Sections 27-29 and 32-34 of Twp 81, Rge 11; Sections 3-5, 7, 8, 18-20, 29 and 30 of Twp 82, Rge 11; and Sections 9, 11, 13-17, 21-24, 26-28, 34 and 35 of Twp 82, Rge 12, all west of the 4^{th} meridian.

4.1.1 SURFACE DISTURBANCES

Surface disturbances will occur from the construction of the laydown area, road/utility corridors, remote sumps, well pads, and from borrow pits excavated for construction material. The project will be developed over time in three phases. The areas of these disturbances in each phase of the development are summarized in Table 18. The total disturbed area due to the project is 520.9 ha.

Table 18 Summary of disturbed areas due to Project

Disturbance Type	Phase 1 Area (ha)	Phase 2 Area (ha)	Phase 3 Area (ha)	Total Area (ha)
Laydown	9.9			9.9
Road & Utility Corridor	47.0	91.4	84.6	223.0
Remote Sumps	19.3	4.0	4.0	27.3
Well Pads	41.9	53.1	69.0	164.0
Borrow Pits	27.4	40.6	28.7	96.8
Total	145.5	189.1	186.3	520.9

The project disturbances will be located in the drainage basins of both the Horse and Christina Rivers, with 38% of the disturbance area in the Horse River basin and 62% in the Christina River basin. Over the life of the project, surface disturbances will be located in 14 separate watersheds which drain the LSA (Figure 21).

Table 19 summarizes the extent of the spatial disturbances within these individual watersheds. The greatest percentage area of disturbance will occur in Watershed C1b, where 7.8% of the land will be disturbed by the project. Another watershed with a significant percentage of disturbed area is Watershed B3b, where 5.5% of the land will be disturbed by the project. The disturbances in the other watersheds are smaller, ranging from 0.13% to 3.3% of the watershed areas. However, the percentage disturbance of the entire area of Watershed B is only 0.8% while the percentage disturbance of the entire area of Watershed C is only 0.3%. It would be difficult to quantify the effect of this low intensity scale of development on any hydrologic parameter.

Table 19 Summary of spatial extent of disturbances due to Project

Watershed	Drainage Area (ha)	Disturbance Areas						Percent of Drainage Area (%)
		Laydown (ha)	Road & Utility Corridor (ha)	Remote Sumps (ha)	Well Pads (ha)	Borrow Pits (ha)	Total (ha)	
B1	4302		20.1		23.0	8.2	51.3	1.2
B3a	1063		2.8			6.8	9.6	0.90
B3b	1973		47.0	6.2	43.9	12.2	109.3	5.5
B3c	696		1.5		4.0	6.5	12.0	1.7
B3d	803		4.5		4.0		8.5	1.1
B3e	1209		2.0		3.3		5.3	0.4
B	24305		77.9	6.2	78.3	33.6	196.0	0.81
C1b	1609	7.8	51.1	7.2	33.0	25.8	124.9	7.8
C1c	252				2.4	0.0	2.4	1.0
C2a	2251	2.1	41.2	5.9	17.9	7.5	74.7	3.3
C2b	1860		29.2	4.0	11.4	14.8	59.4	3.2
C2c	1698		7.5		8.6		16.1	0.95
C3	1729		13.5	4.0	12.1	0.3	29.9	1.7
C4	6080		1.6		0.1	7.2	8.9	0.15
C	93599	9.9	144.0	21.1	85.6	55.6	316.3	0.34
D1	6527		1.1		0.1	7.5	8.6	0.13

Laydown

A 9.9 ha laydown area will be located adjacent to the Algar plant site on high ground which drains into watersheds C1b and C2a. The runoff coefficient of the gravelled area is believed to be about 0.6, which is substantially higher than the natural annual runoff coefficient of 0.19.

Road and Utility Corridor

The locations of the road and utility corridors are shown in Figure 21. These linear features will have a total length of 44.6 km, with a right-of-way width of 50 m. The total disturbed area of these road and utility corridors is 233.0 ha. The majority of the corridor area will be located in three watersheds, 51.1 ha in Watershed C1b, 47.0 ha in Watershed B3b and 41.2 ha in Watershed C2a.

The runoff coefficient from the gravel road surfaces is believed to be about 0.60. The runoff from the road surface will flow into the ditches where some of the runoff will be stored. The remaining surface of the access corridor right-of-way will be non-forested vegetation with a runoff coefficient of about 0.25, slightly higher than the undisturbed value of 0.19. Thus, it is estimated that the effective runoff coefficient for the road and utility corridor will be about 0.40.

Remote Sumps

Remote sumps will be located in Watersheds B3b, C1b, C2a, C2b and C3. The remote sumps have a total surface area of 27.3 ha. Any precipitation falling on the remote sump areas will be contained in the sumps where it will evaporate or be disposed of. No runoff will be generated from this area.

Well Pads

The locations of the well pads are shown in Figure 21. The total disturbed area of these well pads is 164.0 ha. The majority of the well pads will be located in three watersheds, with 43.9 ha in Watershed B3b, 33.0 ha in Watershed C1b and 17.9 ha in Watershed C2a.

The well pads will be constructed of gravel so the runoff coefficient for the well pads is believed to be about 0.60. This is substantially higher than the natural annual runoff coefficient of 0.19. The water quality of the runoff from the well pads is not believed to be substantially different from the runoff from the undisturbed site so the runoff will be directed off the pads through riprap channels to prevent erosion. Where the pads are located near streams, the runoff will be directed off the pads so that the runoff does not enter the stream directly.

Borrow Pits

Borrow pits will be excavated at various locations to supply fill material for the construction of roads and well pads. The locations of these borrow pits are shown in Figure 21. The bottoms of the pits will be lower in elevation than the surrounding land so any precipitation falling on a borrow pit area will be contained in the borrow pit where it will either evaporate or seep into the ground. No surface runoff will be generated from these areas.

4.1.2 Stream Disturbances

Six locations have been identified where the road and utility corridors will cross streams which have defined channels. The locations are shown in Figure 21 and listed in Table 20. These channels are generally quite narrow. The widest crossings occur near measurement sites 5 and 6 in NW 20-82-11 and NW 8-82-11 where the bankfull channel widths were about 9 and 3 m respectively. These channels can be crossed with single span structures so no disturbance of the channels is required.

All other types of disturbed area will be located away from the channels, except Well Pad 106 in Phase 3 of the Project, which may impinge on a stream channel in Watershed B3b (Table 20). The existence of and location of a channel at this location has not been confirmed because the hydrology field work was completed before the location of this site was determined. This site should be investigated further before the well pad is constructed; and, if the location of this well pad is found to interfere with a stream channel, the shape or location of the well pad should be modified to provide a 30 m buffer from the edge of the bank.

Table 20 Summary of stream crossing locations

Crossing Site	Watershed	Location	Disturbance Type	Project Phase
1	C1b	NW 20-82-11	Corridor Crossing	Phase 2
2	C2a	NW 8-82-11	Corridor Crossing	Phase 2
3	C2b	SE 32-81-11	Corridor Crossing	Phase 2
4	C2b	NW 33-81-11	Corridor Crossing	Phase 3
5	B3b	NW 21-82-12	Corridor Crossing	Phase 3
6	B3b	SE 27-82-12	Corridor Crossing	Phase 3
7	B3b	NW 28-82-12	Well Pad	Phase 3

4.1.3 Water Supply

The main use of water by the project is for production of steam that will be injected into the oil bearing formation. This process water will be re-circulated and reused as much as possible. However, some of the water will be lost in the formation and some of the water will be taken up in disposing of unwanted by-products. This lost water must be replaced from an external supply. It is anticipated that local deep groundwater supplies will be used to provide water for the project. No surface water will be used for process water.

4.2 HYDROLOGIC IMPACTS

The Project may potentially affect a number of valued environmental components (VECs) related to hydrology in the local study area (LSA). These VECs include:

- Runoff volumes and streamflows
- Water levels and surface areas
- Channel morphology and sediment concentrations

A summary of the project effects on these VECs is provided in Table 21. These project effects are evaluated in more detail in the following sections.

4.2.1 RUNOFF VOLUMES AND STREAMFLOWS

Project disturbances have the potential to cause changes to surface runoff characteristics. Changes in surface drainage patterns or changes in the runoff coefficients may affect the runoff volumes, flow rates, and timing of peak flows in the local streams. Water levels in lakes and wetlands may also be affected. If these changes are significant they may in turn produce changes in the channel regime of the local streams.

To minimize the impacts on surface runoff, there will be no significant changes in the surface drainage patterns due to Project. Drainage around the development is shown in Figure 22. The only change to basin boundaries will occur at the plant site where 5.9 ha of basin now part of Watershed C2a will be drained to the plant water quality pond for release to Watershed C1b. Appropriate drainage will be provided at crossings of any significant drainage courses and there will be no transfer of water from one watershed to another along ditches and road right-of-ways. Drainage patterns to lakes and wetlands will be maintained.

The effect of development on runoff volumes in each individual watershed depends on the proportions of the watershed area that are used for the laydown, road and utility corridor, remote sumps, well pads, and borrow pits. The remote sumps and borrow pits will reduce runoff volumes and flood peaks because water will not be released from these areas. Road and utility corridors, laydown areas and well pads will increase both runoff volumes and flood peaks due to the reduction in vegetation and the addition of less permeable surfaces.

Changes in runoff volumes due to the project development were estimated assuming a worst case condition of the disturbed areas being directly connected to the drainage network in the watersheds and that the estimated runoff coefficients for each disturbance type are applicable for all runoff events. These changes in runoff volumes are summarized in Table 22. The greatest changes in runoff volume occur in Watershed B3b and C1b, with increases of 6.5% and 7.0% respectively. The greatest total changes in runoff volume from project plus baseline development occur in Watershed B3b and C1b, with increases of 10.0% and 9.4% respectively.

Table 21 Significance of impacts on valued environmental components (VECs)

VEC	Nature of Potential Impact or Effect	Mitigation/ Protection Plan	Type of Impact or Effect	Geographical Extent of Impact or Effect[1]	Duration of Impact or Effect[2]	Frequency of Impact or Effect[3]	Ability for Recovery from Impact or Effect[4]	Magnitude of Impact or Effect[5]	Project Contribution[6]	Confidence Rating[7]	Probability of Impact or Effect Occurrence[8]	Significance[9]
1. Runoff Volumes and Streamflows												
	Changes to runoff volume, peak flows, and low flows	1) Return to natural state when project completed 2) Discharge runoff into natural environment away from streams	Project	Local	Long	Seasonal	Reversible in long term	Low	Negative	High	High	Insignificant
			Cumulative	Local	Long	Seasonal	Reversible in long term	Low	Negative	High	High	Insignificant
2. Water Levels and Surface Areas												
	Changes in water levels and surface area due to streamflow changes	1) Return to natural state when project completed 2) Discharge runoff into natural environment away from streams	Project	Local	Long	Seasonal	Reversible in long term	Low	Negative	High	High	Insignificant
			Cumulative	Local	Long	Seasonal	Reversible in long term	Low	Negative	High	High	Insignificant
3. Channel Morphology and Sediment Concentration												
	Changes in channel shape and sediment conc. due to flow changes and crossing construction	1) Return to natural state when project completed 2) Design and construct crossings to minimize impacts	Project	Local	Long	Occasional	Reversible in long term	Low	Negative	High	Low	Insignificant
			Cumulative	Local	Long	Occasional	Reversible in long term	Low	Negative	High	Low	Insignificant

[1] Local, Regional, Provincial, National, Global
[2] Short, Long, Extended, Residual
[3] Continuous, Isolated, Periodic, Occasional, Accidental, Seasonal
[4] Reversible in short term, Reversible in long term, Irreversible - rare
[5] Nil, Low, Moderate, High
[6] Neutral, Positive, Negative
[7] Low, Moderate, High
[8] Low, Medium, High
[9] Insignificant, Significant

Table 22 Summary of changes in runoff volumes due to changes in runoff coefficients from baseline and project development

Water-shed	Natural Drainage Area (ha)	Mean Annual Flow[1] (m^3/s)	Worst Case Change in Runoff Volume due to Baseline Development (%)	Worst Case Change in Runoff Volume due to Project Development (%)	Worst Case Total Change in Runoff Volume due to Development (%)	Average Change in Runoff Volume due to Baseline Development (%)	Average Total Change in Runoff Volume due to Development (%)
A1a	704	0.019	1.9%	0%	1.9%		
A1b	622	0.017	1.5%	0%	1.5%		
B1	4302	0.118	0.9%	1.5%	2.4%		
B3a	1063	0.029	0.2%	-0.3%	-0.1%		
B3b	1973	0.054	3.5%	6.5%	10.0%	1%	1.7%
B3c	696	0.019	4.9%	0.6%	5.4%		
B3d	803	0.022	0.4%	1.7%	2.1%		
B3e	1209	0.033	0.5%	0.8%	1.3%		
B4	1596	0.044	1.5%	0.0%	1.5%		
C1b	1609	0.044	2.4%	7.0%	9.4%	1.4%	2.2%
C1c	252	0.007	0.0%	2.1%	2.1%		
C2a	2251	0.062	0.4%	3.3%	3.7%	-0.2	-0.1
C2b	1860	0.051	0.0%	2.1%	2.1%		
C2c	1698	0.047	0.0%	1.6%	1.6%		
C3	1729	0.047	0.0%	2.1%	2.1%		
C4	6080	0.167	0.0%	-0.1%	-0.1%		
D1	6527	0.179	0.0%	-0.1%	-0.1%		

[1] March to Oct flows only

HSPF modelling was also used to further assess the hydrologic effects of the project and baseline developments relative to pre-development conditions. Simulations of the pre-development condition used the land runoff parameters determined by calibration to measured data from undeveloped basins as presented in Section 2.4.5. Simulations of the project development condition incorporate the modifications for the baseline development case (Section 3.2.1) and project development conditions assuming a maximum-impact scenario with full development of all project phases before any reclamation occurs. For most types of development footprint, the HSPF runoff parameters were adjusted to reflect the effects of clearing and soil compaction. The effects of clearing were simulated using a 25% reduction in potential evapotranspiration in cleared-but-vegetated areas such as utility corridors. An additional 75% reduction in soil storage capacity was assumed where the land is compacted for gravel roads and well pads. Areas of excavated pits and sumps were assumed to be non-draining and were removed from the watershed contributing areas.

Simulations were carried out for three watersheds, B3b, C1b, C2a, including flow routing through Lake UL1 contained within Watershed C2a and Lake UL3 contained within Watershed C1b . The effects on runoff volume were greatest for watershed C1b with an overall average increase of 2.2% over pre-development conditions. Runoff volume increases were smallest in wet years while larger impacts occurred in dry years, when annual flow volumes increase by up to 6.0% above pre-development conditions.

There were no perceptible impacts on either the magnitude of peak annual flows or on the timing of runoff hydrographs due to the project development but summer peaks flows were slightly greater. The simulated peak annual flows were dominated by snowmelt events. These snowmelt events were less affected by the changes in runoff parameters because evapotranspiration effects are generally not significant during the period of snow accumulation and because the effects of compaction are less important when the ground is frozen. Summer peak flows tended to be slightly greater for the project development case and were consistent with the runoff volume analysis presented in Table 22.

No significant changes to low flow rates are anticipated in most streams in the LSA because they have little or no flow in winter. The simulations indicate that the annual minimum monthly flow rates were less than 1% lower for the application case than they were for the pre-development case for watersheds C1b and C2a. The effects on low flows are reduced in these watersheds because both these streams have upstream lakes which supply base flow during dry periods. Watershed B3b which does not have any lakes was found to have annual minimum monthly low flows about 5% lower after development; however, these affects were due to the existing developments rather than the application case.

4.2.2 Water Levels and Surface Areas

Annual peak water levels and surface areas in the streams are not anticipated to change due to project disturbances because annual peak flows will not change. However, stream minimum water levels and surface areas may be about 2% lower due to reduced minimum flows.

The baseline and application case developments have some disturbed area in the watershed of Lake UL1. The simulation results showed that the application development case may cause late summer monthly average water levels to be up to 20 mm higher than the pre-development case, but that such effects were generally restricted to dry years. Correspondingly, annual minimum water levels were up to 13 mm higher than the pre-development case. There were no perceptible effects on the annual maximum lake levels. The 20 mm increase in the minimum water level would correspond to about a 1% increase in the lake minimum surface area in dry years.

4.2.3 CHANNEL MORPHOLOGY AND SEDIMENT CONCENTRATIONS

Sediment concentrations in streams have the potential to increase due to increases in streamflow or from sediment introduced to the stream from disturbances. Sediment concentrations in the streams are not anticipated to increase due to changes in the surface runoff characteristics. The projected changes in the flow regime due to surface disturbances are small so they will not impact the sediment concentrations significantly. The stream crossings in the project footprint will be designed to minimize the disturbance to the channels so sediment inputs are not anticipated to increase due to local disturbances.

5 PLANNED DEVELOPMENT CASE

The only planned development within the LSA is the expansion of Hwy 63. It is presumed that the highway drainage for the expansion will be designed according to current practices and will not increase peak flows or divert water from one watershed to the next.

6 CUMULATIVE IMPACT ASSESSMENT

The cumulative impact of projects in the hydrology RSA was considered; however, the only activities in the hydrology RSA not included in the assessment within the LSA is a gravel mining operation in Watershed A and some minor oil & gas developments.

The gravel mining operation occupies an area of about 15 ha in Watershed A. The area of this disturbance is quite small relative to the 10,935 ha drainage area of Watershed A so the effect of this disturbance is insignificant. The gravel mining operation also has a water licence to use 73,000 m^3/yr of water from an unnamed aquifer in this watershed. No project development is proposed in Watershed A so no cumulative impact analysis was carried out.

The oil & gas developments in the RSA are typical of the developments which are distributed throughout the region. The hydrologic effects of such developments are not believed to be significant and are already included in the regional flow analysis in the assessment of baseline conditions. No further evaluation of these developments was carried out.

7 Mitigation and Monitoring

Mitigation is carried out to reduce the impacts of the project on the identified VECs and monitoring is carried out to confirm that the impacts are within their anticipated ranges. The VECs identified for surface water hydrology are runoff volumes and streamflows; water levels and surface areas; and channel morphology and sediment concentrations.

7.1 Mitigation

The effects of the project on runoff volumes and streamflow presented in the previous sections were evaluated assuming that all the disturbed areas were directly connected to the drainage network. However, the disturbed areas will discharge runoff into the natural landscape rather than directly into a channel. The natural landscape will tend to buffer the effects of increased runoff from the compacted soils by infiltration, depression storage and evapotranspiration. Therefore, the actual increases in runoff and streamflows will be less the worst case increases presented in Table 20.

The runoff volume and streamflow analysis also assumed that the disturbances from all three phases of the project would occur at the same time. However, as well pads are abandoned they will be reclaimed and the landscape will be restored to be similar hydrologically to the pre-existing conditions. After the project is complete, the entire project disturbance will be reclaimed and the landscape will be similar to the pre-existing conditions.

The mitigation of runoff volume and streamflow effects will also provide mitigation for effects of the project on water levels and surface areas.

The effects on the project on channel morphology and sediment concentrations will be mitigated by design. Stream crossings will be designed to avoid or minimize any impact on stream channels and erosion of channel banks. Any facility constructed near stream channels will be set back from the channels to provide a buffer between the channel and the facility. Runoff from the facility will be directed to vegetated buffer areas to avoid direct or concentrated flows from disturbed areas to stream channels.

Construction of stream crossings will be carried out according to the Code of Practice for Watercourse Crossings (2007) to minimize the impacts on the channels.

The effect of the project disturbances on the annual peak flows is insignificant so there will be no changes in channel morphology from increased flows. As well, with the exception of the plant site where 5.9 ha will be diverted from Watershed C2a to C1b, drainage will be provided around the disturbance so that runoff is not directed from one watershed into another.

7.2 MONITORING

The anticipated impact of the project disturbances on the runoff volumes and streamflows is insignificant so no streamflow monitoring is required. Runoff volumes from the plant site runoff ponds will be monitored to determine how much runoff is pumped into the natural environment.

Sediment monitoring will be carried out during the construction of stream channel crossings to ensure that sediment from construction sites do not adversely impact the downstream channels.

8 SUMMARY OF CONCLUSIONS

8.1 BASELINE SETTING

The regional surface water hydrology for baseline conditions was described and mapped. A regional analysis of historical climate data was carried out to describe the variation in temperature, precipitation and evaporation. A regional analysis of historical streamflows was carried out to describe flow regimes and peak flows in the region. Historical lake levels in the region were evaluated. Regional watersheds were mapped and drainage areas quantified.

Local water levels and streamflows were measured at five lake and stream sites during the 2007 field season. Snow course measurements were also taken in late winter of 2007 and again in 2008. Flow regimes were evaluated from the regional streamflow analysis and from the HSPF hydrologic model which was calibrated with the local streamflow measurements.

8.2 BASELINE DEVELOPMENT CASE

A baseline development case consisting of existing and approved developments in the LSA was described and the effects of the development on the hydrology were quantified. Effects were evaluated for runoff volumes and streamflows; water levels and surface areas; and channel morphology and sediment concentrations. Runoff volumes were found to increase the greatest in watershed C1b with an increase of 1.4% over pre-development conditions. The increase could be as much 3.5% in dry years. There is no perceptible change on annual peak flows or on the timing of runoff hydrographs. Summer peak flows and runoff volumes tend to be slightly higher with increases for individual rainfall events up to about 5% during dry periods. Very little change in low flows occurs in watersheds C1b and C2a due to baseline development but in watershed B3b, which has no lake storage minimum monthly flow are about 5% less than for the pre-development case.

The effect of baseline development on water levels and surface areas was also quantified. Peak water levels and surface areas in streams are not anticipated to change because annual peak flows do not change. However, minimum water levels and surface areas may be about 2% lower due to reduced minimum flows. There is no change in the annual range of water levels and surfaces areas of lakes but summer water levels may be up to 8 mm higher during dry year and surface areas may be up to 0.5% greater.

Channel morphology and sediment concentrations have not changed due to baseline development because changes to the flow regime are small. The highway and access road stream crossings do not appear to have caused any increases in sediment concentration or erosion.

8.3 APPLICATION DEVELOPMENT CASE

The three phases of the application development case were described and the effects of the development on the hydrology were quantified. The entire project was assumed to be developed at the same time to assess the maximum effect on the hydrology. Effects were evaluated for runoff volumes and streamflows; water levels and surface areas; and channel morphology and sediment concentrations. The effects on runoff volume will be greatest for Watershed C1b with an increase over pre-development conditions of 2.2%. The increase may be as much 6.0% in dry years. The timing of peak flows and runoff hydrographs are not anticipated to change. Annual minimum monthly flows may be up to 1% lower for the streams with upstream lakes. Watershed B3b which has no lake storage may have annual minimum monthly flows of about 5% less than the pre-development case, but this is almost entirely due to the effects of the baseline development.

The effect of the application development case on water levels and surface areas was found to be small. Peak water levels and surface areas in streams are not anticipated to change; however, minimum water levels and surface areas may be about 2% lower due to reduced minimum flows. There will be no perceptible change in the annual range of water levels and surfaces areas of lakes but summer water levels may be up to 20 mm higher and surface areas up to 1.0% greater during dry years.

Channel morphology and sediment concentrations will not change due to the application development case because changes to the flow regime are small. The road and utility corridor stream crossings will be designed to minimize the disturbance to the channels so sediment inputs are not anticipated to increase.

8.4 CUMULATIVE IMPACT ASSESSMENT

The only activities in the hydrology RSA not included in the baseline and application development cases is a gravel mining operation in Watershed A and some minor oil & gas developments. The effect of the surface disturbance of the gravel mining operation on Watershed A is insignificant and no project development is proposed in Watershed A so no cumulative impact analysis was carried out.

The oil & gas developments in the RSA are typical of these types of developments which are distributed throughout the region. The hydrologic effects of these developments are believed to be insignificant and are already included in the regional flow analysis in the assessment of baseline conditions. No further evaluation of these developments was carried out.

8.5 MITIGATION AND MONITORING

The effects of the project will be mitigated by design and reclamation. The surface disturbances will be designed to discharge runoff into the natural landscape rather than directly into the drainage network as was assumed in the impact assessment. Infiltration, depression storage and evapotranspiration will tend to buffer the effects of increased runoff from compacted soils. Any facility constructed near stream channels will be set back from the channels to provide a buffer between the channel and the facility. Stream crossings will be designed to minimize the impact on stream channels and erosion of channel banks and construction carried out to minimize the impacts on the channels. As well, drainage will be provided around the disturbance so that runoff is not directed from one watershed into another. Impacts will also be reduced because some areas will likely be reclaimed before other areas are developed so the maximum footprint will be less than that of the total project. As well, the entire project disturbance will be reclaimed and the landscape restored to be similar to the pre-existing conditions after the project is complete.

Streamflow monitoring is not required because the effects of the project on streamflows will be small. Runoff volumes from the plant site runoff ponds will be monitored to determine how much runoff is pumped into the natural environment. Sediment monitoring will be carried out during the construction of stream channel crossings to ensure that sediment from construction sites do not adversely impact the downstream channels.

9 REFERENCES

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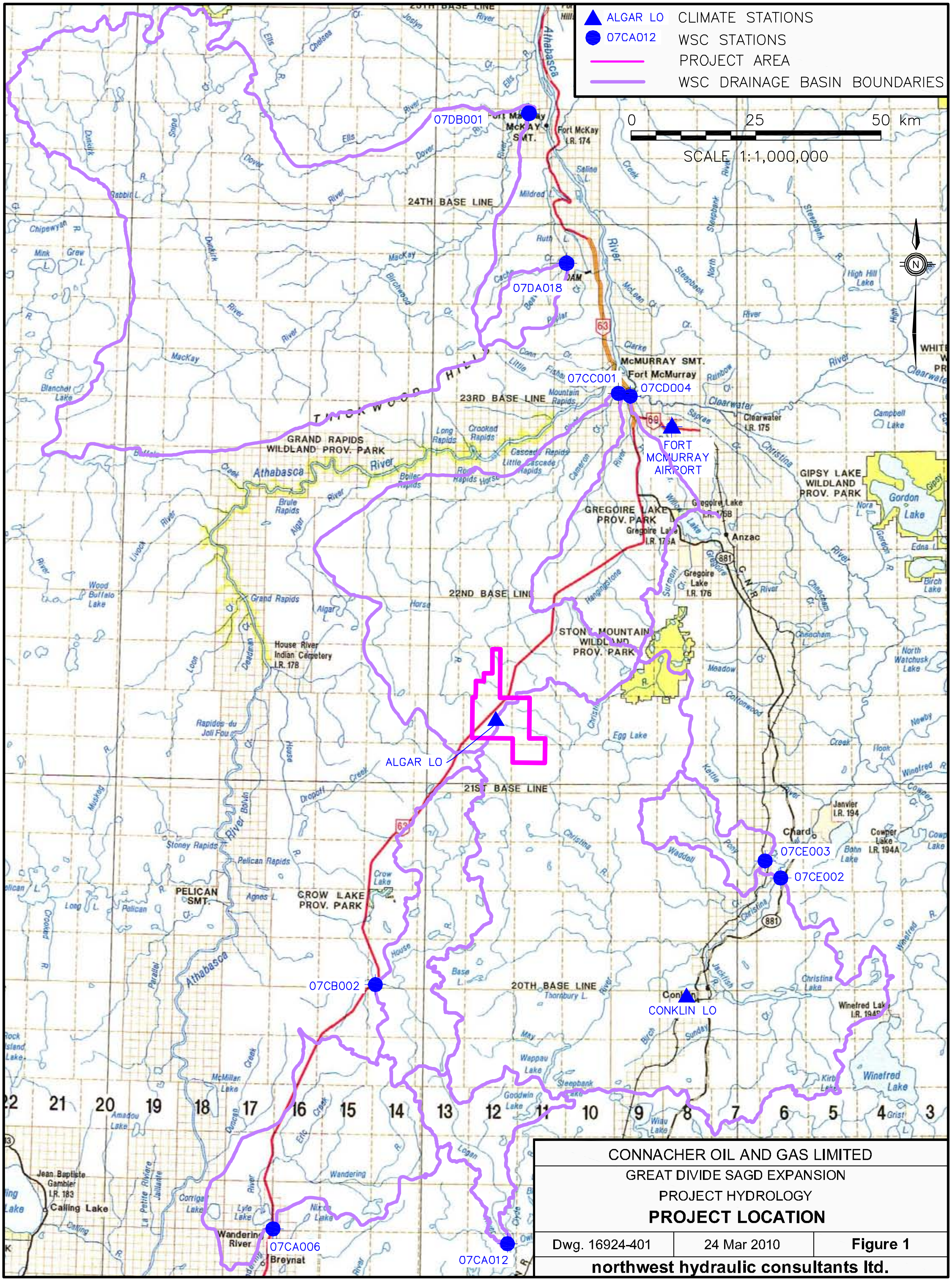


CONNACHER OIL AND GAS LIMITED

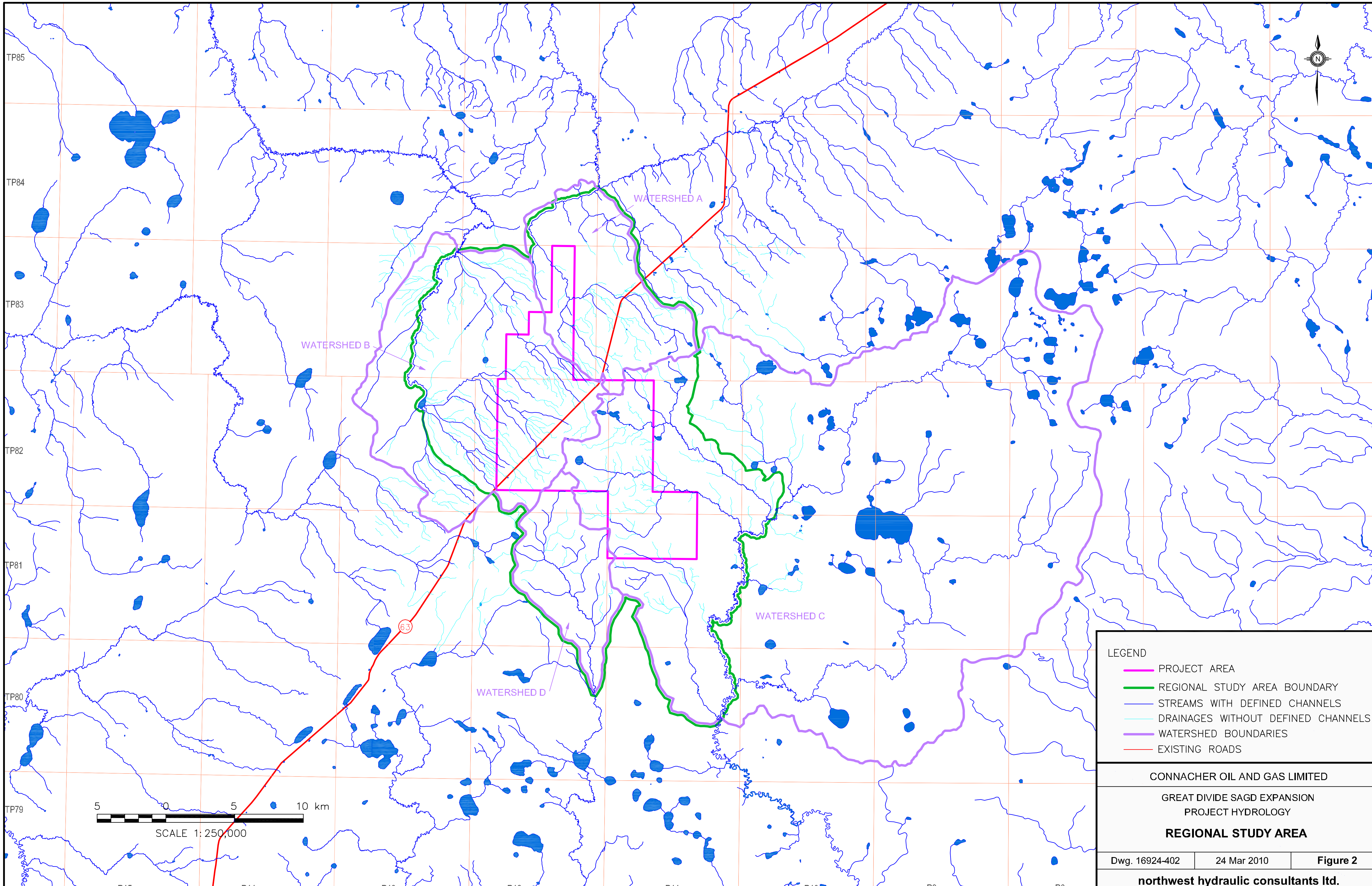
GREAT DIVIDE SAGD EXPANSION

PROJECT HYDROLOGY

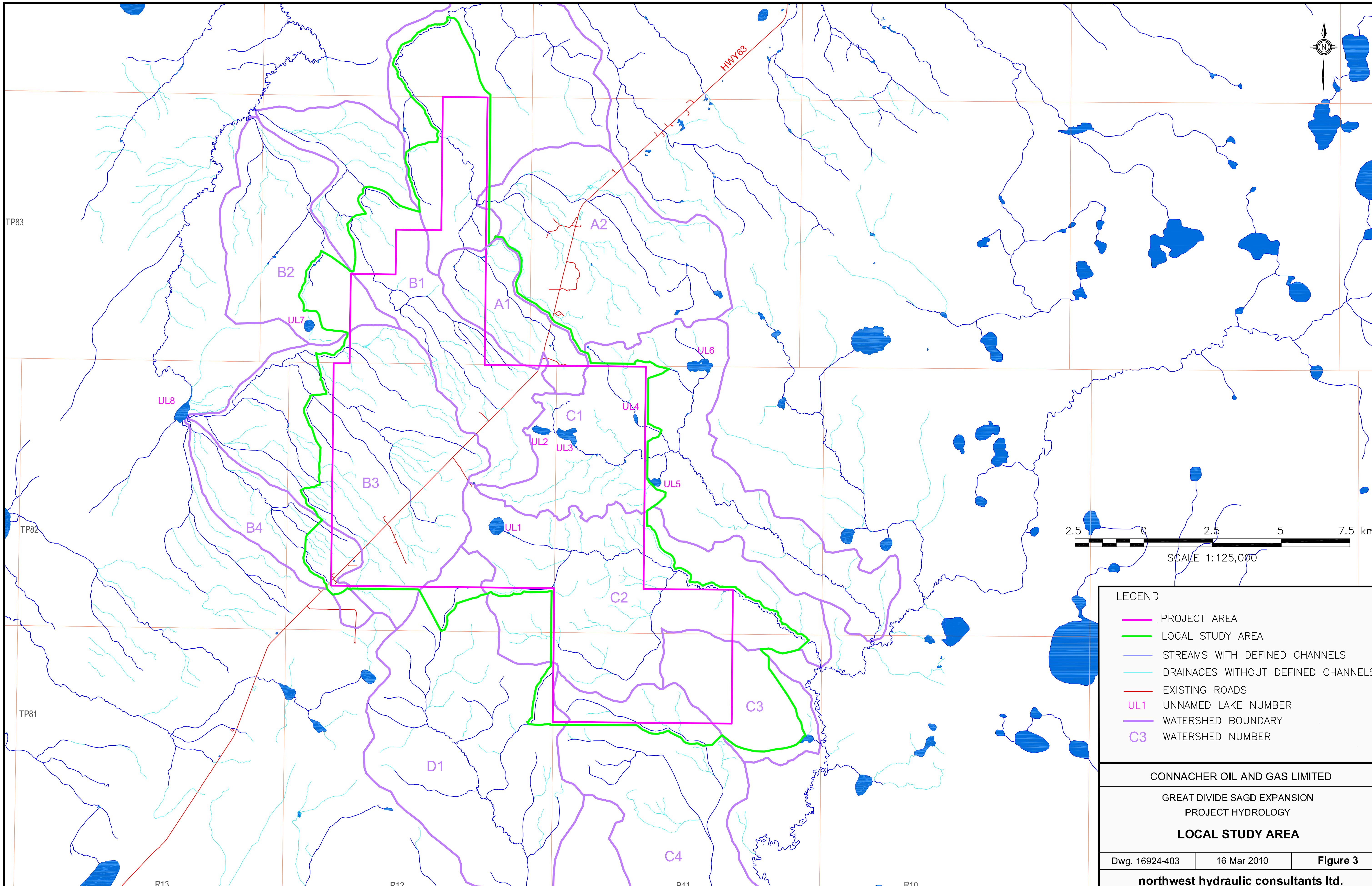
PROJECT LOCATION

Dwg. 16924-401	24 Mar 2010	**Figure 1**

northwest hydraulic consultants ltd.



TP85
TP84
TP83
TP82
TP81
TP80
TP79
R15
R14
R13
R12
R11
R10
R9
R8
N
WATERSHED A
WATERSHED B
WATERSHED C
WATERSHED D
63
5 0 5 10 km
SCALE 1: 250,000
LEGEND
PROJECT AREA
REGIONAL STUDY AREA BOUNDARY
STREAMS WITH DEFINED CHANNELS
DRAINAGES WITHOUT DEFINED CHANNELS
WATERSHED BOUNDARIES
EXISTING ROADS
CONNACHER OIL AND GAS LIMITED
GREAT DIVIDE SAGD EXPANSION
PROJECT HYDROLOGY
REGIONAL STUDY AREA
Dwg. 16924-402
24 Mar 2010
Figure 2
northwest hydraulic consultants ltd.



HWY63
A1
A2
B1
B2
B3
B4
C1
C2
C3
C4
D1
UL1
UL2
UL3
UL4
UL5
UL6
UL7
UL8
TP83
TP82
TP81
R13
R12
R11
R10
2.5 0 2.5 5 7.5 km
SCALE 1:125,000
LEGEND
PROJECT AREA
LOCAL STUDY AREA
STREAMS WITH DEFINED CHANNELS
DRAINAGES WITHOUT DEFINED CHANNELS
EXISTING ROADS
UL1 UNNAMED LAKE NUMBER
WATERSHED BOUNDARY
C3 WATERSHED NUMBER
CONNACHER OIL AND GAS LIMITED
GREAT DIVIDE SAGD EXPANSION
PROJECT HYDROLOGY
LOCAL STUDY AREA
Dwg. 16924-403
16 Mar 2010
Figure 3
northwest hydraulic consultants ltd.

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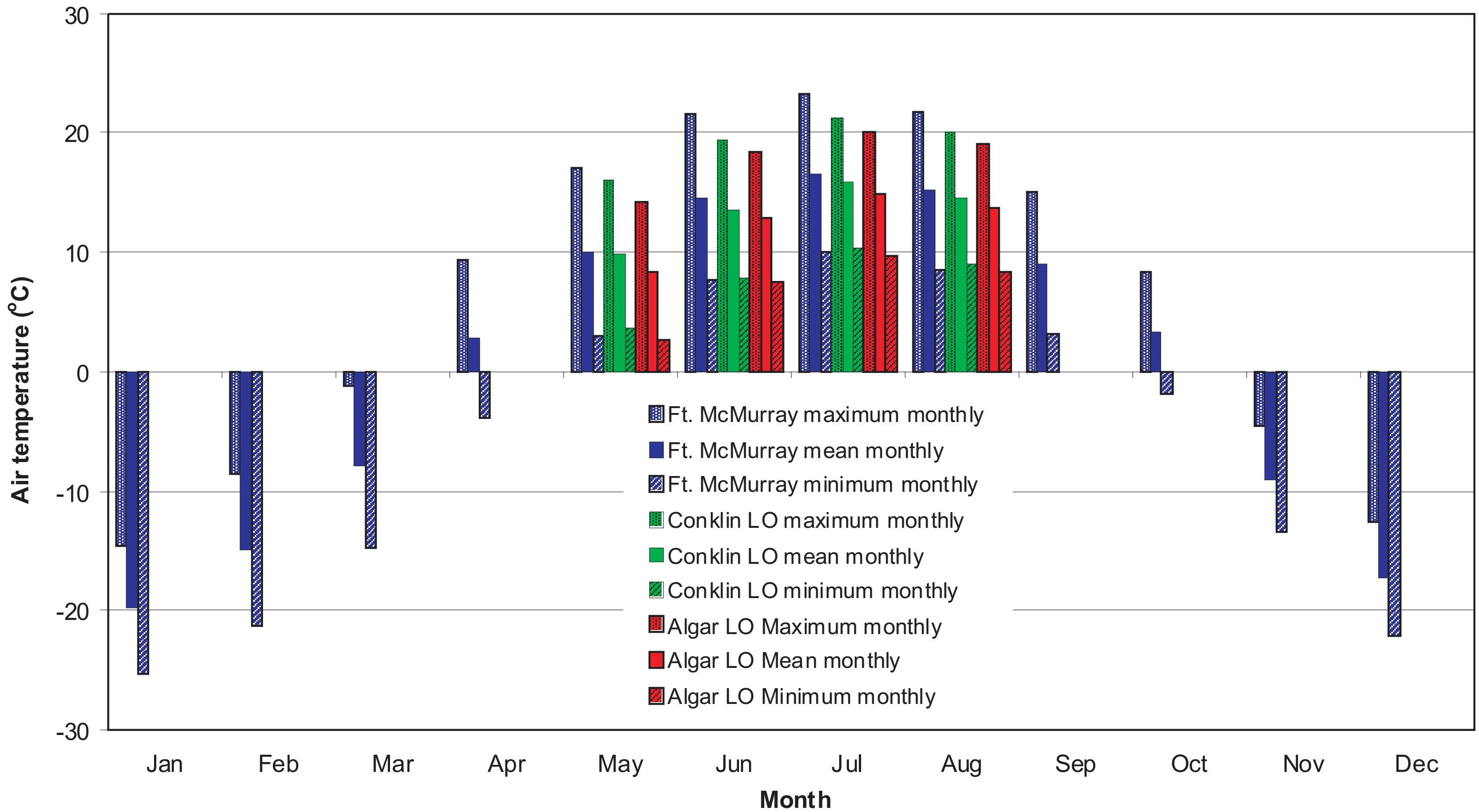


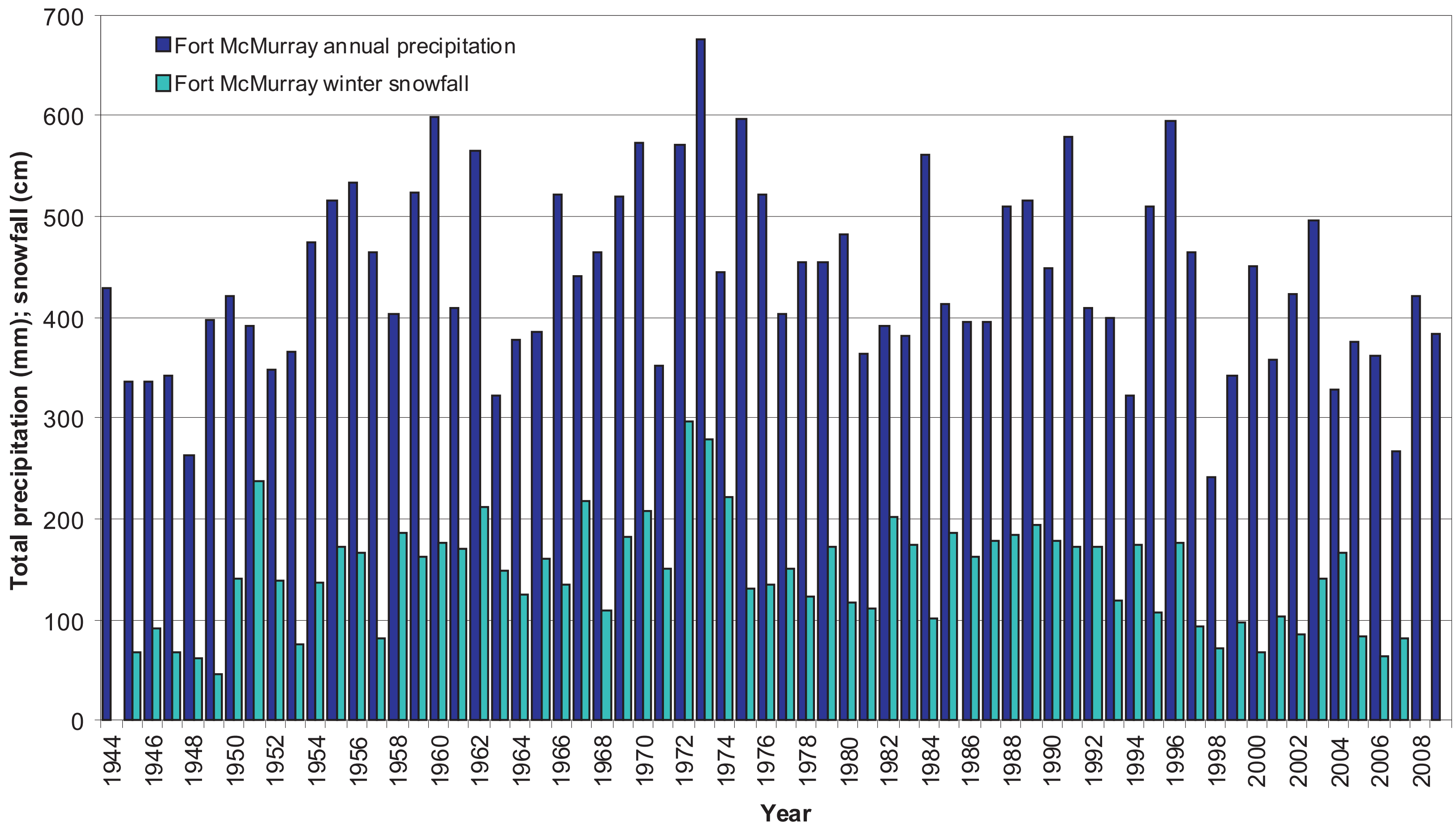
CONNACHER OIL AND GAS LIMITED

GREAT DIVIDE SAGD EXPANSION
PROJECT HYDROLOGY

MONTHLY AIR TEMPERATURES

File 16924-04	23 Mar 2010	**Figure 4**

northwest hydraulic consultants ltd.



CONNACHER OIL AND GAS LIMITED

GREAT DIVIDE SAGD EXPANSION
PROJECT HYDROLOGY

FORT MCMURRAY TOTAL PRECIPITATION AND SNOWFALL

File 16924-05	23 Mar 2010	**Figure 5**

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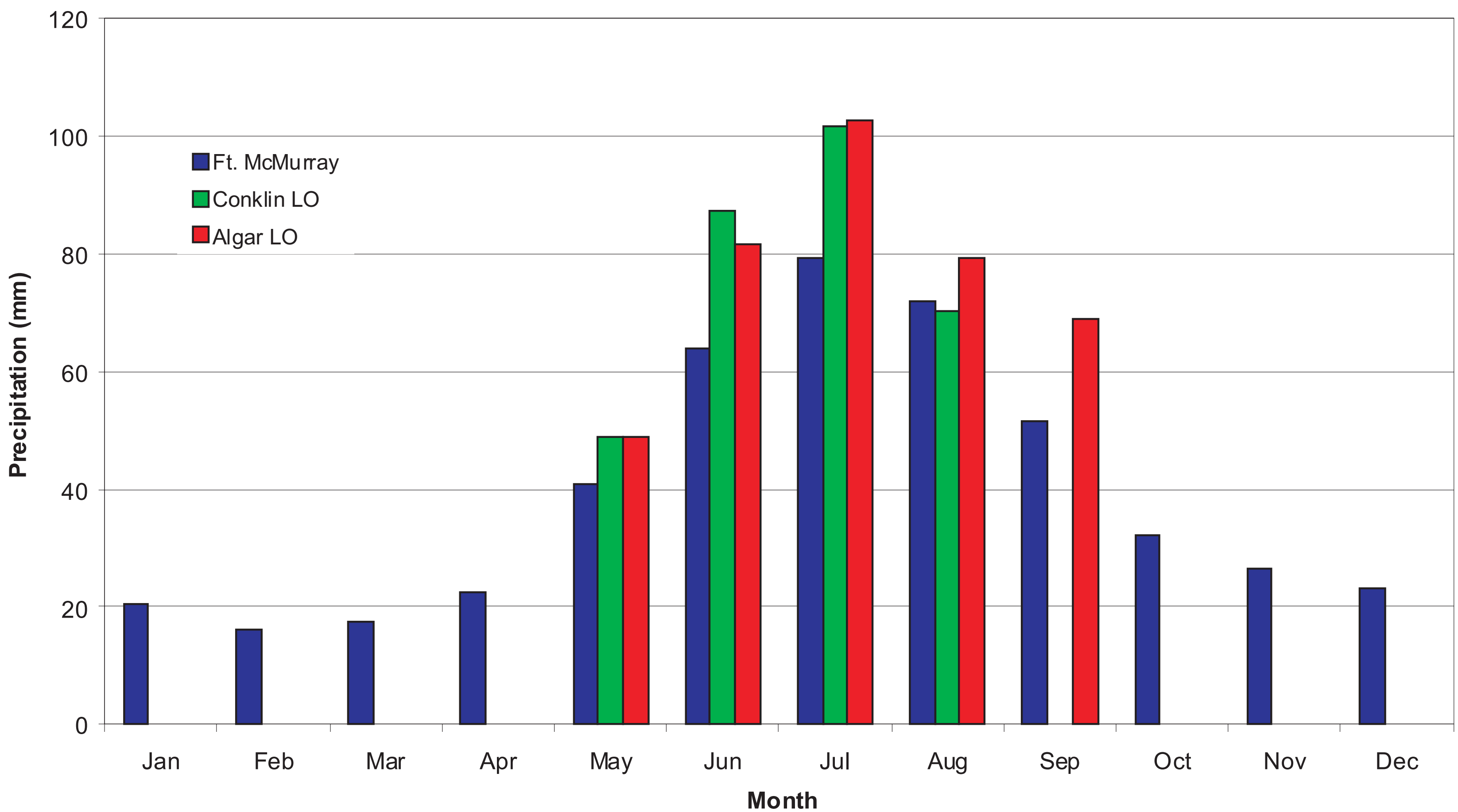
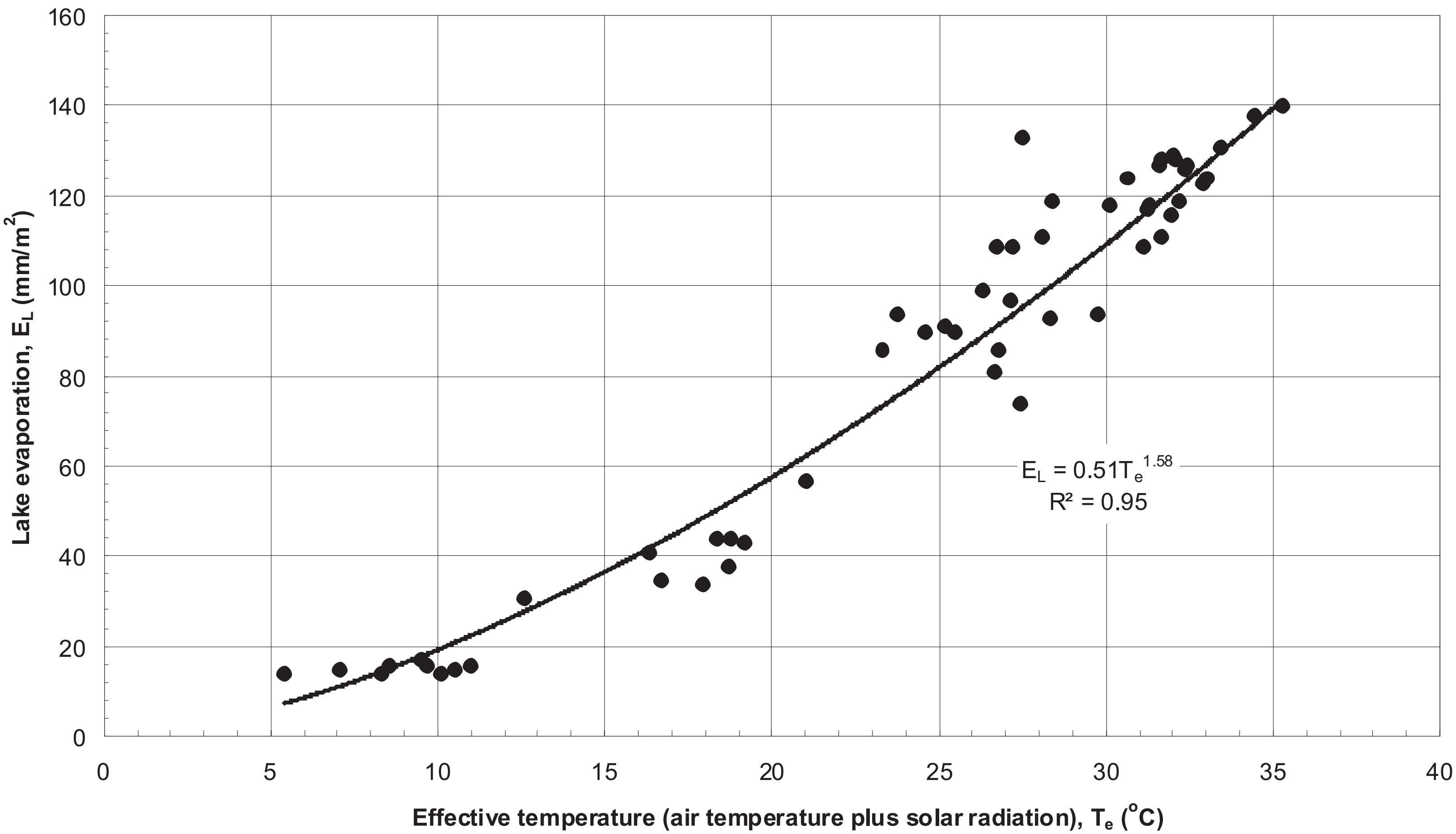
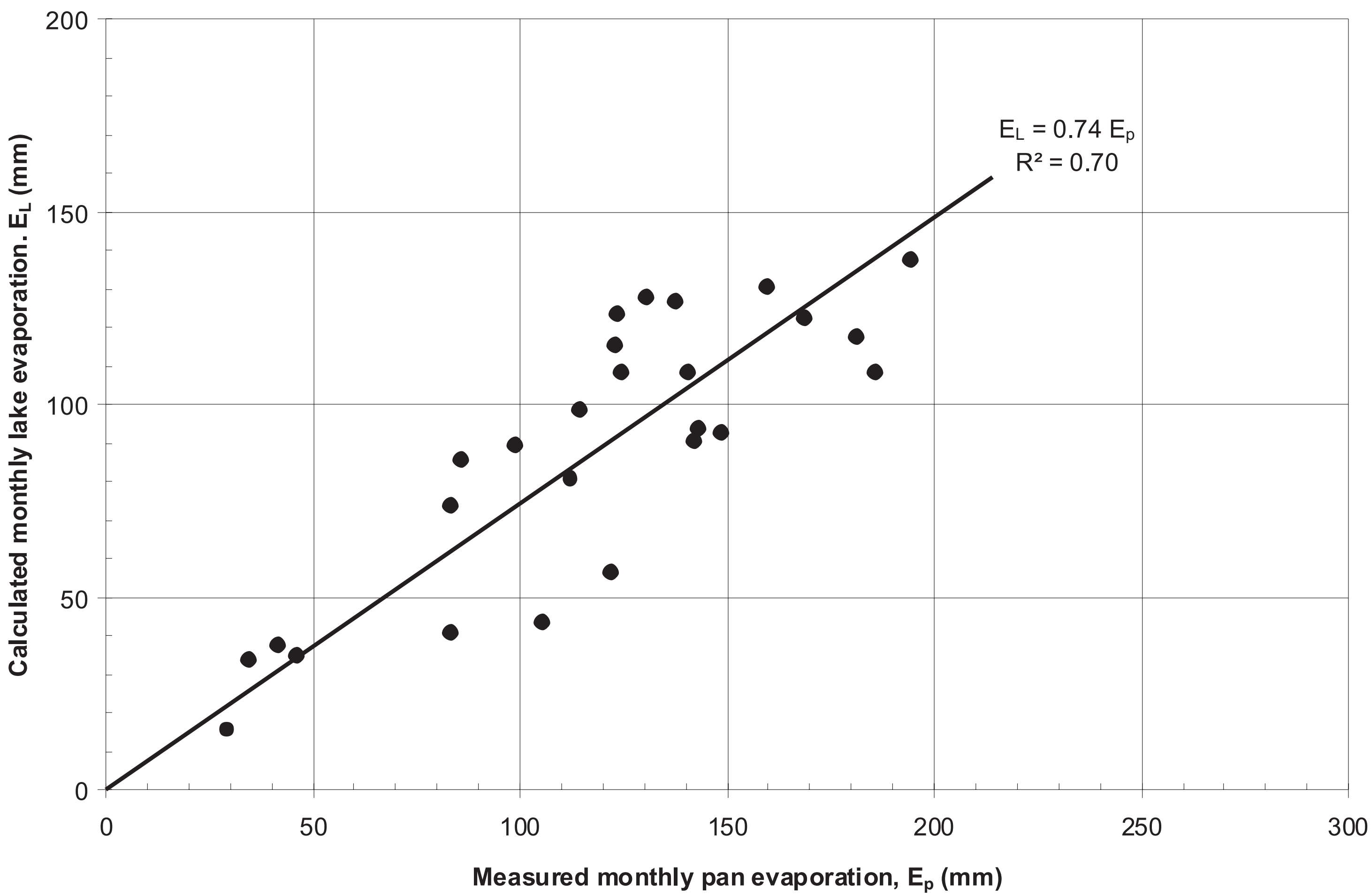


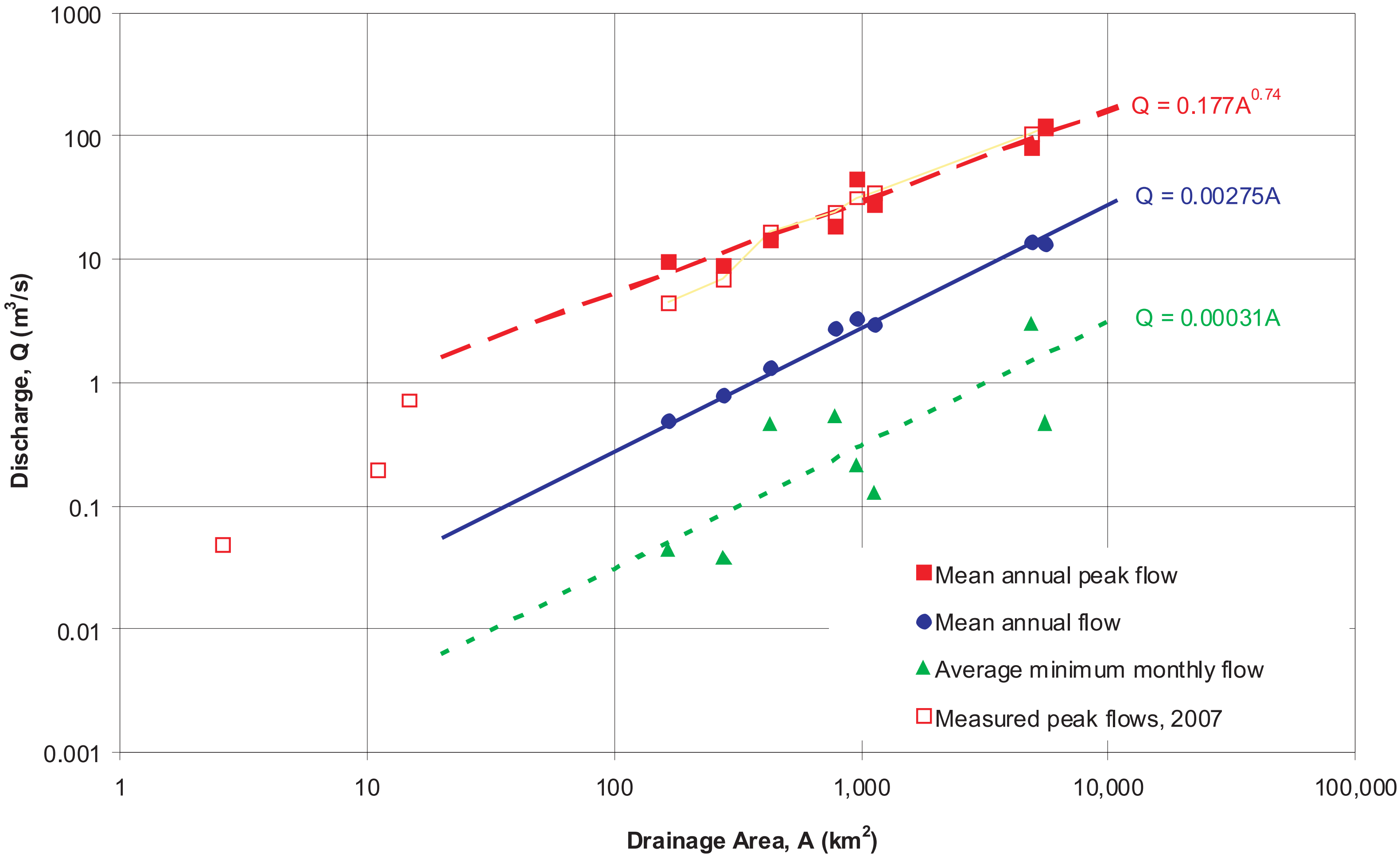
CONNACHER OIL AND GAS LIMITED		
GREAT DIVIDE SAGD EXPANSION PROJECT HYDROLOGY **MONTHLY PRECIPITATION**		
File 16924-06	23 Mar 2010	**Figure 6**
northwest hydraulic consultants ltd.		



CONNACHER OIL AND GAS LIMITED		
GREAT DIVIDE SAGD EXPANSION PROJECT HYDROLOGY		
VARIATION OF LAKE EVAPORATION WITH EFFECTIVE TEMPERATURE		
File 16924-07	23 Mar 2010	**Figure 7**
northwest hydraulic consultants ltd.		



CONNACHER OIL AND GAS LIMITED		
GREAT DIVIDE SAGD EXPANSION PROJECT HYDROLOGY **COMPARISON OF LAKE EVAPORATION WITH PAN EVAPORATION**		
File 16924-08	23 Mar 2010	**Figure 8**
northwest hydraulic consultants ltd.		



CONNACHER OIL AND GAS LIMITED

GREAT DIVIDE SAGD EXPANSION
PROJECT HYDROLOGY

VARIATION OF FLOW RATES WITH DRAINAGE AREA

File 16924-09	23 Mar 2010	**Figure 9**

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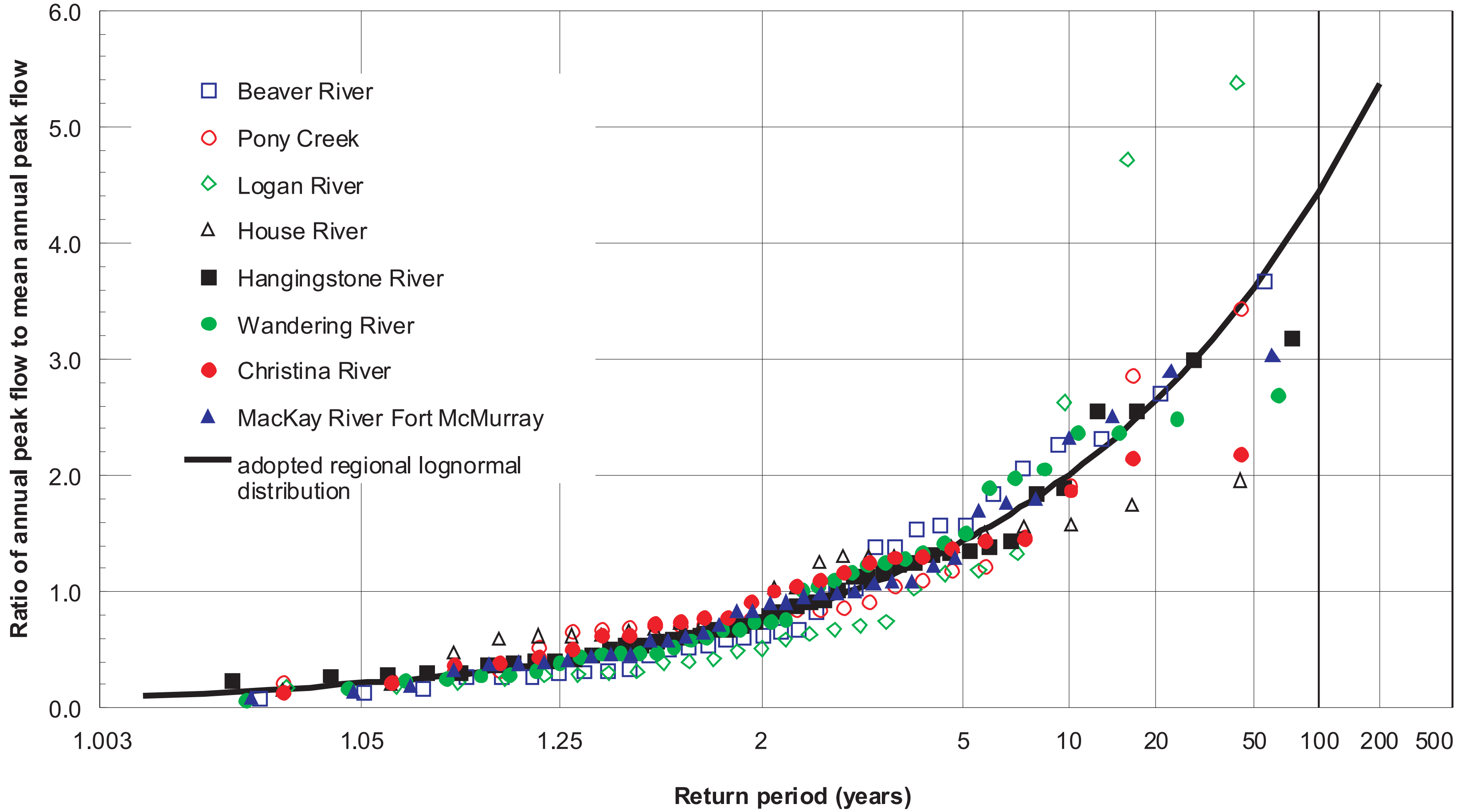


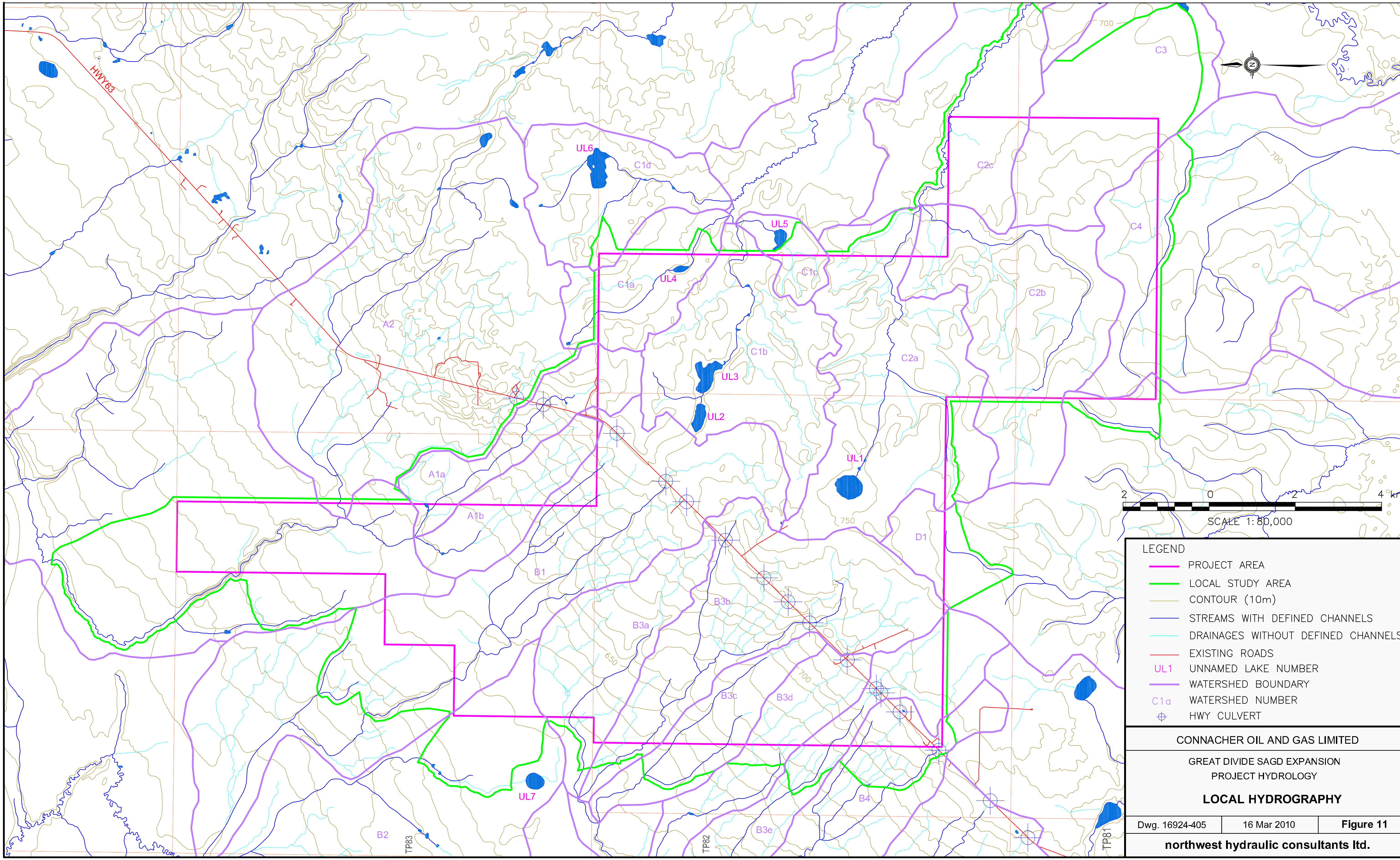
CONNACHER OIL AND GAS LIMITED

GREAT DIVIDE SAGD EXPANSION
PROJECT HYDROLOGY

NORMALIZED REGIONAL PEAK FLOW FREQUENCY DISTRIBUTION

File 16924-10	23 Mar 2010	**Figure 10**

northwest hydraulic consultants ltd.


HWY63
UL6
C1d
UL5
C1a
UL4
C1c
C1b
UL3
UL2
UL1
A2
A1a
A1b
B1
B3b
B3a
B3c
B3d
B4
B3e
B2
UL7
C2c
C2b
C2a
C4
C3
D1
700
750
650
R11
R12
TP83
TP82
TP81
2 0 2 4 km
SCALE 1: 80,000
LEGEND
PROJECT AREA
LOCAL STUDY AREA
CONTOUR (10m)
STREAMS WITH DEFINED CHANNELS
DRAINAGES WITHOUT DEFINED CHANNELS
EXISTING ROADS
UL1 UNNAMED LAKE NUMBER
WATERSHED BOUNDARY
C1a WATERSHED NUMBER
HWY CULVERT
CONNACHER OIL AND GAS LIMITED
GREAT DIVIDE SAGD EXPANSION
PROJECT HYDROLOGY
LOCAL HYDROGRAPHY
Dwg. 16924-405
16 Mar 2010
Figure 11
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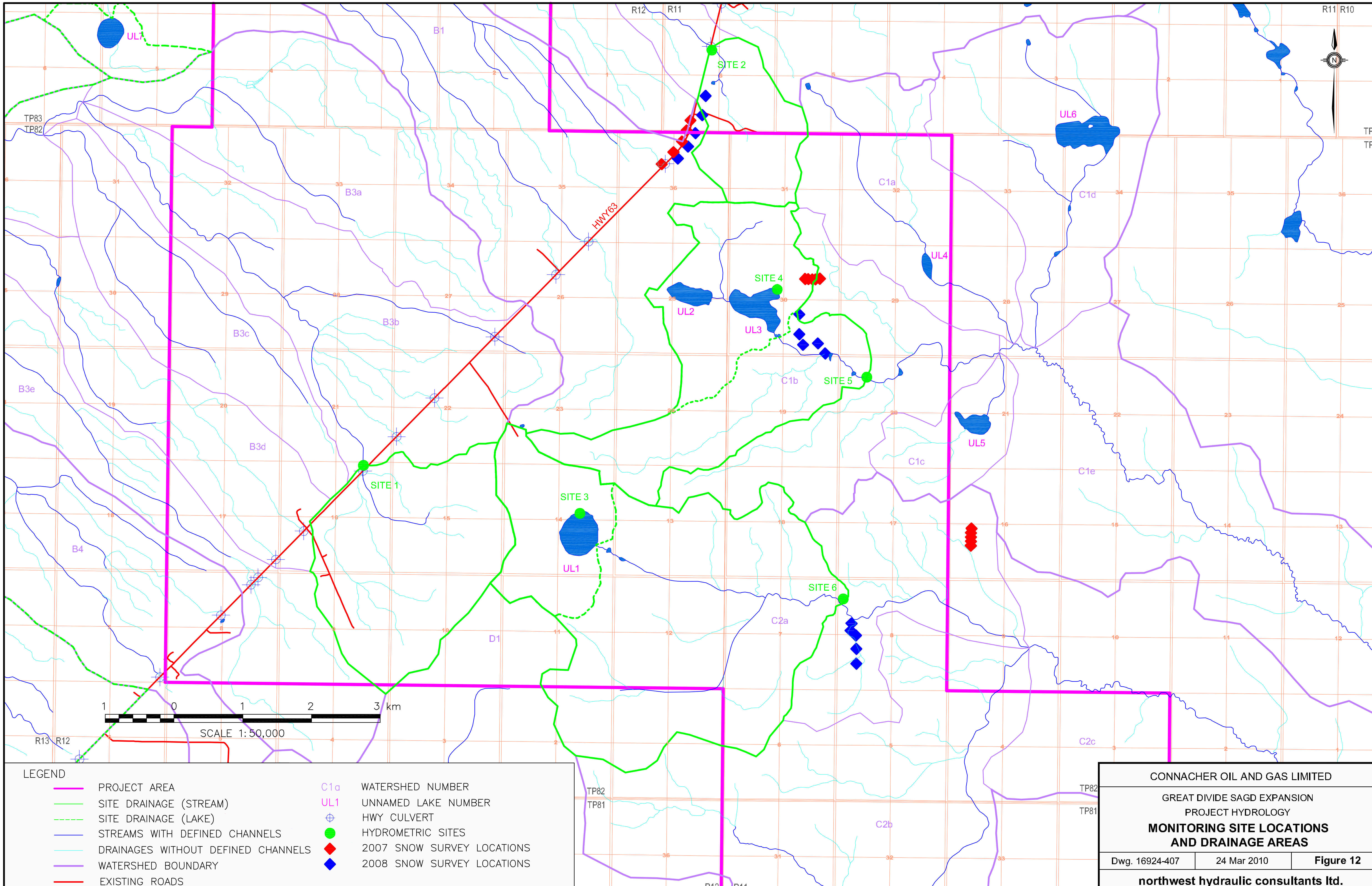
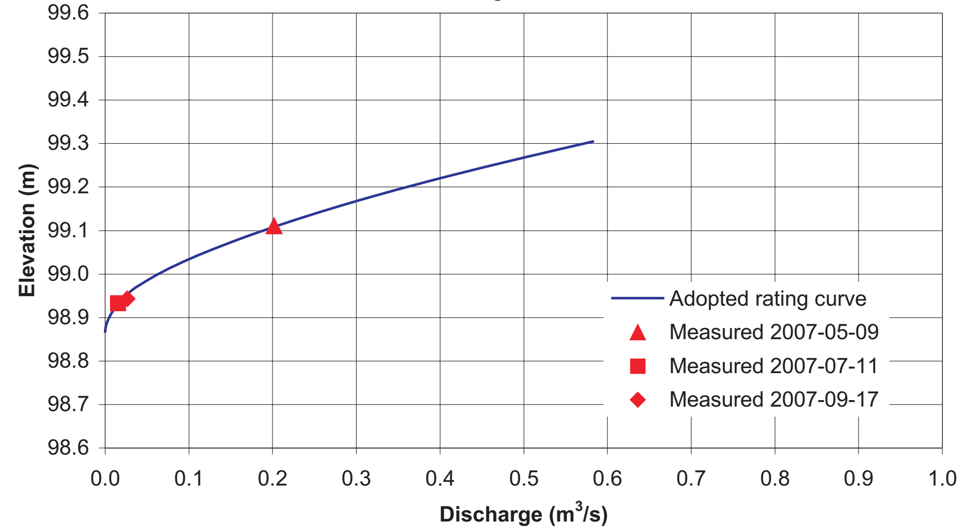
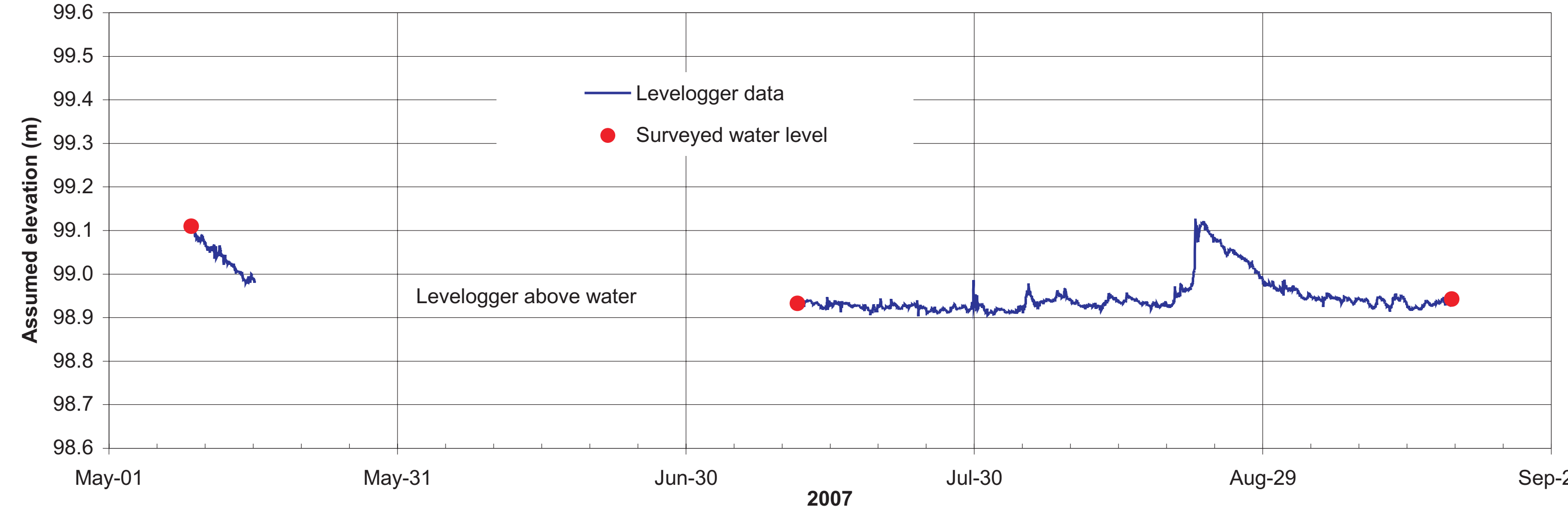


R12 R11
R11 R10
TP83
TP82
TP81
R13 R12
UL7
UL6
UL4
UL2
UL3
UL5
UL1
SITE 1
SITE 2
SITE 3
SITE 4
SITE 5
SITE 6
HWY63
B1
B3a
B3b
B3c
B3d
B3e
B4
C1a
C1b
C1c
C1d
C1e
C2a
C2b
C2c
D1
1 0 1 2 3 km
SCALE 1:50,000
LEGEND
PROJECT AREA
SITE DRAINAGE (STREAM)
SITE DRAINAGE (LAKE)
STREAMS WITH DEFINED CHANNELS
DRAINAGES WITHOUT DEFINED CHANNELS
WATERSHED BOUNDARY
EXISTING ROADS
C1a WATERSHED NUMBER
UL1 UNNAMED LAKE NUMBER
HWY CULVERT
HYDROMETRIC SITES
2007 SNOW SURVEY LOCATIONS
2008 SNOW SURVEY LOCATIONS
CONNACHER OIL AND GAS LIMITED
GREAT DIVIDE SAGD EXPANSION
PROJECT HYDROLOGY
MONITORING SITE LOCATIONS
AND DRAINAGE AREAS
Dwg. 16924-407
24 Mar 2010
Figure 12
northwest hydraulic consultants ltd.

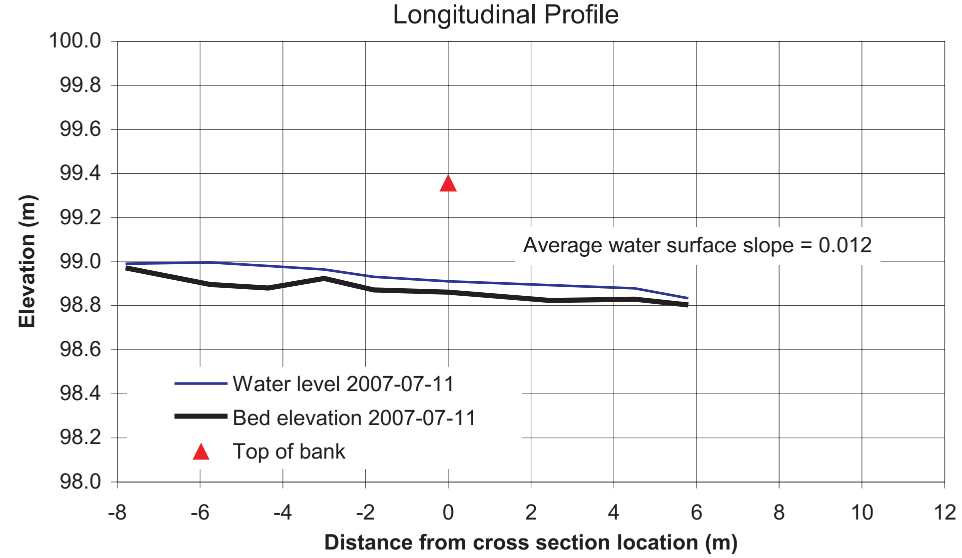
Rating Curve



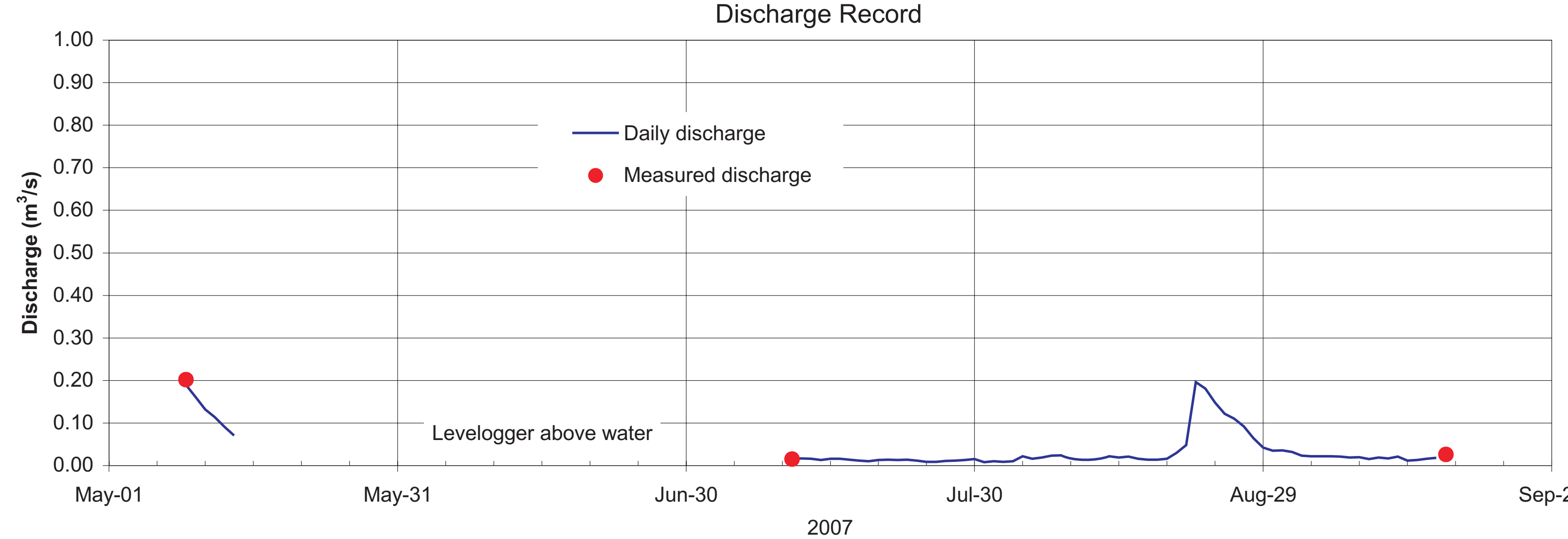
Water Level Record



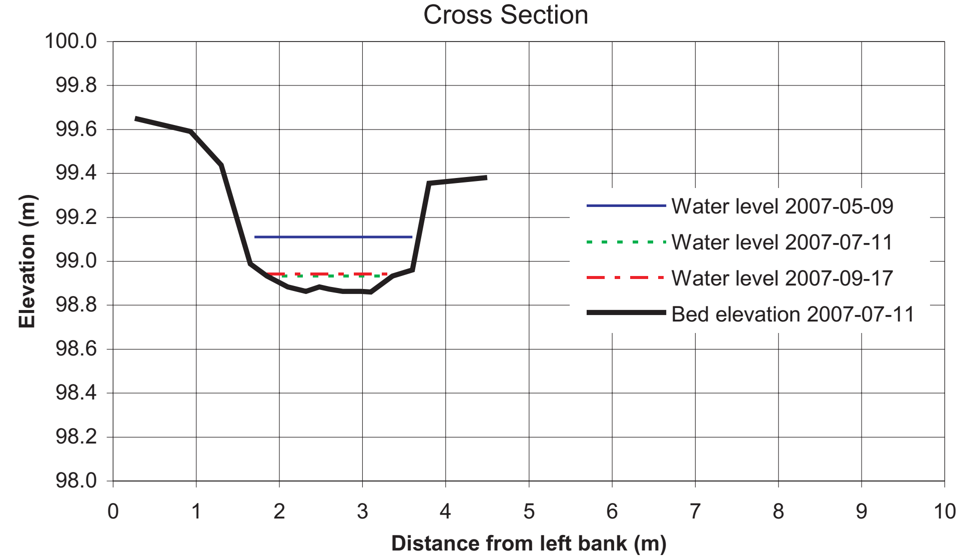
Longitudinal Profile



Discharge Record



Cross Section



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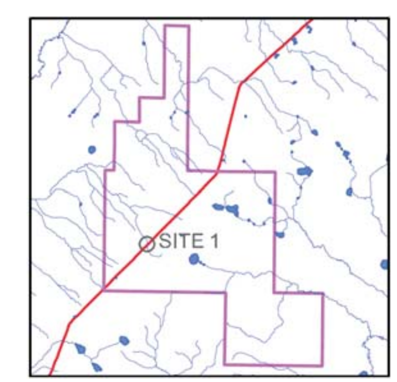


CONNACHER OIL AND GAS LIMITED

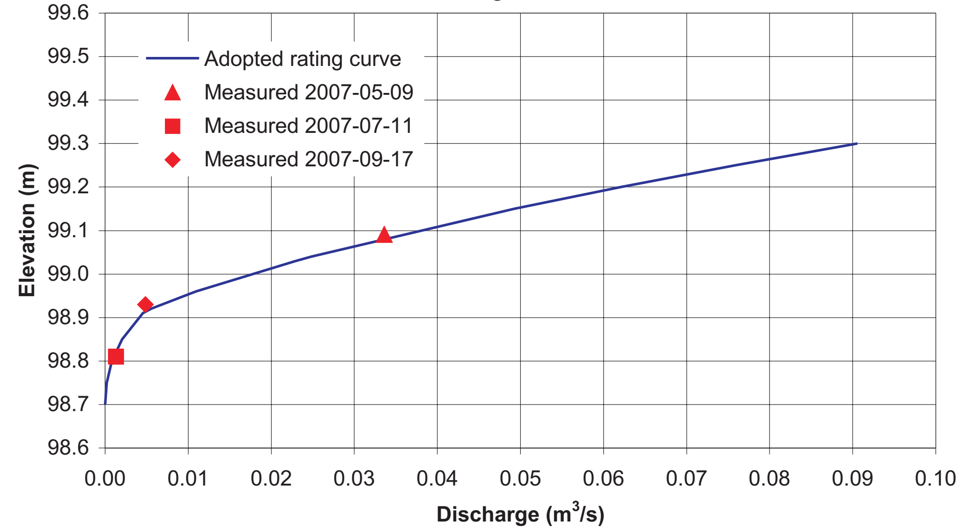
GREAT DIVIDE SAGD EXPANSION
PROJECT HYDROLOGY

HYDRAULIC CHARACTERISTICS AT SITE 1

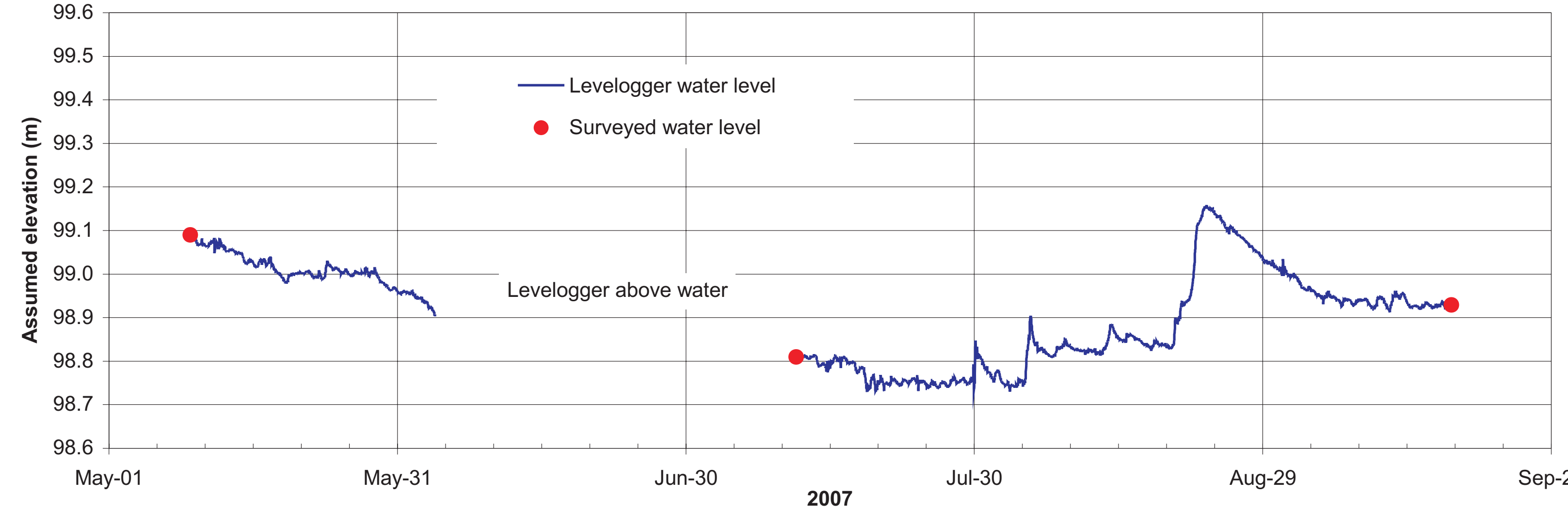
File 16924-13	23 Mar 2010	**Figure 13**

northwest hydraulic consultants ltd.

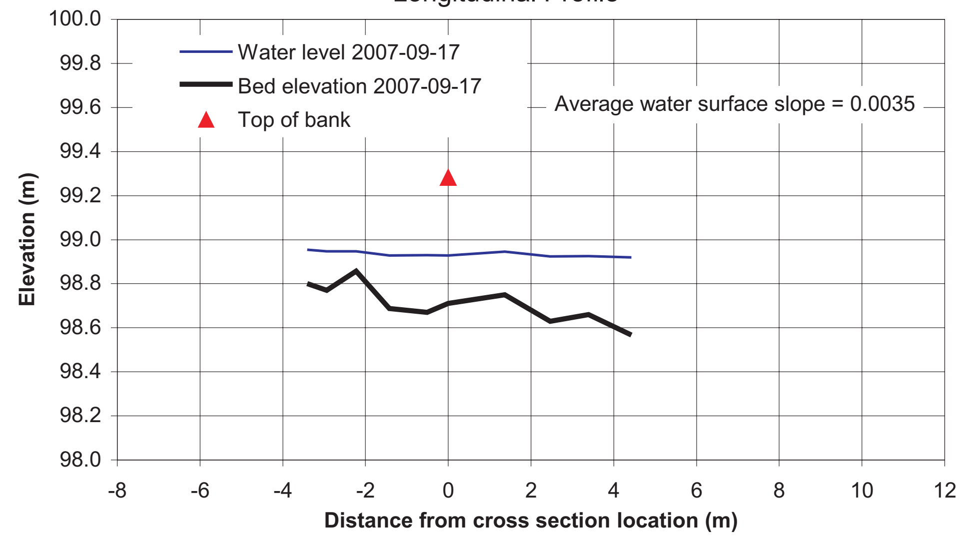
Rating Curve



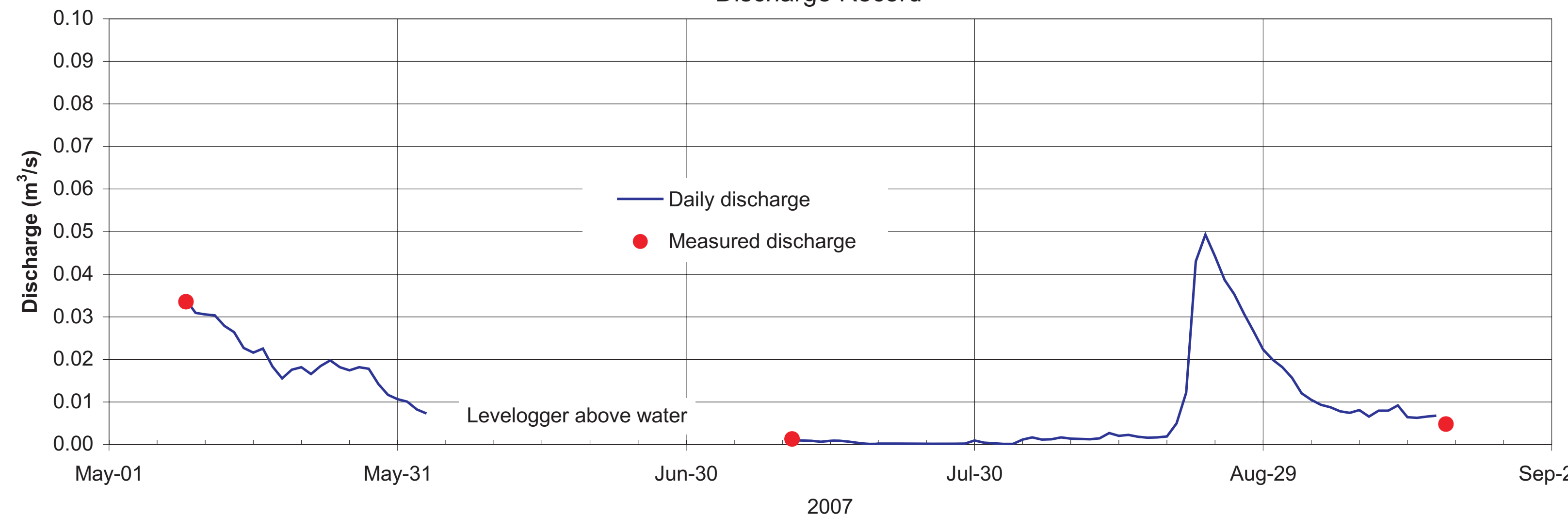
Water Level Record



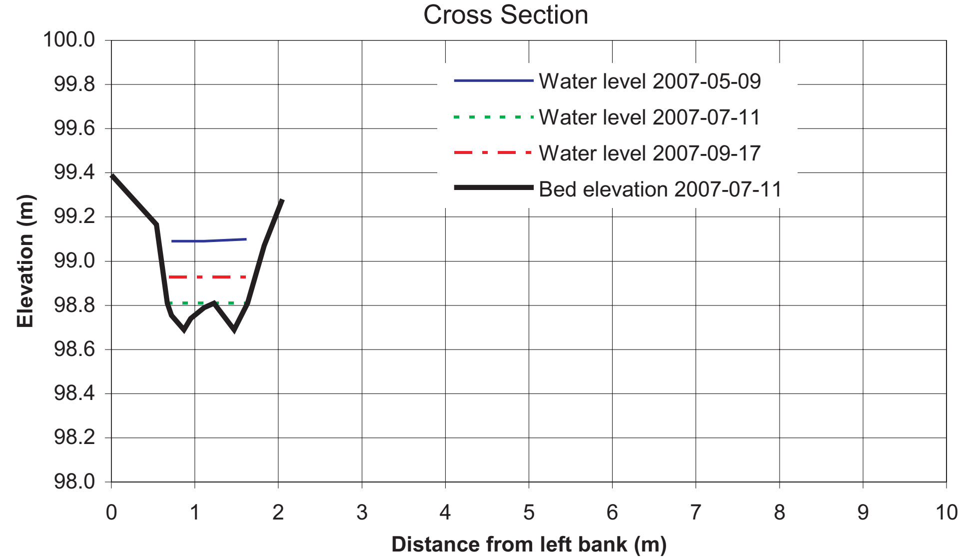
Longitudinal Profile



Discharge Record



Cross Section



Site Photograph 2007-09-17

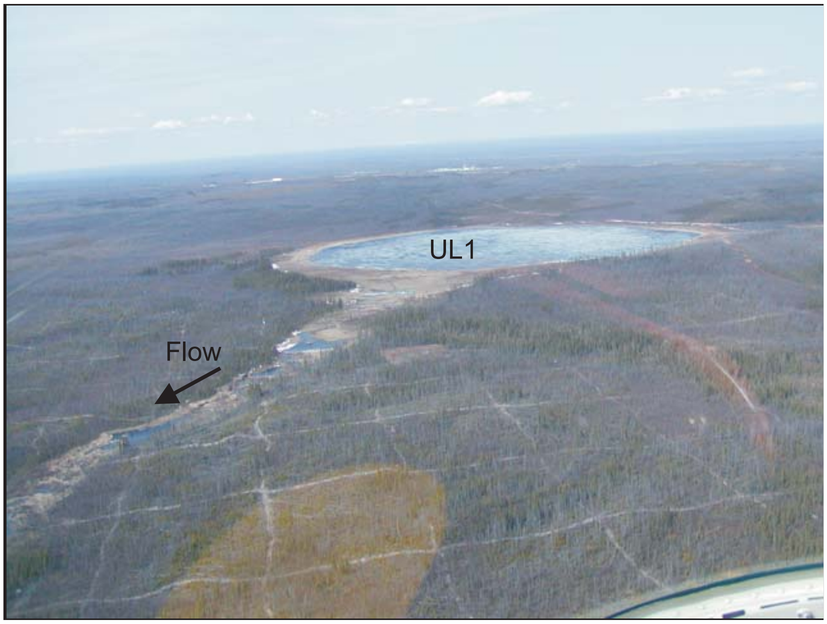
CONNACHER OIL AND GAS LIMITED

GREAT DIVIDE SAGD EXPANSION
PROJECT HYDROLOGY

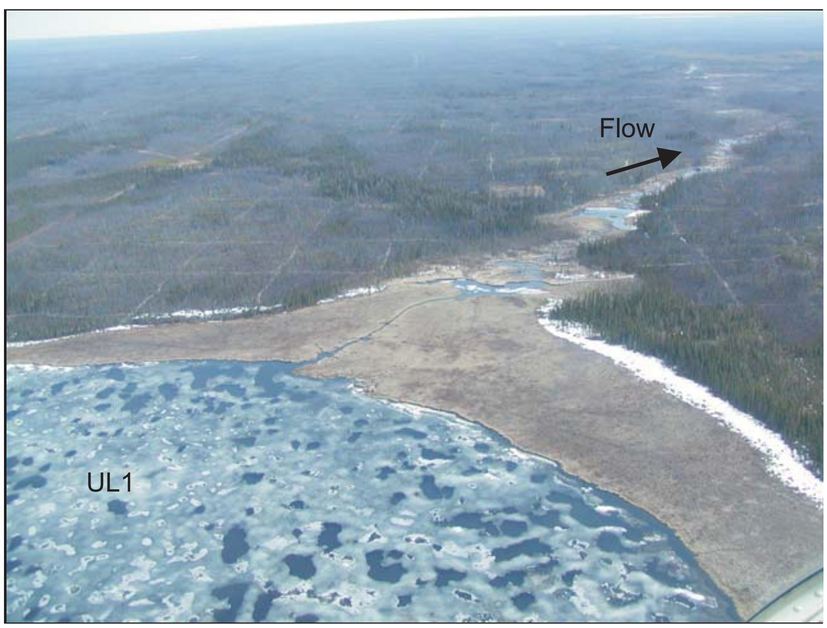
HYDRAULIC CHARACTERISTICS AT SITE 2

File 16924-14	23 Mar 2010	**Figure 14**

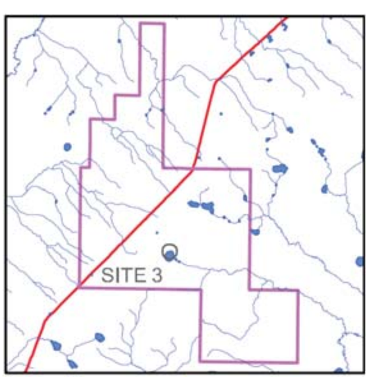
northwest hydraulic consultants ltd.



Aerial view of Lake UL1 from east



Aerial view of outlet of Lake UL1



CONNACHER OIL AND GAS LIMITED

GREAT DIVIDE SAGD EXPANSION
PROJECT HYDROLOGY

PHOTOGRAPHS AT SITE 3

File 16924-15	23 Mar 2010	**Figure 15**

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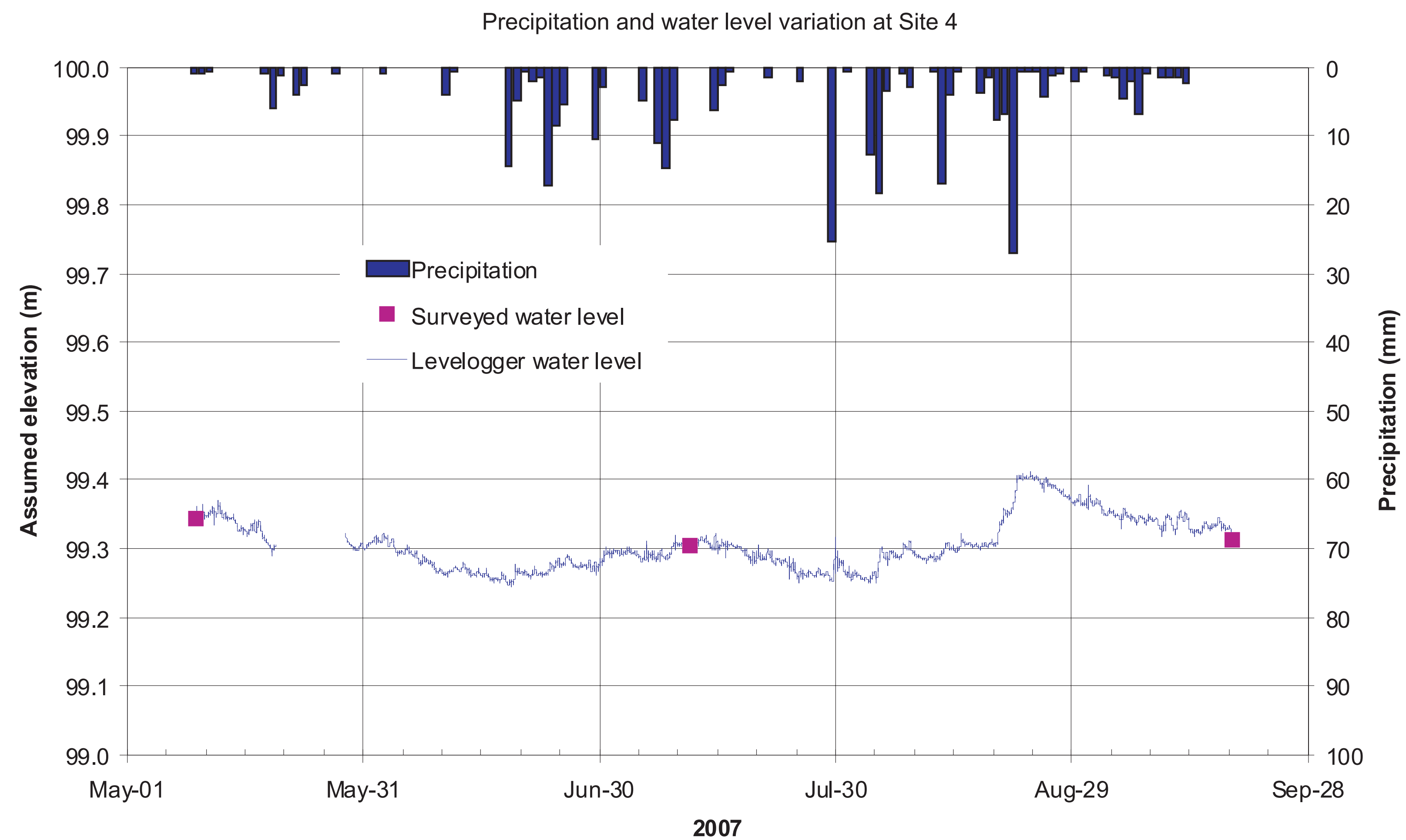
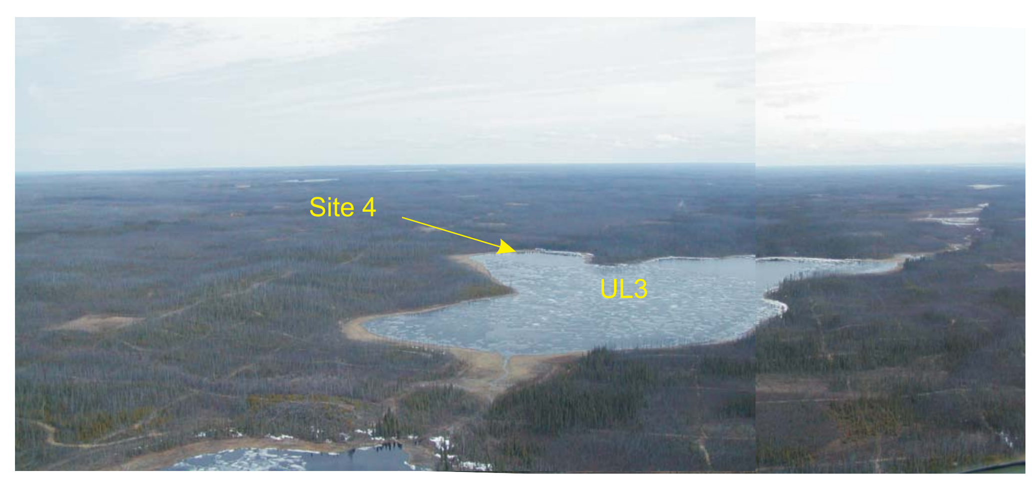
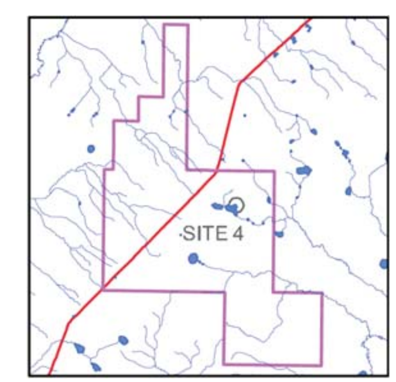
View of Site 4 on July 12, 2007



View of lakes UL3 and UL2 on May 02, 2007

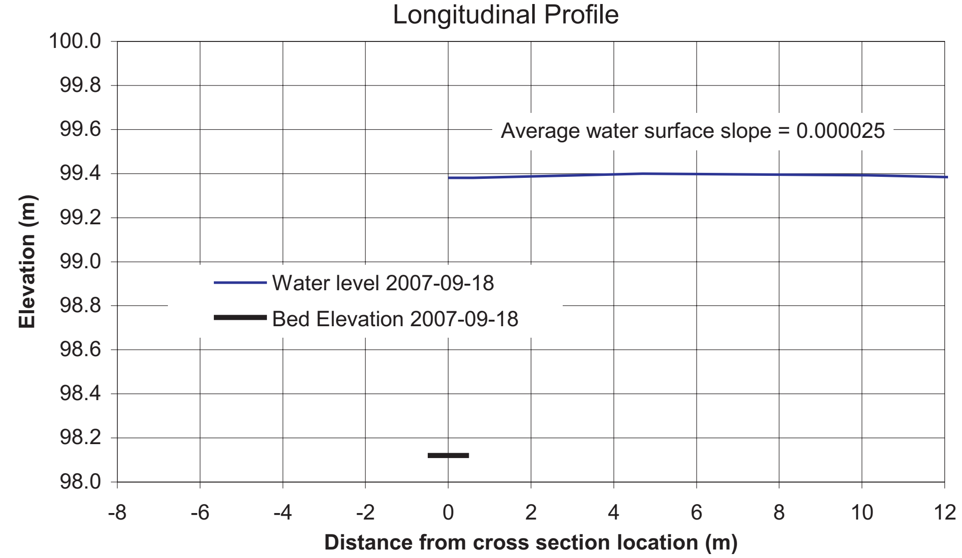


View of Site 4 on May 02, 2007

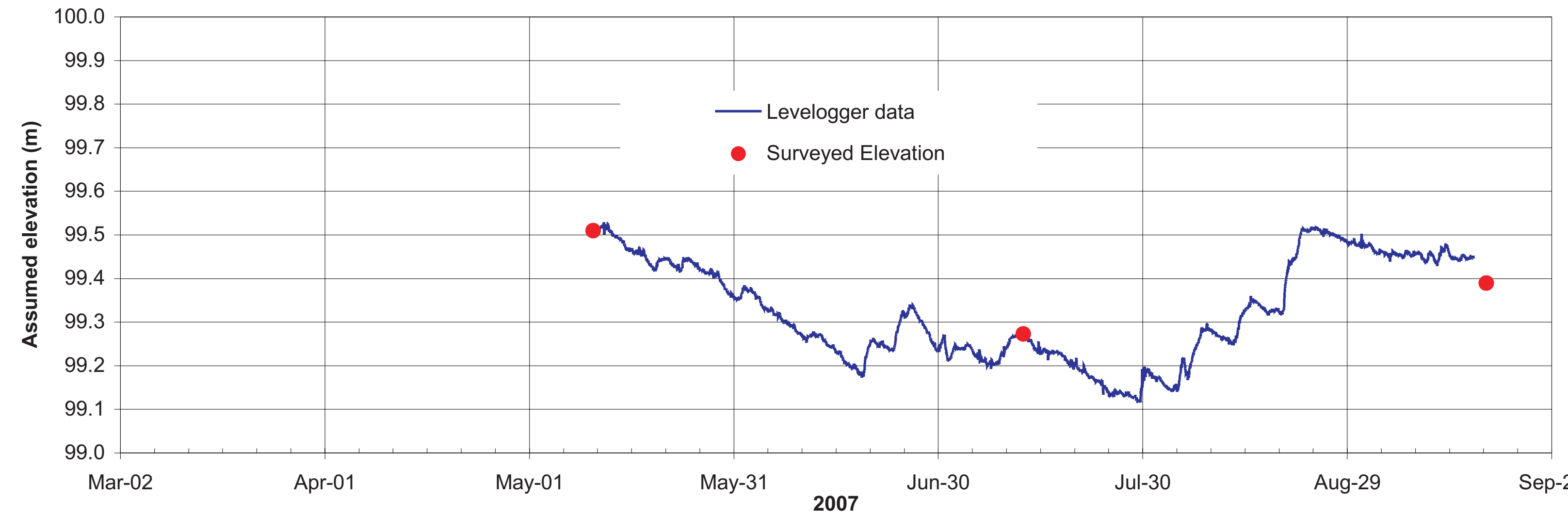


CONNACHER OIL AND GAS LIMITED		
GREAT DIVIDE SAGD EXPANSION PROJECT HYDROLOGY		
LAKE CHARACTERISTICS AT SITE 4		
File 16924-16	23 Mar 2010	**Figure 16**
northwest hydraulic consultants ltd.		

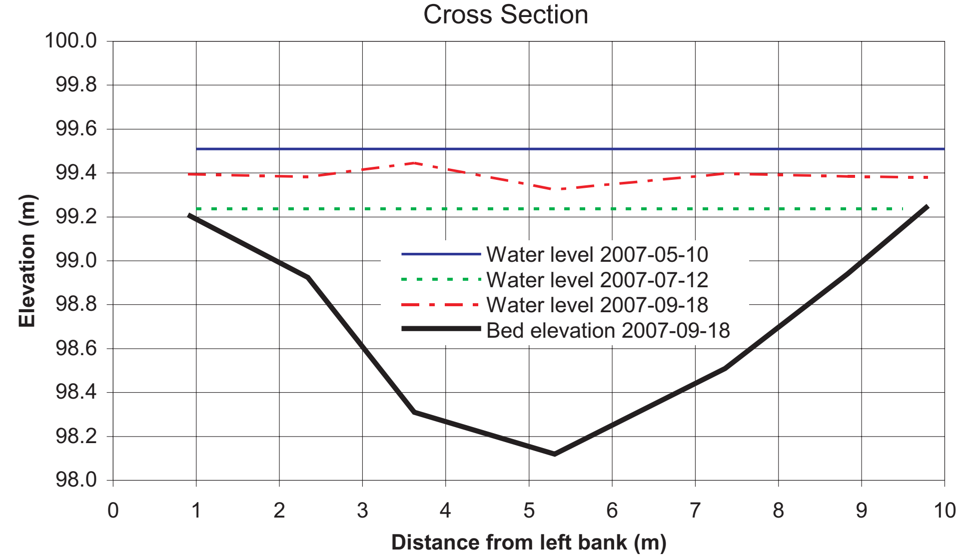
Longitudinal Profile



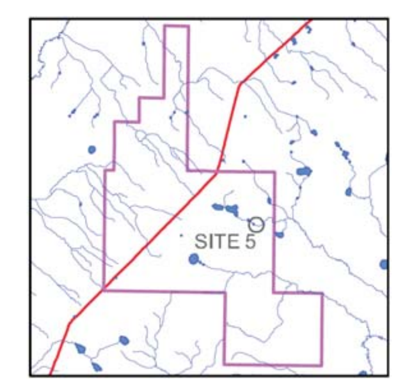
Water Level Record



Cross Section



Site Photograph 2007-07-12



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GREAT DIVIDE SAGD EXPANSION
PROJECT HYDROLOGY

HYDRAULIC CHARACTERISTICS AT SITE 5

File 16924-17	23 Mar 2010	**Figure 17**

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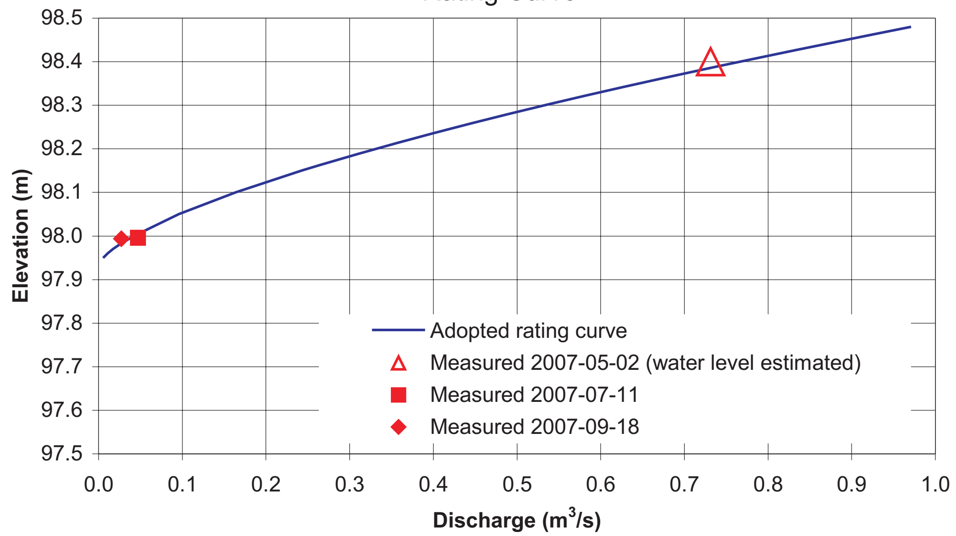
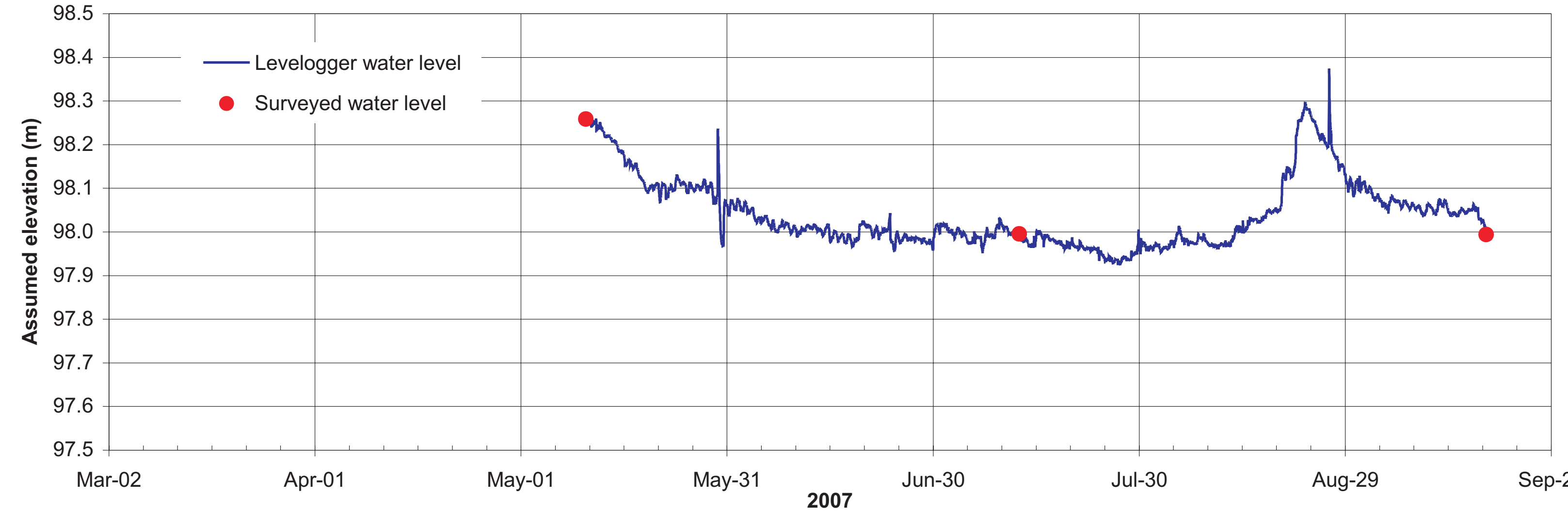
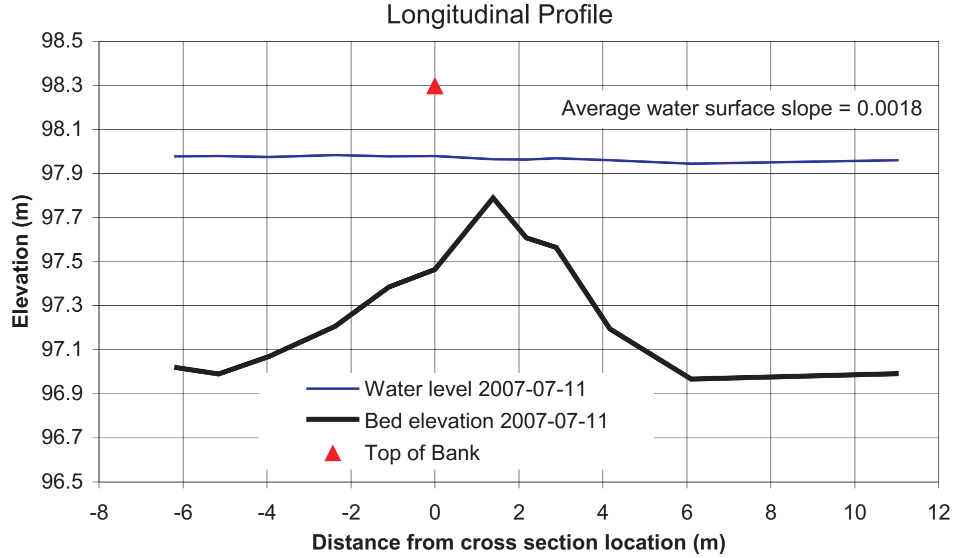
Rating Curve



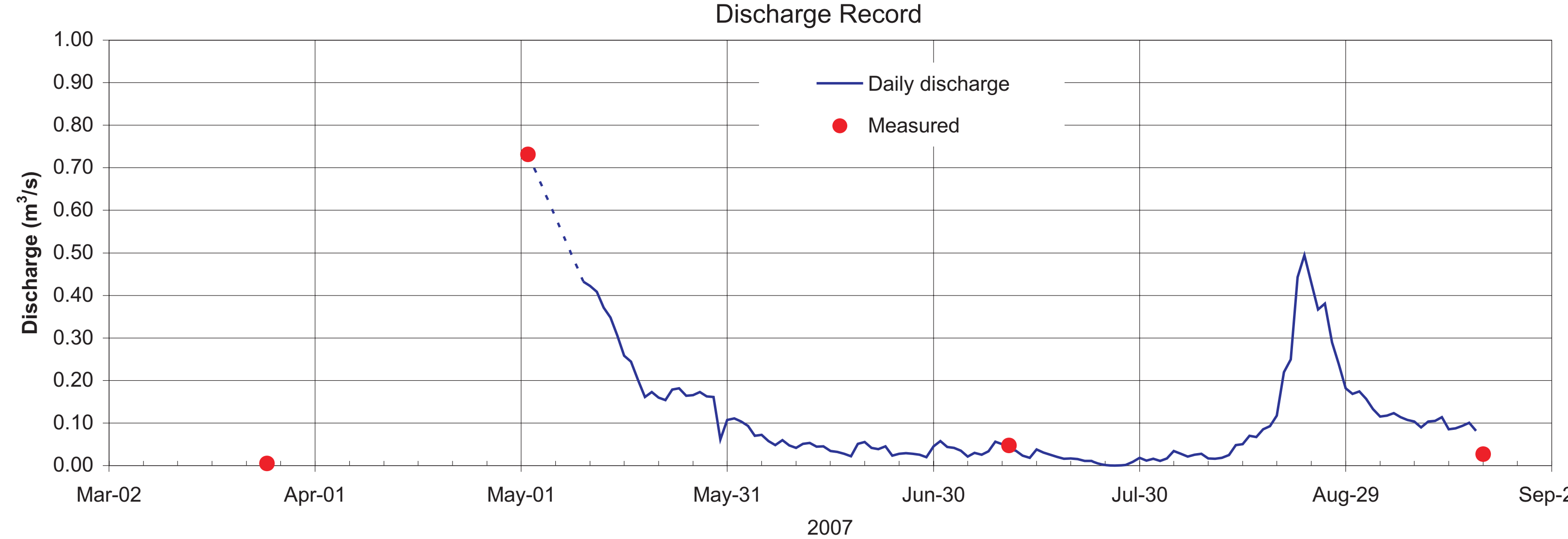
Water Level Record



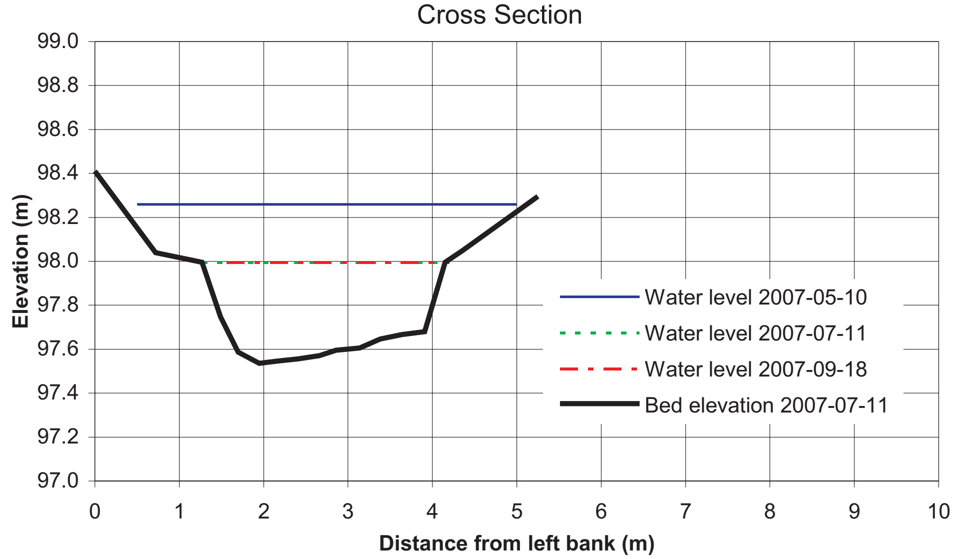
Longitudinal Profile



Discharge Record



Cross Section



Site Photograph 2007-07-11

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GREAT DIVIDE SAGD EXPANSION
PROJECT HYDROLOGY

HYDRAULIC CHARACTERISTICS AT SITE 6

File 16924-18	23 Mar 2010	**Figure 18**

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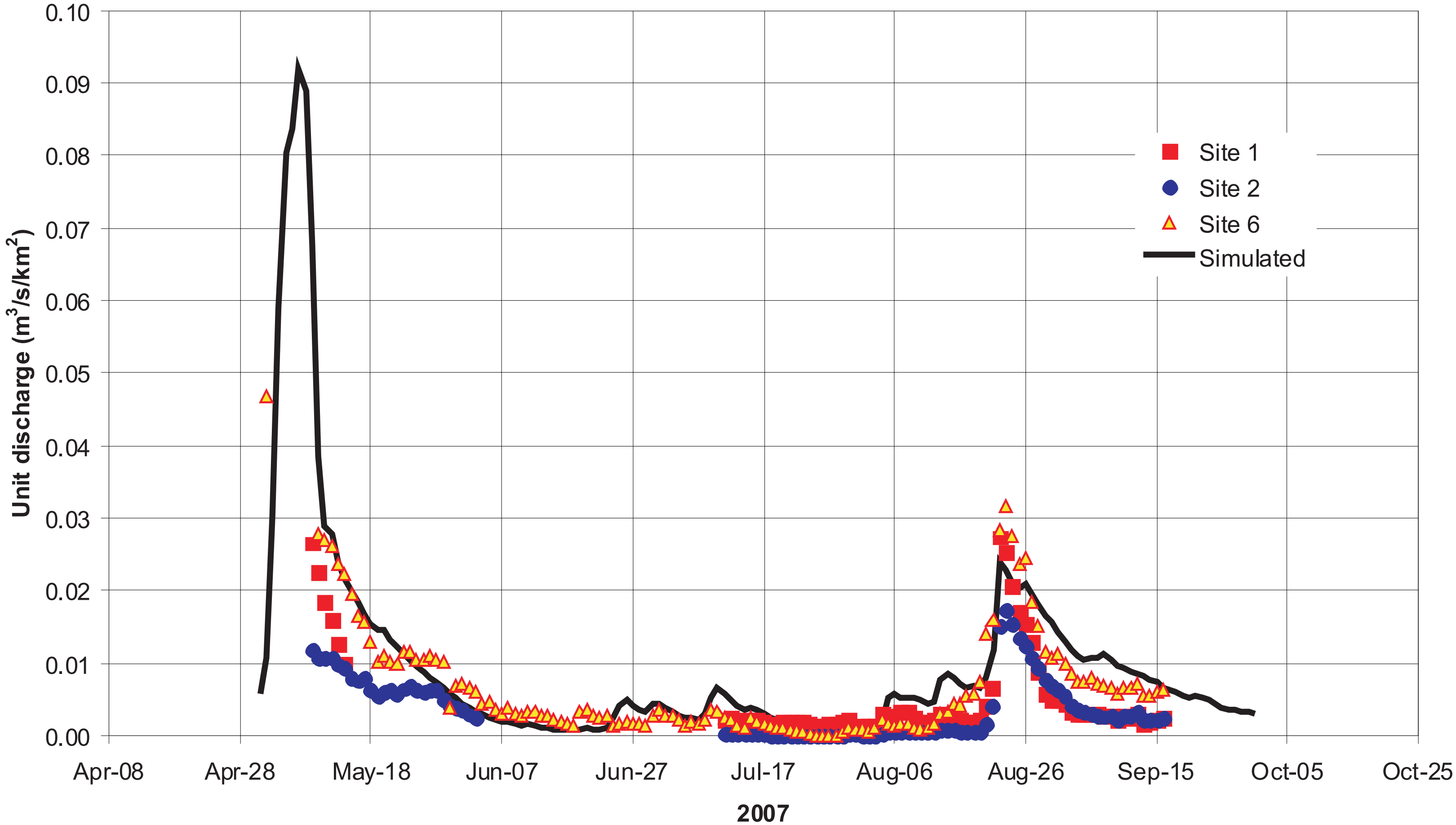

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GREAT DIVIDE SAGD EXPANSION
PROJECT HYDROLOGY

COMPARISON OF MEASURED AND SIMULATED UNIT DISCHARGE

File 16924-19	23 Mar 2010	**Figure 19**

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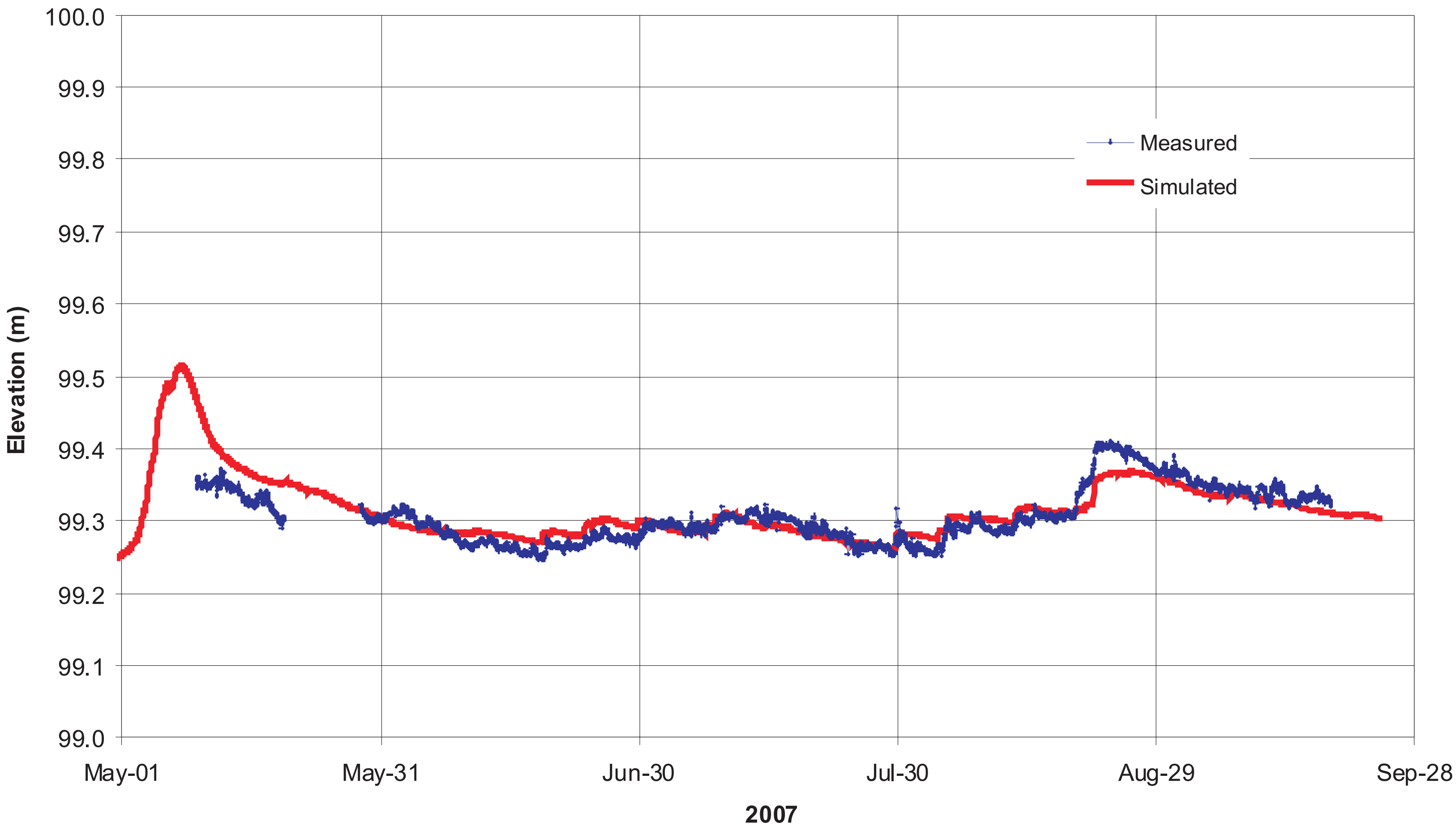

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GREAT DIVIDE SAGD EXPANSION
PROJECT HYDROLOGY

COMPARISON OF MEASURED AND SIMULATED WATER LEVELS AT SITE 4

File 16924-20	24 Mar 2010	**Figure 20**

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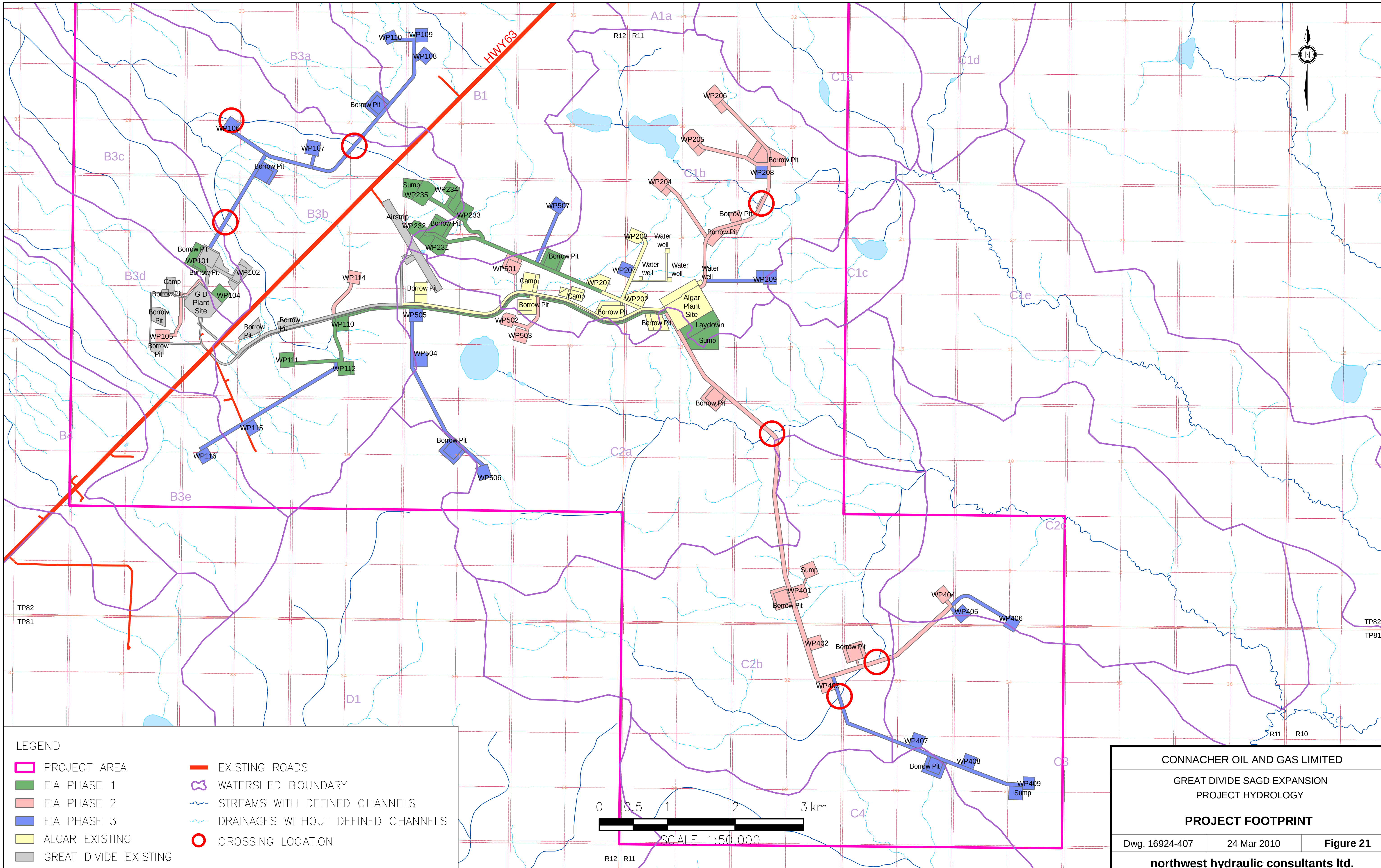
HWY63
A1a
B1
B3a
B3b
B3c
B3d
B3e
B4
C1a
C1b
C1c
C1d
C1e
C2a
C2b
C2c
C3
C4
D1
R12
R11
R10
TP82
TP81
WP101
WP102
WP104
WP105
WP106
WP107
WP108
WP109
WP110
WP111
WP112
WP114
WP115
WP116
WP201
WP202
WP203
WP204
WP205
WP206
WP207
WP208
WP209
WP231
WP232
WP233
WP234
WP235
WP401
WP402
WP403
WP404
WP405
WP406
WP407
WP408
WP409
WP501
WP502
WP503
WP504
WP505
WP506
WP507
Borrow Pit
Sump
Camp
Airstrip
Water well
G D Plant Site
Algar Plant Site
Laydown
LEGEND
PROJECT AREA
EIA PHASE 1
EIA PHASE 2
EIA PHASE 3
ALGAR EXISTING
GREAT DIVIDE EXISTING
EXISTING ROADS
WATERSHED BOUNDARY
STREAMS WITH DEFINED CHANNELS
DRAINAGES WITHOUT DEFINED CHANNELS
CROSSING LOCATION
0 0.5 1 2 3 km
SCALE 1:50,000
CONNACHER OIL AND GAS LIMITED
GREAT DIVIDE SAGD EXPANSION
PROJECT HYDROLOGY
PROJECT FOOTPRINT
Dwg. 16924-407
24 Mar 2010
Figure 21
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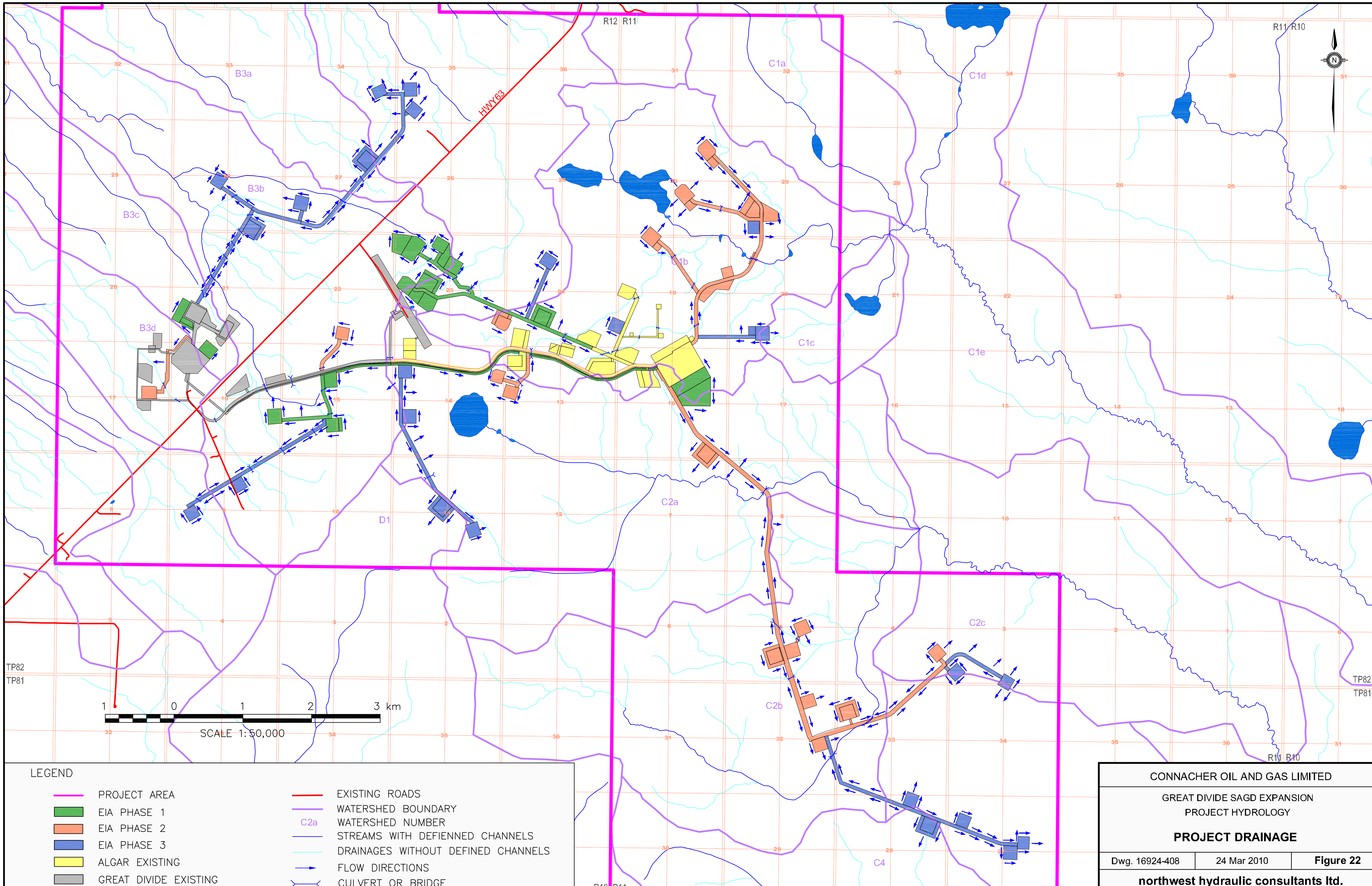
R12 R11
R11 R10
HWY63
B3a
B3b
B3c
B3d
C1a
C1b
C1c
C1d
C1e
C2a
C2b
C2c
C4
D1
TP82
TP81
1 0 1 2 3 km
SCALE 1:50,000
LEGEND
PROJECT AREA
EIA PHASE 1
EIA PHASE 2
EIA PHASE 3
ALGAR EXISTING
GREAT DIVIDE EXISTING
EXISTING ROADS
WATERSHED BOUNDARY
C2a WATERSHED NUMBER
STREAMS WITH DEFIENNED CHANNELS
DRAINAGES WITHOUT DEFINED CHANNELS
FLOW DIRECTIONS
CULVERT OR BRIDGE
CONNACHER OIL AND GAS LIMITED
GREAT DIVIDE SAGD EXPANSION
PROJECT HYDROLOGY
PROJECT DRAINAGE
Dwg. 16924-408
24 Mar 2010
Figure 22
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