PENGROWTH ENERGY CORPORATION

HYDROLOGY ASSESSMENT FOR LINDBERGH SAGD EXPANSION PROJECT

NOVEMBER, 2013

northwest hydraulic consultants

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EXECUTIVE SUMMARY

Pengrowth Energy Corporation is proposing to develop the Lindbergh SAGD Expansion Project (the Project), which will expand bitumen production of the Lindbergh SAGD Project (Phase 1) from 1,987 m^3/day (12,500 barrel per day (bpd)) to 4770 m^3/day (30,000 bpd). The Project is located approximately 24 km southeast of Bonnyville within St. Paul County No. 19 and Municipal District of Bonnyville No 87. All facilities will be located within Townships 58 and 59 and Ranges 4 and 5, West of the 4th Meridian.

A hydrologic assessment was carried out for the Project which evaluated physiography, climate, and streamflow characteristics in the vicinity of the Project, assessed the hydrological effects of the Project, and recommended mitigation and monitoring strategies.

The local hydrology was assessed from regional climate and streamflow data and from local observations. Local hydrography was determined from available map data and confirmed during a site inspection. Local channel characteristics were evaluated at six sites.

The hydrologic effects of the Project are limited to surface disturbances. The effects of surface disturbances caused by the development of the Project on the hydrology in the area were investigated and found to be small. The surface disturbances associated with the Project will produce some changes in runoff volumes but these changes are expected to be small in the larger basins. The small changes in runoff volumes may also produce small increases in lake water levels and surface area.

The development was designed to avoid affecting stream channels and will be carried out to minimize effects on drainage patterns. The development will cross a number of channels and mapped drainages without impeding the flows. Surface drainage will be directed around disturbances and back into their original pathways.

In summary, the effects of disturbances caused by the development of the Project on the hydrology were investigated and found to be small. Where effects could potentially occur, the Project should be designed to minimize these effects.

CREDITS AND ACKNOWLEDGEMENTS

This project was carried out by Gary Van Der Vinne, M.Sc., P. Eng., Tony Ye, M. Eng., P. Eng., James Snyder, E.I.T., Kerry Paslawski, C.E.T. and Aaron Snyder. Climate data used in this report was obtained from Environment Canada's National Climate Data and Information Archive and from AgroClimatic Information Service (ACIS) which provide climate data integrated from Alberta Agriculture and Development and its partners (Alberta Environment, Environment Canada, Alberta Sustainable Resources Development, and Agriculture and Agri-food Canada). Streamflow data was obtained from Environment Canada's Water Survey Canada Archived Hydrometric Data and the Regional Aquatics Monitoring Database. Mapping information was obtained from the National Topographic Service's National Topographic Database (NTDB) and the AltaLIS digital mapping service. Digital elevation data was obtained from Geobase. Airphoto and LiDAR data were provided by Pengrowth Energy Corporation.

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TABLE OF CONTENTS

LIST OF TABLES

List of Figures

1 Introduction

Pengrowth Energy Corporation (Pengrowth) is proposing to develop the Lindbergh SAGD Expansion Project (the Project), which will expand bitumen production of the Lindbergh SAGD Project (Phase 1) from 1,987 m^3/day (12,500 barrels per day (bpd)) to 4,770 m^3/day (30,000 bpd). The development of Pengrowth's steam assisted gravity drainage (SAGD) projects on their Lindbergh lease is presented in Table 1.

Table 1 Status of Pengrowth SAGD Projects at Lindbergh

Project	Phase	Status	Production Capacity
Lindbergh SAGD Pilot Project	Pilot	Operational	200 m^3/day (1,258 bpd)
Lindbergh SAGD Project	Phase 1	Under Construction	1,987 m^3/day (12,500 bpd)
Lindbergh SAGD Expansion Project	Phase 2	Proposed	4,770 m^3/day (30,000 bpd)

The Project is located approximately 24 km southeast of Bonnyville within St. Paul County No. 19 and Municipal District of Bonnyville No. 87. All facilities will be located within Townships 58 and 59 and Ranges 4 and 5, West of the 4th Meridian.

Planned facilities for Phase 2 include a number of well pads and well pairs, with associated infrastructure including roads, above ground gathering and distribution pipeline systems. The Phase 2 expansion components for the central processing facility (CPF) will be built within the existing Phase 1 CPF footprint, which will not increase in physical size. The existing water source will be utilized for the Project.

Pengrowth has identified two development scenarios, the Initial Development footprint required to bring production up to the design capacity of 4,770 m^3/day (30,000 bpd) and the Future Development required to sustain production for the life of the Project (Figure 1, Table 2). The Project is expected to produce approximately 43.7 million m^3 (275 million barrels) of bitumen over 25 years.

Table 2 Summary of Project Footprint Components

	Component Area (ha) by Phase of Development					Total Project Component Area (ha)
	Existing and Approved Development (Pilot + Phase 1)	Proposed Development (Phase 2)				
		Initial Development[1]		Future Development[2]		
		New Clearing	Previously Disturbed	New Clearing	Previously Disturbed	
Central Processing Facility (Phase 1)	28.4	-	-	-	-	28.4
Central Processing Facility (Pilot)	9.2	-	-	-	-	9.2
Access/Utility Corridor	54.8	20.3	4.1	301.1	2.5	376.2
Well Pads	19.4	16.7	4.7	204.5	6.6	240.6
Borrow Pits	29.5	9.3	-	100.1	-	138.8
Soil Storage	18.2	8.5	1.9	131.9	0.6	158.6
Disposal Wells	1.6	-	-	-	-	1.6
Camps	13.2	-	-	-	-	13.2
Total Disturbance	174.3	54.8	10.7	737.6	9.7	966.6

[1] Initial Development refers to the initial stage of development required to bring production up to 4,770 m^3/day.

[2] Future Development refers to future stages of development required to sustain production at 4,770 m^3/day for the life of the Project.

This report provides a summary of the baseline hydrologic characteristics in the vicinity of the Lindbergh Expansion Project, and addresses the impacts of the existing developments and the proposed Project on the surface water hydrology. 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 streamflows, water levels and channel characteristics of the affected watersheds.

2 Terms of Reference

This surface water hydrology assessment was conducted according to the final Terms of Reference (TOR) issued by Alberta Environment and Sustainable Resource Development (ESRD). The specific requirements for surface water hydrology and the sections of this report which address these requirements are listed below:

> *"**3.3.1 Baseline Information***
>
> *[A] Describe and map the surface hydrology in the Project Area.*
>
> *[B] Identify any surface water users who have existing approvals, permits or licenses.*
>
> ***3.3.2 Impact Assessment***
>
> *[A] Describe the extent of hydrological changes that will result from disturbances to groundwater and surface water movement, and:*
>
> *a) include changes to the quantity of surface flow, water levels and channel regime in watercourses (during minimum, average and peak flows) and water levels in waterbodies;*
>
> *b) assess the potential impact of any alterations in flow on the hydrology and identify all temporary and permanent alterations, channel realignments, disturbances or surface water withdrawals;*
>
> *c) discuss the effect of these changes on hydrology (e.g., timing, volume, peak and minimum flow rates, river regime and lake levels), including the significance of effects for downstream watercourses; and*
>
> *d) identify any potential erosion problems in watercourses resulting from the Project.*
>
> *[B] Describe impacts on other surface water users resulting from the Project. Identify any potential water use conflicts.*
>
> *[C] Discuss the impact of low flow conditions and in-stream flow needs on water supply and water and wastewater management strategies."*

The locations within this document where these terms of reference are addressed are summarized in Table 3. The effects of the Project on groundwater movement are discussed in the Hydrogeology Assessment (MEMS, 2013).

Table 3 Terms of Reference Concordance Table

Term of Reference	Description	Location in Document
3.3.1 [A]	Describe surface hydrology	Section 4.3
3.3.1 [B]	Identify surface water users	Section 5.1
3.3.2 [A] a)	Describe changes to flows, levels and channels	Section 5.3, 6.2
3.3.2 [A] b)	Assess impacts of alterations to flow and channels	Section 5.3, 6.2
3.3.2 [A] c)	Discuss effects of changes to flow	Section 5.3, 6.2
3.3.2 [A] d)	Identify potential erosion problems	Section 5.3.3, 6.2.3
3.3.2 [B]	Describe impacts to other water users	Section 6.1.3, 6.2
3.3.2 [C]	Discuss impacts to low lows	Section 6.1.2, 6.2.1

3 Assessment Method

3.1 Location and Spatial Boundaries

Figure 1 shows the location of the Project and the relevant climate and hydrometric stations in north-eastern Alberta.

The Project lies in a small zone of Central Mixedwood Boreal Forest situated within a larger region of Dry Mixedwood Boreal Forest. The Project is drained by tributaries of Mooswa Creek, by Garnier Creek (the creek connecting Garnier Lakes to Muriel Lake), Reita Lake, Muriel Lake and Borden Lake. Mooswa Creek flows southward into Moosehills Creek which flows into the North Saskatchewan River near the Hamlet of Lindbergh. Borden Lake flows southward into the North Saskatchewan River about 10 km downstream of the Hamlet of Riverview. Garnier Creek flows north into Muriel Lake which drains northeast through Muriel Creek into the Beaver River near Cold Lake. Reita Lake drains northeast into Angling Lake and then into the Beaver River (Figure 2).

The spatial boundaries considered for the Surface Water Hydrology Assessment include the:

- Regional Study Area (RSA);
- Local Study Area (LSA); and
- Project Footprint.

3.1.1 *Regional Study Area*

The Hydrology RSA is defined as the area in which flows and water levels could be directly or indirectly affected by the Project. The boundary of the RSA is shown in Figure 2. With a total area of 756.4 km^2, the RSA consists of drainage areas of Mooswa Creek to Mitchell Lake, Garnier Creek to Muriel Lake, Reita Creek to Reita Lake and Middle Creek to Borden Lake. The RSA has been selected because potential impacts to waterbodies downstream of these drainage basins are anticipated to be negligible.

3.1.2 *Local Study Area*

The Hydrology LSA is defined as the Project Footprint and surrounding areas which would be directly affected by runoff from the Project. The boundary of the LSA is shown in Figure 3 along with the boundaries of the smaller scale drainage basins within the LSA and is 485.4 km^2 in area. The LSA has been selected as no direct impacts to waterbodies downstream of the LSA are anticipated.

3.1.3 PROJECT FOOTPRINT

The Project Footprint for surface water hydrology is defined as the area of direct disturbance provided by Pengrowth with a total of 966.6 ha (Table 2), with 174.3 ha of disturbance existing for the Pilot and Phase 1 activities. The Project Footprint is shown in Figure 2 and Figure 3. Elevations within the Project Footprint vary from 592 to 700 m above sea level (asl).

3.2 TEMPORAL BOUNDARIES

The temporal boundary for the surface water hydrology assessment was defined by the life span of the Project. Pengrowth has identified two development scenarios, the Initial Development footprint required to bring production up to the design capacity of 4,770 m^3/day (30,000 bpd) and the Future Development required to sustain production for the life of the Project (Table 2). However, the assessment considers that the entire Project is developed for the entire operational phase of the Project (25 years). This results in a conservative evaluation so that effects are not underestimated.

Three assessment cases were considered:

- Baseline Case - includes existing environmental conditions and existing and approved developments within six months of submission;
- Application Case - includes the Baseline Case and the Project; and
- Planned Development Case - includes the Application Case and all reasonably foreseeable projects.

Hydrologic conditions defined by an analysis of historical regional climate and hydrometric data were used as the basis of comparison for the assessment of these cases.

3.3 Assessment Criteria

Valued environmental components (VECs) of the surface water hydrology were identified and the residual effects of the Project on these VECs after mitigation were assessed according to the following criteria:

- Type of Effect: Application; Cumulative
- Geographical Extent: Local, Regional, Provincial, National, Global
- Duration: Short, Long, Extended, Residual
- Frequency: Continuous, Isolated, Periodic, Occasional
- Reversibility: Short term, Long term, Irreversible
- Magnitude: Nil, Low, Moderate, High
- Project Contribution: Neutral, Positive, Negative
- Confidence Rating: Low, Medium, High
- Probability of Occurrence: Low, Median, High
- Impact Rating: No Impact, Low, Moderate, High

Potential residual effects on hydrology were assessed quantitatively wherever feasible. Qualitative assessments and professional judgment were incorporated where necessary.

The following list of VECs was included in the hydrology assessment:

- runoff volumes and streamflows;
- water levels and surface areas; and
- channel morphology and sediment concentrations.

4 Hydrologic Setting

4.1 Regional Climate

Climate influences many hydrologic characteristics. Over the long term, the climate and local surficial geology determine the vegetation in the area. Surficial geology and vegetation affect the runoff coefficients and evapotranspiration rates in the area. On a shorter time scale, the magnitude of the winter snowpack and severity of summer rain events affect the severity of spring and summer runoff events.

Environment Canada (EC) provides climate data for seven climate station in the vicinity of the Project. The locations of these stations are shown on Figure 1 and station summaries are provided in Table 4. Cold Lake provides hourly data but the other stations only provide daily or monthly values of air temperature and precipitation. The elevation range of the stations is 541 to 605 m asl, which is lower than the elevation range of the Project of 600 to 700 m asl.

Table 4 Summary of climate station information

Station Name	ID	Latitude	Longitude	Elevation (m asl)	Operation		Period of Record
Elk Point	3012280	53°53' N	111°04' W	605	Annual	Daily	1911 to 1997
Iron River	3083480	54°25' N	111°00' W	549	Annual	Daily	1925 to 1975
Cold Lake A	3081680	54°25' N	110°17' W	541	Annual	Hourly	1954 to 2012
Fort Kent CDA EPF	3082660	54°18' N	110°37' W	549	Annual	Daily	1954 to1965
Bonnyville EXP ST	3080740	54°17' N	110°38' W	549	Annual	Daily	1952 to 1954
Glendon	30828JF	54°15' N	111°09' W	588	Annual	Monthly	1936 to 1947
La Corey RS	3083725	54°25' N	110°46' W	579	Annual	Daily	1962 to 1976

Four of the stations, Ft. Kent, Bonnyville, Glendon, and La Corey have short incomplete records so the data are of limited use. The remaining three stations, Elk Point, Iron River, and Cold Lake, have overlapping records which can be used to compile continuous monthly climate record from 1911 to 2012.

4.1.1 *Air Temperature*

Air temperature is an important climatic variable in the hydrologic cycle because it determines the relative proportion of rain and snow within the total annual precipitation and the start and severity of snowmelt runoff in the spring. The average daily maximum, mean, and minimum temperatures for each month at Elk Point and Cold Lake for the climate normal period between 1971 and 2000 are summarized in Table 5. The monthly mean temperatures are also shown in Figure 4. The monthly mean temperature ranges from 17°C in July to -17°C in January. Air temperatures at Cold Lake are about 0.5°C higher than those at Elk Point, possibly due to the lower elevation of the Cold Lake station. The mean daily air temperature drops below freezing from November through March.

4.1.2 *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 summer rain events produce summer peak flows. Precipitation from previous events also affects the amount of runoff from a rainfall event.

The average monthly precipitation at Elk Point and Cold Lake for the climate normal period from 1971 to 2000 are shown on Figure 5 and listed in Table 5. Mean monthly precipitation reaches a maximum of 77 mm in June and July while winter precipitation (November to March) is relatively constant from month to month, averaging about 18 mm per month. While there are some differences in precipitation on a monthly basis, the average annual precipitation for Cold Lake is only 4% lower than the value for Elk Point.

A composite record of monthly precipitation was compiled from the records from Elk Point, Iron River, Cold Lake and Glendon. Missing precipitation values from Elk Point were filled in from other stations rather than averaging available data so that extreme values in the monthly data were preserved. If a month was missing from the Elk Point record, the precipitation from Iron River was used to fill the gap. If the precipitation for Iron River was also missing then the precipitation from Cold Lake was used. The precipitation from Glendon was used the few time records were missing from the other three stations. The resulting composite record is complete from 1924 to 2012.

The variation in annual precipitation is shown in Figure 6. These values were calculated from November to October of each year to include winter snowfall amounts in each year of record which are likely to produce runoff in the spring. The mean annual precipitation for this precipitation record is 417 mm, which is less than the mean annual precipitation for both Elk point and Cold Lake for the climate normal period from 1971 to 2000. This is likely due to the series of high precipitation years which occurred in the 1970's. The maximum annual precipitation of 596 mm occurred in 1956, while the minimum of 260 mm occurred in 1929. The variation in total winter precipitation from November to April is also shown on Figure 6. This is the total precipitation available during spring runoff. The maximum total winter precipitation of 176 mm occurred 1956 while the minimum of 41 mm occurred in 1998. The average total winter precipitation is 91 mm.

Rainfall intensity analysis provided by Environment Canada for Cold Lake is summarized in Table 6. The 10-year 24-hour rainfall is 64.7 mm while the 100-year 24-hour rainfall is 96.4 mm.

Table 5 Summary of climate normal data (1971 to 2000)

Month	Mean Monthly Temperature		Mean Monthly Precipitation		Mean Monthly Snowfall	
	Elk Point (mm)	Cold Lake (mm)	Elk Point (mm)	Cold Lake (mm)	Elk Point (mm)	Cold Lake (mm)
Jan	-16.7	-16.6	21.1	17.9	20.4	22.9
Feb	-13.1	-12.4	14.3	12.4	13.9	16.4
Mar	-6.1	-5.3	17.8	15.1	16.7	16.8
Apr	3.7	4.1	30.1	24.9	10.1	11.7
May	10.3	10.7	44.9	41.7	1.7	4.2
Jun	14.3	14.8	75.9	72.1	0.0	0.0
Jul	16.2	16.9	76.5	77.4	0.0	0.0
Aug	15.0	15.8	65.1	67.8	0.6	0.1
Sep	9.5	10.0	38.6	39.9	0.8	1.6
Oct	3.6	4.0	17.0	17.5	5.5	7.0
Nov	-7.5	-6.7	18.8	20.1	17.8	24.5
Dec	-15.1	-14.6	22.2	19.9	21.7	24.7
Annual	1.2	1.7	442.3	426.7		

Table 6 Rainfall intensity-duration-frequency statistics for Cold Lake

Duration	Rainfall (mm)					
	2-year	5-year	10-year	25-year	50-year	100-year
5 minutes	5.8	8.2	9.9	11.9	13.5	15
10 minutes	8.8	12.8	15.4	18.7	21.2	23.7
15 minute	10.5	15.7	19.1	23.4	26.6	29.8
30 minutes	13	20	24.7	30.6	34.9	39.2
1 hour	15.8	24.5	30.4	37.7	43.1	48.5
2 hour	19.2	28.6	34.8	42.7	48.5	54.3
6 hours	26.8	36.5	43	51.1	57.2	63.2
12 hours	33.1	46.2	54.8	65.7	73.8	81.9
24 hours	39.4	54.6	64.7	77.5	87	96.4

4.1.3 *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 about 70% of the measured pan or potential evaporation due to the higher humidity over the lake, although this percentage varies substantially with location (Linsley, et al, 1982). Evaporation from small ponds may be higher than lake evaporation and may approach the potential evaporation measured by evaporation pans.

Lake evaporation can be calculated from consideration of air temperatures, solar radiation, atmospheric pressure, and humidity; however, the first two parameters are most significant, especially in shallow lakes. Alberta Environment (1999) calculated potential and lake evaporation for Cold Lake from 1974 to 1994. The average annual lake evaporation of 621 mm for this period is about 74% of the average annual potential evaporation of 839 mm for the same period.

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 for Cold Lake is estimated to be about 357 mm (Alberta Environment, 1999), which is about 57% of the lake evaporation. Figure 7 shows the mean evaporation and evapotranspiration for each month. The majority of evaporation occurs from May to September, with the highest evaporation rates occurring in July and August.

4.2 Regional Hydrology

Evaluating the magnitude and variability of stream flows and lake levels is a major component of a hydrologic assessment. The evaluation of streamflow includes an analysis of runoff coefficients, mean flows and extreme flows. Evaluation of lake levels includes an analysis of annual variations as well as longer term trends.

4.2.1 *Regional Flow Characteristics*

Water Survey of Canada (WSC) maintains a number of 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 7. Only the gauge on the Beaver River near Cold Lake operates continuously through the year, the other gauges operate seasonally from March to October. Ten of the gauges were still operating as of 2010 and have at least 29 years of complete records. The other five gauges operated for short periods in the 1980's and 1990's with years of complete records of only 9 to 13 years so are not useful for establishing long term trends. All the gauges report both gross drainage area and effective drainage area because some areas do not contribute to runoff from the watersheds. The effective drainage areas for these gauges range from 37.7 km^2 for the Moosehills Creek near Elk Point to 11,800 km^2 for the Beaver River near Cold Lake.

Table 7 Summary of WSC gauges in the region

Stream	Location	Gauge Number	Gauge Type	Period of Record	Years of complete record	Gross Drainage Area (km^2)	Effective Drainage Area (km^2)
Beaver River	Cold Lake	06AD006	Continuous	1955-2011	55	14,500	11,800
Sand River	mouth	06AB001	Seasonal	1967-2011	42	4,910	4,730
Beaver River	Goodridge	06AA001	Seasonal	1970-2011	41	4,700	3,680
Sturgeon River	Ft Saskatchewan	05EA001	Seasonal	1913-2011	80	3,310	2,390
Vermilion River	Marwayne	05EE007	Seasonal	1979-2010	29	7,260	2,000
Amisk River	Hwy 36	06AA002	Seasonal	1971-2011	39	2,500	1,880
Jackfish Creek	La Corey	06AC001	Seasonal	1971-2010	37	492	344
Atimoswe Creek	Elk Point	05ED002	Seasonal	1975-2010	34	368	312
Waskateneau Creek	Waskateneau	05EC002	Seasonal	1966-2011	42	312	207
Moosehills Creek	Elk Point	05ED003	Seasonal	1978-2009	30	41.0	37.7
Moose Lake River	Franchere	06AC006	Seasonal	1980-1993	13	1,010	627
Punk Creek	mouth	06AB003	Seasonal	1981-1991	10	395	384
Manatokan Creek	Iron River	06AC009	Seasonal	1983-1991	10	449	359
Columbine Creek	mouth (Glendon)	06AA004	Seasonal	1979-1997	9	241	229
Reita Creek	Angling Lake	06AD013	Seasonal	1981-1991	10	161	161

Mean flows, runoff depths and runoff coefficients were calculated for the ten gauges with long term records (Table 8). Runoff depths are defined as the volume of water leaving a watershed as runoff volume divided by the watershed area while runoff coefficients define the fraction of annual precipitation which leaves the basin as streamflow each year. Winter streamflows were only available for the Beaver River at Cold Lake where they averaged 11% of the March to October flows. However, several large lakes help provide these winter flows so it is expected that smaller watersheds without lakes would have relatively less winter flows. The trend of mean flows with drainage areas for the complete flow record shown in Figure 8 indicates that average annual runoff is proportional to drainage area. The long term average runoff coefficient for the region is 0.066.

Mean flows were evaluated for the period from 1980 to 1995 as well as the complete record length because during this shorter period at least nine out of ten gauges were operational each year. Using this period reduces the bias of variable record length when comparing the data. The average runoff coefficient for 1980 to 1995 period is 0.046, considerably less than the long term average coefficient.

Table 8 Summary of runoff coefficients and mean flows

Stream	Location	Effective Drainage Area (km^2)	Mean Flow (m^3/s)		Runoff Depth (mm)		Runoff Coefficient	
			Complete Record	1980-1995	Complete Record	1980-1995	Complete Record	1980-1995
Beaver River	Cold Lake	11,800	25.1	11.6	44.9	20.7	0.099	0.052
Sand River	mouth	4,730	14.2	8.47	63.5	37.9	0.140	0.095
Beaver River	Goodridge	3,680	4.30	1.75	24.6	10.1	0.052	0.026
Sturgeon River	Ft Saskatchewan	2,390	4.15	3.62	36.9	32.0	0.083	0.082
Vermilion River	Marwayne	2,000	1.38	1.38	14.6	14.6	0.034	0.037
Amisk River	Hwy 36	1,880	2.52	1.07	28.4	12.0	0.060	0.031
Jackfish Creek	La Corey	344	0.415	0.177	25.5	10.9	0.056	0.028
Atimoswe Creek	Elk Point	312	0.167	0.148	11.3	10.0	0.026	0.027
Waskateneau Creek	Waskateneau	207	0.263	0.138	26.9	14.1	0.057	0.038
Moosehills Creek	Elk Point	37.7	0.0411	0.0344	23.1	19.3	0.055	0.050
Average					30.0	18.2	0.066	0.046

Seasonal data (March to October) except Beaver River near Cold Lake

The 1980-1995 period of record tends to have lower mean flows than those for the complete record (Table 8). This trend is also evident in the annual series of average runoff depths and runoff coefficients shown in Figure 9. There is a distinct drop in both these parameters between 1980 and 1990 which persists to 2010. For comparison, the variations in the annual series of precipitation and evapotranspiration are also shown in Figure 9. Precipitation also drops during this period which would cause the runoff depth to decrease but does not explain the decrease in runoff coefficient. There is also a small increase in evapotranspiration during this period but it is not sufficient to explain the decrease in runoff coefficient.

The mean annual peak flows for the WSC gauges in the region are summarized in Table 9. The mean annual peak flows generally increase with drainage area (Figure 8), but smaller drainage areas produce higher mean annual peak flows per unit area.

Average minimum monthly flows are listed in Table 9 for the WSC gauges in the region. These minimum flows include winter flows when available. Minimum flows typically occur during the winter months but can also occur during summer dry periods. The relationship of these minimum flows with drainage area is shown in Figure 8.

Table 9 Summary of peak flows and minimum flows

Stream	Location	Effective Drainage Area (km^2)	Mean Annual Peak Flow (m^3/s)	Mean Minimum Monthly Flow (m^3/s)
Beaver River	Cold Lake	11,800	111	2.19
Sand River	mouth	4,730	64.0	1.93
Beaver River	Goodridge	3,680	30.3	0.42
Sturgeon River	Ft. Saskatchewan	2,390	20.6	0.44
Vermilion River	Marwayne	2,000	14.0	0.04
Amisk River	Hwy 36	1,880	14.2	2.47
Jackfish Creek	La Corey	344	2.36	0.42
Atimoswe Creek	Elk Point	312	4.80	0.21
Waskateneau Creek	Waskateneau	207	7.09	0.01
Moosehills Creek	Elk Point	37.7	1.11	0.00

Extreme flows from the historical records of the WSC gauges were evaluated. The peak flows estimated using log-normal distributions are listed in Table 10 for a range of return periods. Flow frequency distributions of the annual peak flows from the gauges, normalized by mean annual peak flow, are shown in Figure 10. An adopted regional log-normal distribution is also shown in Figure 10.

Table 10 Summary of extreme flows for the WSC gauges in the region

Stream	Location	Effective Drainage Area (km^2)	Estimated Peak Flow (m^3/s)				
			2-Yr	5-Yr	10-Yr	25-Yr	100-Yr
Beaver River	Cold Lake	11,800	81.3	160	227	331	525
Sand River	mouth	4,730	50.7	91.5	125	173	259
Beaver River	Goodridge	3,680	14.5	48.4	91.1	179	408
Sturgeon River	Ft. Saskatchewan	2,390	15.3	31.2	45.4	67.8	111
Vermilion River	Marwayne	2,000	8.41	22.0	36.4	62.2	120
Amisk River	Hwy 36	1,880	7.50	23.5	42.7	80.8	176
Jackfish Creek	La Corey	344	1.54	3.56	5.51	8.79	15.6
Atimoswe Creek	Elk Point	312	1.71	7.85	17.4	40.7	115
Waskateneau Creek	Waskateneau	207	2.60	9.82	19.7	41.3	103
Moosehills Creek	Elk Point	37.7	0.648	1.88	3.29	5.96	12.4

4.2.2 Regional Lake Levels

Water levels in Muriel Lake are reported by WSC since 1981. Previously, Alberta Environment had carried out water level measurements on Muriel Lake between 1967 and 1979. The water level data show relatively steady water levels from 1967 to 1980 followed by a relatively steady decline in water level of about 4 m between 1981 and 2010 (Figure 11). Since 1981 the water levels in Muriel Lake have increased by an average of 0.10 m each spring and then fallen by an average of 0.24 m due to evaporation over the summer. This trend is not unique to Muriel Lake. Data from Lower Mann Lake show a similar decline over this period (Figure 11) and the regional study by Van der Kamp (2008) indicated an even more widespread trend of decreasing water levels.

4.3 Local Hydrology

4.3.1 Local Hydrography

The LSA is drained by tributaries of Mooswa Creek and Middle Creek which flow southward into the North Saskatchewan River, and tributaries of Muriel Creek and Reita Creek which flow northward into the Beaver River (Figure 2). The two largest watersheds within the LSA drain northwest into Muriel Lake mainly through Garnier Creek and southwest through Mooswa Creek into Mitchell Lake. Two other much smaller watersheds drain northeast into Reita Lake and south into Borden Lake through Middle Creek. Most of the LSA is drained by small ephemeral streams and undefined drainages which flow into a few larger permanent creeks.

The mapped stream network in the vicinity of the lease was divided into permanent stream, ephemeral streams, and drainages without defined channels (Figure 12). Both the permanent and ephemeral streams have defined channels but the ephemeral streams are often dry for a portion of the year. Observations 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 12 were derived from NTS maps with some minor modifications to maintain consistency with Digital Elevation Model (DEM) data obtained from the Geobase database and LiDAR and with observations carried out by aerial reconnaissance. Additional hydrography obtained from 1:20,000 scale maps obtained from AltaLIS are shown on Figure 12 as drainages without defined channels. AltaLIS mapping was also used along with ground observations to help determine which channels were ephemeral and which were permanent.

4.3.2 Local Lake Level Monitoring Sites

Short term water level records were also collected on five lakes within the RSA to determine typical season variation in water levels. These lakes are listed in Table 11 and their locations shown in Figure 13. The measured water level variations are presented in Appendix A. The data from one on the sites, Site L3 on Muriel Lake, was provided by WSC. Water levels typically increased by about 0.3 m in the spring due to snow melt runoff and then decreased over time due to outflows and evaporation. Some of these lakes, such as Muriel Lake, Reita Lake, and Bluet Lake were too low to produce outflow during the period of record.

The present areas of these lakes also appear to be smaller than they were previously. This is consistent with the water level declines observed on Muriel Lake since 1980.

Table 11 Summary of lake level monitoring sites

Site	Lake	Published Lake Area (km^2)	Current Lake Area (km^2)	Drainage Area (km^2)	Monitoring Period	Annual Water Level Variation (m)
L1	Michel Lake	0.78	0.52	3.3	2011-2012	0.36
L2	Garnier Lake	2.03	1.05	28.4	2011-2013	0.32
L3	Muriel Lake (WSC)	69.84	56.0	456.0	1967-2013	0.24
L4	Bluet Lake	1.48	1.05	12.2	2013	0.24
L5	Reita Lake	12.55	5.93	74.0	2013	0.25

4.3.3 Local Stream Flow Monitoring Sites

Stream flows were monitored at eight stream sites to determine typical variations in water levels and flow rates. A water level recorder was installed at each of the sites which recorded hourly water level fluctuations. These water level records were transformed to discharge records using the flow measurement data collected during period site visits. These sites are listed in Table 12 and their locations shown in Figure 13.

Summaries of the channel characteristics, water levels, and flow measurements at each site are presented in Appendix B. Some of the smaller sites did not have measurable flow. As shown in Figure 8, the estimated peak flows are less than the mean annual peak flows established from the regional analysis.

Table 12 Summary of stream flow monitoring sites

Site	Watershed	Easting (m)	Northing (m)	Monitoring Period	Drainage Area (km^2)	Peak Flow (m^3/s)
S1	Mooswa Creek	521517	5980995	2011-2012	60.0	0.27
S2	G5	525897	5989440	2011-2012	1.7	0.022
S3	ML1	524188	5993990	2011-2012	4.7	No detectable flow
S4	Garnier Creek	525111	5995077	2011-2013	118.6	0.93
S5	G2	529181	5995665	2011-2013	18.0	0.26
S6	ML5	525787	5996810	2013	25.0	No detectable flow
S7	G4	528560	5991893	2013	38.3	No detectable flow
S8	Bluet Lake	527730	5983398	2013	12.2	No detectable flow

4.3.4 Local Channel Characteristics

Local channel characteristics were assessed at six sites in 2011 and an additional six sites in 2013. The locations of these sites are shown on Figure 13. Photographs of the locations were taken and water levels, cross-sections and velocities were measured where possible. A summary of the flow measurements at the 12 sites is given in Table 13. Photographs and cross-sections of the sites are provided in Appendix C.

Table 13 Summary of channel measurements

Site	Watershed	UTM Position (Zone 12)		Date	Top Width (m)	Mean Depth (m)	Discharge (m^3/s)
		Easting (m)	Northing (m)				
A1	M3b	523008	5985374	2011-08-10	1.25	0.10	0.0020
A2	G10	526308	5985333	2011-08-09	no measurable flow		
A3	G7	526273	5987267	2011-08-09	0.57	0.06	0.0007
A4	Garnier Creek	526881	5988615	2011-08-11	0.34	0.05	0.0001
A5	G6	527118	5988806	2011-08-11	no measurable flow		
A6	G5	525904	5989444	2011-08-12	0.35	0.06	0.0014
C1	Reita1	535350	5996481	2013-06-27	no measurable flow		
C2	G2	532241	5996628	2013-06-28	0.48	0.17	0.0026
C3	ML5	529084	5998945	2013-06-28	no measurable flow		
C4	G4	531599	5993466	2013-10-04	no channel		
C5	G4	529375	5990665	2013-10-01	no channel		
C6	Bluet Lake	529522	5981465	2013-10-01	no measurable flow		

4.4 HSPF Model Calibration

A Hydrologic Simulation Program – FORTRAN (HSPF) model was developed to simulate local flow conditions. The HSPF model simulates watershed 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. This climate data was based on the daily data from the Cold Lake Airport Climate station; however, the data was extracted from a database generated by AgroClimatic Information Service (ACIS) which included the estimation of missing data from surrounding stations listed in Table 4. The data included maximum and minimum daily temperatures and daily precipitation from Nov of 1960 to Oct of 2013.The daily precipitation was disaggregated to hourly using a single pattern file based on the intensity-duration-frequency (IDF) curves for Cold Lake Airport listed in Table 6. The daily temperatures were disaggregated to hourly values using the HSPF routine WDMutil. Daily evaporation was also computed using WDMutil but calibrated to the lake evaporation values calculated by Alberta Environment.

The model was calibrated to simulate the Water Survey Canada recorded flow for Moosehills Creek near Elk Point (05ED003) for years 1978 through 2009, as it represents the typical long term flows in the region and has a relatively small gross watershed area of 41 km^2. The model was developed as a single hydrologic response unit representing the entire watershed so that the results could be used to simulate the small watersheds within the LSA. The first year was used to initialize drainage watershed moisture conditions so the results for this year were excluded from the calibration. The average seasonal (Mar-Oct) runoff volume from the simulation was less than 0.1% lower than the measured runoff volume, excluding 1998 when the WSC did not report flows for part of the year. The standard error in seasonal runoff volume was less than 1%. The comparison of simulated versus measured daily flow durations presented in Figure 14 shows that the simulation results provide a reasonable representation of the measured flows, except at very low flows when the model over predicts flows. The frequency distributions of peak flows presented in Figure 15 shows that the simulated peak flow distribution is representative of the measured peak flow distribution; however, there were differences in the timing and magnitude for individual peak flow events.

The calibrated model was then modified to represent the characteristics of each of the watersheds in the LSA. The runoff from each of these watersheds was routed through the streams and lakes shown in Figure 12 to simulate stream flows and water levels at various locations in the RSA. These simulated stream flows and water levels were validated using the stream flows and water levels collected in the RSA. There were differences in the timing and magnitude for individual runoff events but the measured stream flows and lake levels were simulated well on a seasonal basis. The simulation of lake levels in Muriel Lake shown in Figure 16 track the measured water levels reasonably well so the model appears to provide a reasonable representation of the historical runoff from the RSA.

This calibrated and validated model was used in the following sections to perform a more detailed process-based assessment of the hydrologic effects of development. The simulations produced by the model are expected to be valid on a statistical basis but may be less accurate for individual runoff events.

5 Baseline Case

This section describes the hydrologic impacts of the existing and approved developments in the LSA.

5.1 Existing Water Rights

According to Alberta Environment's Water Rights database, there are 67 surface water users who have existing approvals, permit or licenses within the RSA (Figure 17). The annual volumes for most these water rights are quite small, the equivalent of less than 1.0 m^3/day. A summary of the total annual volume for each of the four major watersheds in the RSA is given in Table 14. Almost all of the water volume is from the Muriel Lake watershed.

Table 14 Summary of water rights within the RSA

Watershed	Annual Volume (m^3/year)	Annual Depth (mm/year)
Muriel Lake	734,430	1.94
Mooswa Cr.	12,151	0.07
Middle Cr.	3,384	0.06
Reita Lake	425	0.01

The Cold Lake Beaver River Basin Water Management Plan (Alberta Environment, 2006) states that there are no licensed withdrawals permitted from Muriel and Reita Lakes. It also states that there will be no long-term diversions for steam injection purposes from lakes, wetlands and streams within the Beaver River watershed.

Water supply for the existing and approved components of the Lindbergh SAGD Project is obtained through an existing intake and pipeline from the North Saskatchewan River. This existing water license allows a maximum rate of 4,404 m^3/day to be diverted from the North Saskatchewan River to the Project.

5.2 Footprint of Existing Developments

The effects of existing and approved disturbances on the hydrology within the LSA were evaluated to determine the baseline conditions in the LSA. The types of disturbances which are widespread throughout the LSA include the following:

- a road network;
- agricultural development;

- seismic cut-lines;
- well pads and access roads; and
- pipeline corridors.

Effects associated with these disturbances are widespread and long term and therefore have been incorporated within the regional analysis of the historical records and the HSPF calibration process. For example, the intensity of these types of disturbances within the LSA (6.6%) is similar to the intensity within the Moosehills Creek watershed (7.2%) which was used to calibrate the HSPF hydrologic model.

The existing and approved developments which were explicitly incorporated in the analysis of the baseline case were the existing Lindbergh SAGD Pilot Project (the Pilot) and the approved Lindbergh SAGD Project (Phase 1). The disturbances from these developments are specific to the LSA and their effects are not represented in the historical record. The areas disturbed by these developments are summarized in Table 2 and their locations are shown in Figure 18.

5.2.1 *Surface Disturbances*

Surface disturbances within the LSA due to the existing Pilot Project and the approved Phase 1 Project include:

- access corridors;
- borrow pits;
- camps;
- central processing facility (CPF);
- soil storage;
- disposal wells; and
- well pads.

Table 15 summarizes the extent of the spatial disturbances within the individual drainage watersheds. The total disturbed in the LSA is 174.3 ha, which is 0.22% of the total area of the LSA. The most disturbed watershed is G7, with 8.3% of the area disturbed, largely because the watershed is quite small, only 191 ha.

Table 15 Summary of specific existing and approved disturbance areas within LSA

Watershed	Access Corridors (ha)	Borrow Pits (ha)	Camps (ha)	CPF (ha)	Soil Storage (ha)	Disposal Wells (ha)	Well Pads (ha)	Total Disturbed area (ha)	Total Watershed Area (ha)	Percentage of Watershed Disturbed
M2	49.4	24.7	13.2	34.0	14.0	1.6	12.3	149.2	2881	5.18%
M3	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.3	1966	0.02%
Mitchell Lake Total	49.4	25.0	13.2	34.0	14.0	1.6	12.3	149.6	14946	1.00%
Mooswa Creek Total	49.4	25.0	13.2	34.0	14.0	1.6	12.3	149.6	16528	0.90%
Bluet Lake	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1223	0.00%
G7	1.8	4.5	0.0	3.6	1.2	0.0	4.9	16.0	191	8.34%
G8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	178	0.00%
G9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	253	0.00%
Garnier Lake Total	5.4	4.5	0.0	3.6	4.2	0.0	7.1	24.7	2838	0.87%
G2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2437	0.00%
G4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4553	0.00%
G5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	412	0.00%
Garnier Creek Total	5.4	4.5	0.0	3.6	4.2	0.0	7.1	24.7	12195	0.20%
ML5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2575	0.00%
Muriel Lake Total	5.4	4.5	0.0	3.6	4.2	0.0	7.1	24.7	45598	0.05%
Reita Lake Total	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7397	0.00%
Middle Creek Total	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6116	0.00%
Grand Total[1]	54.8	29.5	13.2	37.5	18.2	1.6	19.4	174.3	75639	0.23%

[1] The Total may not equal the sum of areas in all watersheds due to rounding.

Access Corridors

Access corridors have been developed to provide road access and pipeline rights-of-way between the various components of the developments. A total of 54.8 ha of access corridor area have been constructed, with 49.4 ha in Watershed M2, 1.8 ha in Watershed G7 and 3.6 ha in direct drainage to Garnier Lakes. The runoff coefficient from the gravel road surfaces within the access corridors is expected to be about of 0.60 while the remaining surfaces within the access roads are non-forested vegetation with a runoff coefficient of about 0.10. It is estimated that the combined effect of these areas have an effective runoff coefficient of about 0.30.

Borrow Pits

Borrow pits are used to supply construction material. The total disturbance area for approved borrow pits is 29.5 ha. Water collected in the borrow pits either evaporates or seeps into the ground. No surface runoff is generated from these areas.

Camps

There are three camps associated with Phase 1; a construction camp, an operator's camp and a supervisor's camp. The total area of the camps is 13.2 ha which is entirely located in Watershed M2. The camp areas consist of buildings on a porous gravel subgrade over compacted fill. The runoff coefficient for these areas is believed to be about 0.60. This is substantially higher than the natural runoff coefficient of 0.07. 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 camp contributes to an increase in runoff.

Central Processing Facility (CPF)

The CPF site will occupy an area of 37.5 ha and will be located within Watersheds M2 and G7. The runoff from the CPF site is collected and stored in a storm water pond, and discharged into the natural environment only after meeting water quality guidelines. The effective runoff coefficient for this area is expected to be similar to the natural runoff coefficient even though the surface is similar to that of the camps because the water is detained in a storage pond. When runoff is discharged into the natural environment, it leaves the site well after the natural runoff would have and is not discharged directly into a stream channel; therefore, much of the water will be lost to evapotranspiration and infiltration rather than reaching the stream network directly.

Soil Storage Areas

Soil storage areas are located adjacent to disturbed areas to store soil for future reclamation of these areas). The total area used for soil storage is 18.2 ha with 14.0 ha located in watershed M2, 1.2 ha in Watershed G7 and 3.0 ha in direct drainage to Garnier Lake. The vegetated slopes of the soil surfaces are steeper than the undisturbed areas so the runoff coefficient for the soil storage areas is expected to be about 0.40.

Disposal Wells

The total disturbed area for disposal wells is 1.6 ha located in watershed M2. The areas for the disposal wells have large vegetation cleared but no ground disturbance so the runoff coefficient is expected to be similar to that of surrounding non-forested landscape, about 0.10.

Well Pads

Most of the well pad area is located in Watershed M2 but some area is located in Watershed G7 and direct drainage to Garnier Lakes. The total area of the well pads is 19.4 ha.

The surface runoff from the well pads is collected within perimeter berms and stored in interior ditches. Exterior perimeter ditches direct natural runoff around the well pads. Surface runoff from the well pads is collected within perimeter berms and stored in interior ditches. Exterior perimeter ditches direct natural runoff around the well pads. Surface runoff from the well pads either evaporates or is discharged after it has been determined to meet water quality guidelines. This water is not discharged directly into the stream network but is discharged into the natural landscape. Little of this discharged water reaches the stream network as surface runoff; therefore, the effective runoff coefficient for this area is expected to be similar to the natural runoff coefficient.

5.2.2 *Stream Disturbances*

The footprint of the existing and approved components of the Lindbergh SAGD Project does not cross streams with defined channels or mapped drainages. The existing public road network, however, crosses a number of streams and drainages. The drainage at these crossings is typically maintained with culverts but there are a few small bridges over the larger creeks such as Garnier Creek and Mooswa Creek.

5.3 Hydrologic Impacts from Baseline Case

Existing and approved development in the LSA may affect the hydrology as defined by the regional analysis presented in Section 4. The effects of this development on the hydrology VECs defined in Section 3.3 are evaluated in the following sections.

5.3.1 *Runoff Volumes and Streamflows*

Existing and approved surface disturbances can cause changes to surface runoff characteristics of the natural environment. Specifically, changes in surface drainage patterns and changes in the runoff characteristics can affect the runoff volumes, peak flow rates, and timing of peak flows in the local streams.

There are no significant changes in the surface drainage patterns due to existing and approved disturbances. Drainage patterns are maintained by providing culverts at appropriate locations.

The effect of existing and approved disturbances on runoff volumes in each individual watershed depends on the proportions of the watershed that were disturbed for development which will tend to increase both runoff volumes and flood peaks due to the reduction in vegetation and the addition of less permeable surfaces.

Changes in runoff volumes were estimated assuming a worst case condition represented by estimated runoff coefficients for each disturbance type applied for all runoff events. These changes in runoff volumes are summarized in Table 16.

According to the runoff coefficient analysis, the greatest change in runoff volume occurs in Watershed M2, which is estimated to have an increase in runoff volume of about 10.6% due to the development in the watershed. The change in runoff volume in Mooswa Creek is about 1.8% while in Muriel Lake it is only 0.1%. There is no change in runoff volume expected in the Reita Lake or Middle Creek watersheds.

HSPF modeling was used to perform a more detailed process-based assessment of the hydrologic effects of existing and approved disturbances. The HSPF model was modified to represent watershed alterations due to these disturbances. For most types of disturbances, 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 for cleared-but-vegetated areas such as pipelines and disposal well sites. An additional 75% reduction in soil storage capacity was assumed to represent the effects of soil compaction for soil-compacted roads and gravel pads.

HSPF simulations were carried out for all local watersheds and changes to runoff volumes, peak flows and minimum flows were assessed. The results of these assessments are summarized in Table 16.

The effects on runoff volumes were greatest for Watershed M2 with an overall average increase of 5.4%. The change in magnitude in 2-year peak flow was also greatest in Watershed M2, with a predicted increase of 6.2%. There were no perceptible changes in the timing of peak flows. Changes in magnitude of summer minimum flow rates ranged between -1.6% and +1.2%.

Table 16 Summary of baseline changes in runoff volumes due to existing and approved disturbances from Lindbergh Project

Watershed	Total Drainage Area (ha)	Total Disturbed Area (ha)	Worst Case Change in Runoff Volume (%)	Average Change in Runoff Volume (%)	Average Change in 2-Year Peak Flow (%)	Average Change in 2-Year Minimum Flow (%)
M2	2,881	149.2	10.6%	5.4%	6.19%	-1.60%
M3	1,966	0.3	0.0%	0.0%	0.00%	-0.98%
Mitchell Lake Total	14,946	149.6	2.0%	1.0%	1.15%	-0.56%
Mooswa Creek Total	16,528	149.6	1.8%	1.0%	1.41%	0.99%
Bluet Lake	1,223	0.0	0.0%	0.0%	-0.02%	-0.06%
G7	191	16.0	3.7%	4.4%	4.20%	0.00%
G8	178	0.0	0.0%	0.0%	0.00%	0.00%
G9	253	0.0	0.0%	0.0%	0.00%	0.79%
Garnier Lake Total	2,838	24.7	1.2%	1.8%	0.00%	0.00%
G2	2,437	0.0	0.0%	0.0%	0.00%	-1.23%
G4	4,553	0.0	0.0%	0.0%	0.00%	0.00%
G5	412	0.0	0.0%	0.0%	0.00%	1.17%
Garnier Creek Total	12,195	24.7	0.3%	0.1%	0.02%	0.65%
ML5	2,575	0.0	0.0%	0.0%	0.00%	-0.27%
Muriel Lake Total	45,598	24.7	0.1%	-0.2%	-0.11%	0.00%
Reita Lake Total	7,397	0.0	0.0%	0.0%	0.00%	0.01%
Middle Creek Total	6,116	0.0	0.0%	0.0%	0.00%	-0.27%

5.3.2 *WATER LEVELS AND SURFACE AREAS*

Annual peak water levels and surface areas in the streams are not anticipated to be affected by existing and approved disturbances since changes to snowmelt-dominated annual peak flows are expected to be small. Stream minimum water levels and surface areas may be slightly higher due to increased minimum flows; however, zero flows will still occur in most of these small watersheds.

Levels in small waterbodies created by beaver dams are controlled by the height of the beaver dams rather than by inflow volumes therefore small changes in streamflows are not expected to affect the water levels and surface areas of these features.

The water levels in the permanent lakes in the LSA are expected to increase slightly due to the increased runoff volumes into these water bodies. The average annual increases in water level in the five major lakes in the LSA are summarized in Table 17. When the lakes are too low to produce outflows, such as in Bluet, Muriel and Reita Lakes, the increases in water level will be cumulative until the water levels rise to the level of the outlets. When the lakes are full enough to produce outflow, such as in Mitchell and Garnier Lakes, there will be very little net increase in water level due to the increase in runoff volume because the additional water volume will flow out of the lake.

Table 17 Summary of baseline changes to lake levels due to changes in runoff volume from existing and approved disturbances

Lake	Ratio of Contributing Area to Lake Area	Annual Change in Elevation due to Worst Case Change in Runoff Volume (mm)	Annual Change in Elevation due to Average Change in Runoff Volume (mm)
Mitchell	252.4	6.0	1.4
Bluet	7.2	0.0	0.0
Garnier	13.0	4.7	2.0
Muriel	5.5	0.2	0.03
Reita	11.5	0.0	0.00

5.3.3 *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 existing and approved disturbances are very small in most cases and would not have a perceptible effect on sediment concentrations.

6 Application Case

This section describes the assessment of potential hydrologic impacts of the Project in addition to the Baseline Case on the local hydrology. The Project footprint is described, the potential effects identified and their severity assessed.

6.1 Project Footprint

The Project will produce surface disturbances of approximately 792.3 ha in addition to the 174.3 ha of the existing and approved phases for a total disturbance area of 966.6 ha. Figure 19 shows the layout of the Project.

6.1.1 *Surface Disturbances*

Surface disturbances for the Project are similar to the disturbances associated with the Pilot and Phase 1, as discussed in the Section 5.1. Table 18 summarizes the extent of the spatial disturbances within individual watersheds. These disturbances include the areas presented in Table 14 for the existing and approved disturbances. The greatest percentage area of disturbance due to the Project will be 27.9% in Watershed G7. The percentage disturbance is large because the watershed is quite small.

Table 18 Summary of application case disturbance areas within LSA

Watershed	Access Corridors (ha)	Borrow Pits (ha)	Camps (ha)	CPF (ha)	Soil Storage (ha)	Disposal Wells (ha)	Well Pads (ha)	Total Disturbed area (ha)	Total Watershed Area (ha)	Percentage of Watershed Disturbed
M2	95.2	64.9	13.2	31.8	38.4	1.6	45.9	290.9	2,881	10.10%
M3	64.2	7.8	0.0	0.0	26.7	0.0	61.8	160.5	1,966	8.16%
Mitchell Lake Total	161.5	78.0	13.2	31.8	73.5	1.6	120.0	479.5	14,946	3.21%
Mooswa Cr. Total	161.5	78.0	13.2	31.8	73.5	1.6	120.0	479.5	16,528	2.90%
Bluet Lake	15.3	0.0	0.0	0.0	0.0	0.0	0.0	15.3	1,223	1.25%
G7	17.8	3.8	0.0	3.6	7.6	0.0	20.6	53.4	191	27.90%
G8	4.2	0.8	0.0	0.0	3.0	0.0	8.5	16.6	178	9.32%
G9	4.8	0.0	0.0	0.0	0.0	0.0	0.0	4.8	253	1.89%
Garnier Lake Total	55.4	4.6	0.0	3.6	15.2	0.0	37.3	116.1	2,838	4.09%
G2	28.0	9.1	0.0	0.0	10.1	0.0	12.9	60.0	2,437	2.46%
G4	43.7	18.4	0.0	0.0	14.3	0.0	6.7	83.1	4,553	1.83%
G5	10.1	2.3	0.0	0.0	7.6	0.0	2.7	22.8	412	5.52%
Garnier Cr. Total	161.3	38.4	0.0	3.6	57.6	0.0	69.3	330.1	12,195	2.71%
ML5	23.2	0.0	0.0	0.0	13.0	0.0	26.6	62.7	2,575	2.44%
Muriel Lake Total	194.3	44.8	0.0	3.6	74.5	0.0	107.4	424.6	45,598	0.93%
Reita Lake Total	16.6	9.1	0.0	0.0	10.7	0.0	19.9	56.3	7,397	0.76%
Middle Creek Total	6.2	0.0	0.0	0.0	0.0	0.0	0.0	6.2	6,116	0.10%
Grand Total	378.6	131.9	13.2	35.4	158.7	1.6	247.3	966.6	75,639	1.28%

[1] The Total may not equal the sum of areas in all watersheds due to rounding. As well, some disturbance areas which overlap with the existing footprint will be reassigned to alternate uses so totals for individual disturbance types may not match those presented in Table 14.

6.1.2 *STREAM DISTURBANCES*

In general, the Project footprint was developed with the following setbacks from streams and drainages:

- waterbodies with fish habitat – 100 m;
- defined channels with no fish habitat – 50 m; and
- drainages without defined channels – 0 m.

The Project footprint will cross mapped channels and drainages at 19 locations. All but one of the crossing locations are for access corridors.

The locations of these crossings are shown in Figure 20 and summarized in Table 19. The crossings were inspected by low-level aerial reconnaissance and on the ground. Most of these locations cross mapped drainages; however, there are six locations where the footprint crosses ephemeral channels and one location where it crosses a small permanent channel. The drainage pathways at all of these locations can be maintained with adequately sized culverts. These crossings are not navigable.

Table 19 Summary of crossing locations

Location	Disturbance Type	Bankfull width (m)	Bankfull depth (m)	Description
Crossing 1	Access corridor	3.0	0.5	standing water
Crossing 2	Access corridor	0.6	0.15	small dry channel
Crossing 3	Access corridor			no defined channel
Crossing 4	Access corridor			no defined channel
Crossing 5	Access corridor			no defined channel
Crossing 6	Access corridor	0.4	0.2	small dry channel
Crossing 7	Access corridor			no defined channel
Crossing 8	Access corridor			dry drainage
Crossing 9	Access corridor			dry drainage
Crossing 10	Access corridor			dry drainage
Crossing 11	Access corridor			no defined channel
Crossing 12	Access corridor	0.4	0.2	small dry channel
Crossing 13	Access corridor	1.2	0.3	small dry channel
Crossing 14	Well pad	0.5	0.25	drainage/intermittent dry channel
Crossing 15	Access corridor	1.2	0.4	small dry channel
Crossing 16	Access corridor			no defined channel
Crossing 17	Access corridor			no defined channel
Crossing 18	Access corridor			wetland
Crossing 19	Access corridor			wetland

6.1.3 *WATER SUPPLY*

Water from the North Saskatchewan River will be used to supply water for the Project. This water will be obtained from an existing intake under an existing water licence. The Project will be designed to recycle water so there will only be a small increase in water use relative to current usage. The existing water license allows a maximum rate of 4,404 m^3/day to be diverted from the North Saskatchewan River.

6.2 Potential Hydrologic Impacts

The Project may affect the hydrology as defined by the regional analysis presented in Section 4. The effects of the Project on the hydrology VECs defined in Section 3.3 are evaluated in the following sections. A summary of the Project effects on these VECs is presented in Table 22 at the end of this section.

6.2.1 *Runoff Volumes and Streamflows*

Surface disturbances from the Project developments can cause changes to surface runoff characteristics of the natural environment. Changes in surface drainage patterns or changes in the runoff coefficient may affect the runoff volumes, flow rates, and timing of peak flows in the local streams. If these changes are significant, they may in turn produce changes in the channel regime of the local streams.

There will be no significant changes in the surface drainage patterns due to the Project. Existing drainage paths will be maintained. As shown in Figure 20 appropriate drainage will be provided at crossings of identified drainages and there will be no transfer of water from one watershed to another along ditches and road right-of-ways.

The effect of the Project on runoff volumes in each individual watershed depends on the proportions of the watershed area that are used for the CPF, borrow pits, soil storage, access corridors and well pads. The borrow pits will reduce runoff volumes and flood peaks because water will not be released from these areas. Soil storage and access corridors will increase both runoff volumes and flood peaks due to the reduction in vegetation and the addition of less permeable surfaces. The CPF and well pads will tend to reduce the flood peaks because of the detention of runoff.

Changes in runoff volumes when the Project is fully developed were estimated assuming a worst case condition that the estimated runoff coefficients for each disturbance type are applicable for all runoff events. These changes in runoff volumes are summarized Table 20. The development of the Project would generally result in increased runoff volumes. The greatest worst case change in runoff volume will occur in Watershed G7 with estimated increases of 47%; however, the worst case increase for the major basins would be about 5% or less.

Table 20 Summary of changes in runoff volumes due to application case disturbances

Watershed	Total Drainage Area (ha)	Total Disturbed Area (ha)	Worst Case Change in Runoff Volume (%)	Average Change in Runoff Volume (%)	Average Change in 2-Year Peak Flow (%)	Average Change in 2-Year Minimum Flow (%)
M2	2,881	290.9	18.4%	6.1%	7.06%	-0.96%
M3	1,966	160.5	16.7%	3.0%	1.22%	0.00%
Mitchell Lake Total	14,946	479.5	6.0%	1.6%	1.77%	1.20%
Mooswa Creek Total	16,528	479.5	5.4%	1.5%	2.19%	2.29%
Bluet Lake	1,223	15.3	4.1%	5.8%	0.00%	0.00%
G7	191	53.4	47.3%	5.6%	2.67%	0.00%
G8	178	16.6	15.4%	1.4%	0.83%	1.87%
G9	253	4.8	6.2%	2.4%	2.59%	8.09%
Garnier Lake Total	2,838	116.1	8.8%	4.9%	0.00%	0.00%
G2	2,437	60.0	5.4%	1.2%	1.41%	3.07%
G4	4,553	83.1	4.2%	1.4%	1.92%	7.69%
G5	412	22.8	16.2%	4.4%	4.59%	-2.86%
Garnier Creek Total	12,195	330.1	6.3%	1.7%	1.97%	9.43%
ML5	2,575	62.7	5.3%	1.4%	1.09%	0.00%
Muriel Lake Total	45,598	424.6	2.1%	0.5%	0.58%	0.00%
Reita Lake Total	7,397	56.3	1.3%	0.1%	0.00%	1.13%
Middle Creek Total	6,116	6.2	0.3%	0.1%	0.14%	-0.27%

HSPF modeling was used to provide a more detailed assessment the hydrologic effects of the Application Case. Simulations for the Application Case incorporate the modifications for the Project disturbances in addition to the Baseline Case disturbances, assuming a maximum impact scenario with full development of all Project phases before any reclamation occurs.

Simulations were carried out for all local watersheds. Changes to runoff volumes, peak flows and minimum flows are summarized in Table 20. The effects for the Application Case on runoff volumes are greatest for Watershed M2; however, the largest increase for the major basins would be less than 2%. The largest increase in magnitude in 2-year peak flow due to the Application Case is 7.1% in Watershed M2. There are no perceptible changes in the timing of peak flows, based on the simulation results. Changes in magnitude of summer minimum flow rates ranged between -2.9% and +9.4%.

6.2.2 WATER LEVELS AND SURFACE AREAS

Annual peak water levels and surface areas in the streams may change slightly due to changes in annual peak flow. These changes will be imperceptible compared to natural variability. Minimum water levels and surface areas may be slightly higher due to increased minimum flows; however, zero flows will still occur in most of these small watersheds.

Levels in small waterbodies created by beaver dams are controlled by the height of the beaver dams rather than by inflow volumes therefore small changes in streamflows are not expected to affect the water levels and surface areas of these features.

The water levels in the permanent lakes in the LSA are expected to increase slightly due to the increased runoff volumes into these water bodies. The average annual increases in water level in the five major lakes in the LSA are summarized in Table 21. When the lakes are full enough to produce outflow, such as in Mitchell and Garnier Lakes, there will be very little net increase in water level due to the increase in runoff volume because the additional water volume will flow out of the lake each year. When the lakes are too low to produce outflows, such as in Bluet, Muriel and Reita Lakes, the increases in water level will be cumulative until the water levels rise to the level of the outlets. These cumulative increases will be quite small, less than 0.1 m over a 30 year period.

Table 21 Summary of changes to lake levels due to changes in runoff volume for application case disturbances

Lake	Ratio of Contributing Area to Lake Area	Annual Change in Elevation due to Worst Case Change in Runoff Volume (mm)	Annual Change in Elevation due to Average Change in Runoff Volume (mm)
Mitchell	252.4	18	2.9
Bluet	7.2	8.9	0.3
Garnier	13.0	34.3	5.6
Muriel	5.5	3.5	0.82
Reita	11.5	4.5	0.02

6.2.3 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 most of the streams in the LSA are not expected to increase due to changes in the surface runoff characteristics because, in most cases, the runoff increase is not significant. However, some small watersheds, such as M2 and G7, may have increases in runoff volumes and peak flows of greater than 5% on average due to the Project disturbances and these increases have the potential to cause erosion and increased sediment concentrations in the channels downstream of the disturbances.

Table 22 Summary of impact rating on surface water hydrology valued environmental components (VECs)

VEC	Nature of Potential Impact or Effect	Mitigation/ Protection Plan	Type of Impact or Effect	Geographical Extent	Duration	Frequency	Reversibility	Magnitude	Project Contribution	Confidence Rating	Probability of Occurrence	Impact Rating
1. Runoff Volumes and Streamflows												
	Changes to runoff volume, peak flows, and low flows	1) Maintain drainage around disturbed areas 2) Reclaim surface disturbances once no longer required 3) Discharge runoff into natural environment away from streams in accordance with EPEA Approval	Application	Local	Long-term	Periodic	Reversible in long term	Low	Negative	High	High	Low
			Cumulative	Local	Long-term	Periodic	Reversible in long term	Low	Negative	High	High	Low
2. Water Levels and Surface Areas												
	Changes in water levels and surface area due to streamflow changes	1) Maintain drainage around disturbed areas 2) Reclaim surface disturbances once no longer required 3) Discharge runoff into natural environment away from streams in accordance with EPEA Approval	Application	Local	Long-term	Periodic	Reversible in long term	Low	Positive	High	High	Low
			Cumulative	Local	Long-term	Periodic	Reversible in long term	Low	Positive	High	High	Low
3. Channel Morphology and Sediment Concentration												
	Changes in channel shape and sediment concentration due to flow changes and crossing construction	1) Maintain drainage around disturbed areas 2) Reclaim surface disturbances once no longer required 3) Design and construct crossings to minimize impacts	Application	Local	Long-term	Periodic	Reversible in long term	Low	Negative	High	Low	Low
			Cumulative	Local	Long-term	Periodic	Reversible in long term	Low	Negative	High	Low	Low

7 Planned Development Case

There are no other planned developments within the hydrology RSA.

8 Mitigation and Monitoring

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

8.1 Mitigation

The following practices and procedures will be carried out to reduce the effects of the development on the surface water hydrology:

- water will not be transferred from one watershed to another;
- appropriate drainage culverts will be provided at crossings of any identifiable drainage courses to maintain existing drainage patterns;
- runoff from well pads will not be discharged directly to drainages;
- run-on from upstream of well pads and plant site will be directed around the disturbances and back into their original pathways;
- surface disturbances will be reclaimed after they are no longer required;
- disturbances will be kept away from streams with defined channels;
- sediment control will be utilized for construction activity where runoff may potentially flow directly into drainages; and
- erosion control measures will be implemented at locations where channel erosion is observed to occur due to increased stream flows. Implementation of erosion control measures in anticipation of potential erosion is not recommended because it is more likely that the channels will remain stable.

The drainage pathways around the Project components shown in Figure 20 were developed by applying the above practices and procedures.

8.2 MONITORING

Impacts on runoff volumes and streamflows will be difficult to distinguish from natural variability so direct monitoring of streamflows is not necessary. However, the following monitoring should be carried out to ensure that the impacts on the surface water hydrology are low:

- routine visual inspections should be carried out to ensure that the access road drainage culverts are working as intended to maintain the natural surface drainage patterns;
- downstream channels should be inspected annually for new areas of channel erosion;
- water volumes pumped from the CPF stormwater ponds into the natural environment should be recorded; and
- the volume of any runoff water used for the Project should be recorded.

9 Summary of Conclusions

A hydrologic assessment was carried out for the Lindbergh SAGD Expansion Project which evaluated physiography, climate, and streamflow characteristics in the vicinity of the Project, assessed the hydrological effects of the Project footprint, and recommended mitigation and monitoring strategies.

9.1 Baseline Case

The regional surface water hydrology for baseline development 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. Regional watersheds were mapped and drainage areas quantified.

Local water levels and streamflows were measured at the site from 2011 to 2013. Flow regimes were evaluated from the regional streamflow analysis and from the HSPF hydrologic model which was calibrated to regional data and verified with local streamflow measurements.

Existing and approved developments in the LSA were described and the effects of these developments 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 M2 with an increase of 5.4% relative to conditions established from the regional hydrology. There is no perceptible change on the timing of runoff hydrographs. Peak flows tend to be higher with increases in 2-year peak flows of up to 6.2%. Changes in magnitude of summer minimum flow rates ranged between -1.6% and +1.2%.

Water levels are expected to increase slightly in Garnier and Mitchell Lakes but these increases will be temporary due to outflow from these the lakes.

Channel morphology and sediment concentrations will not change due to existing and approved development because changes to the flow regime are small. The existing stream crossings do not appear to have caused any increases in sediment concentration or erosion.

9.2 APPLICATION CASE

The Application Case was described and the effects of the proposed development on the hydrology were quantified. The entire Project was assumed to be developed in combination with the existing development to assess the maximum effect on the hydrology. Effects relative to conditions established from the regional hydrology data were evaluated for runoff volumes and streamflows; water levels and surface areas; and channel morphology and sediment concentrations.

The effect of this development scenario on runoff volumes is expected to increase annual runoff by up to 6%. The change in magnitude in 2-year peak flow due to development may increase as much as 7% in some areas. Changes in the timing of peak flows simulated are imperceptible. Changes in magnitude of summer minimum flow rates ranged between -2.9% and +9.4%.

Water levels are expected to increase slightly in Garnier and Mitchell Lakes but these increases will be temporary due to outflow from these the lakes. These increases will be cumulative in Reita, Bluet and Muriel Lakes which are presently below the level of their outlets but the increases will be quite small, less than 0.1 m over the life of the Project.

Channel morphology and sediment concentrations are not expected to change due to the Application Case because changes to the flow regime are small. The access corridor stream crossings will be designed to minimize the disturbance to the channels so sediment inputs are not anticipated to increase.

9.3 PLANNED DEVELOPMENT CASE

The cumulative impact of projects in the hydrology RSA was considered. As there are no other activities planned in the hydrology RSA, the impact rating is low.

9.4 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 conservatively assumed in the impact assessment. Infiltration, depression storage and evapotranspiration will tend to buffer the effects of increased runoff from compacted soils. Drainage will be provided around the disturbances so that runoff patterns are maintained. In general impacts are expected to be less than what is predicted in this report because some areas will likely be reclaimed before other areas are developed so the maximum disturbed area will always be less than that of the total Project. As well, the hydrologic impacts presented in this report will be temporary as the entire Project disturbance will be after the Project is complete.

Streamflow monitoring is not required because the effects of the Project on streamflows in permanent channels will be small and indistinguishable from natural variability. However, the small channels downstream of the disturbances should be inspected annually to determine if channel erosion is occurring.

10 References

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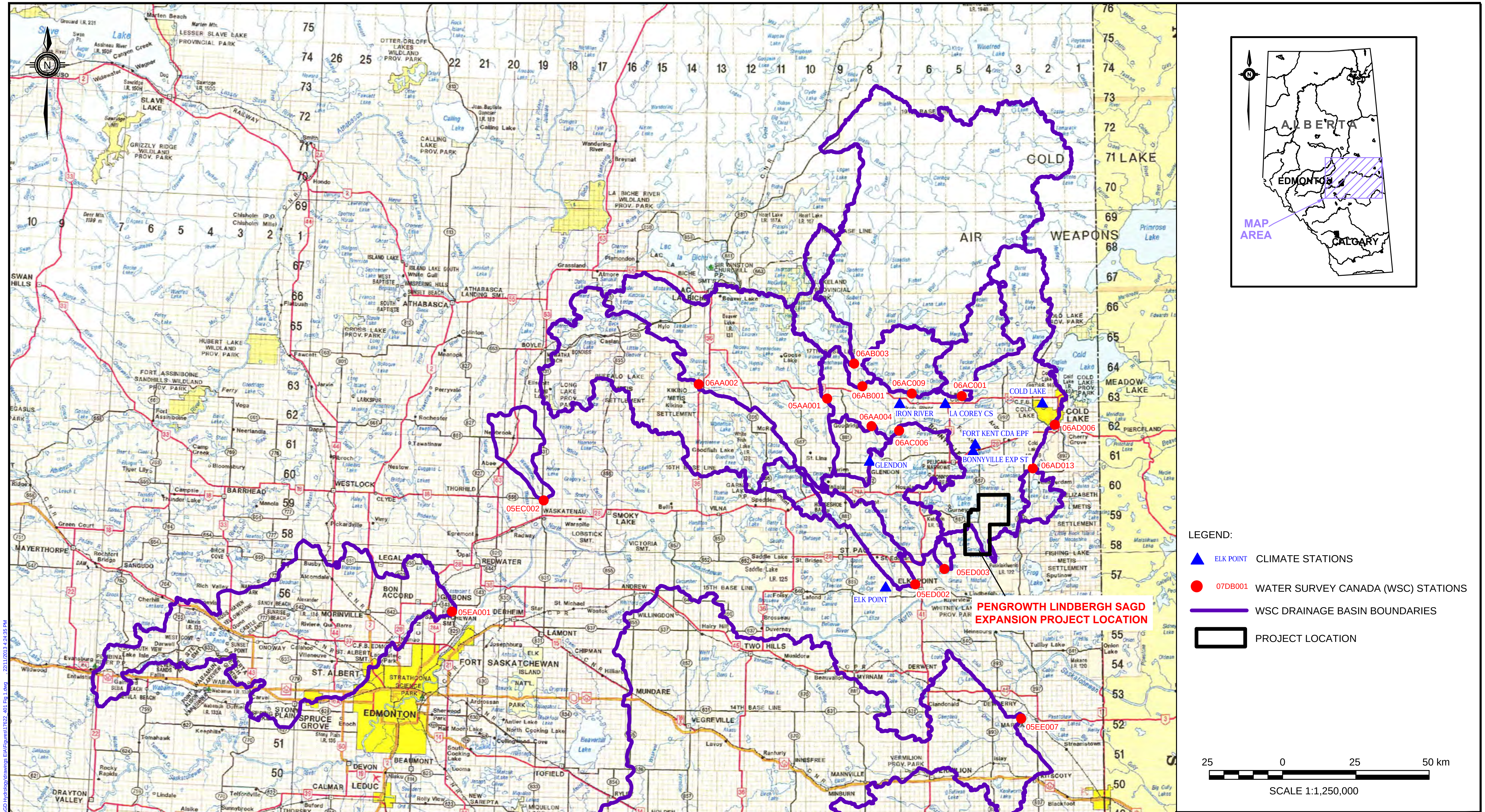

PENGROWTH ENERGY CORPORATION

LINDBERGH SAGD EXPANSION PROJECT
HYDROLOGY ASSESSMENT

PROJECT AND STATION LOCATIONS

Dwg. 7622-401	2013-11-22	Figure 1

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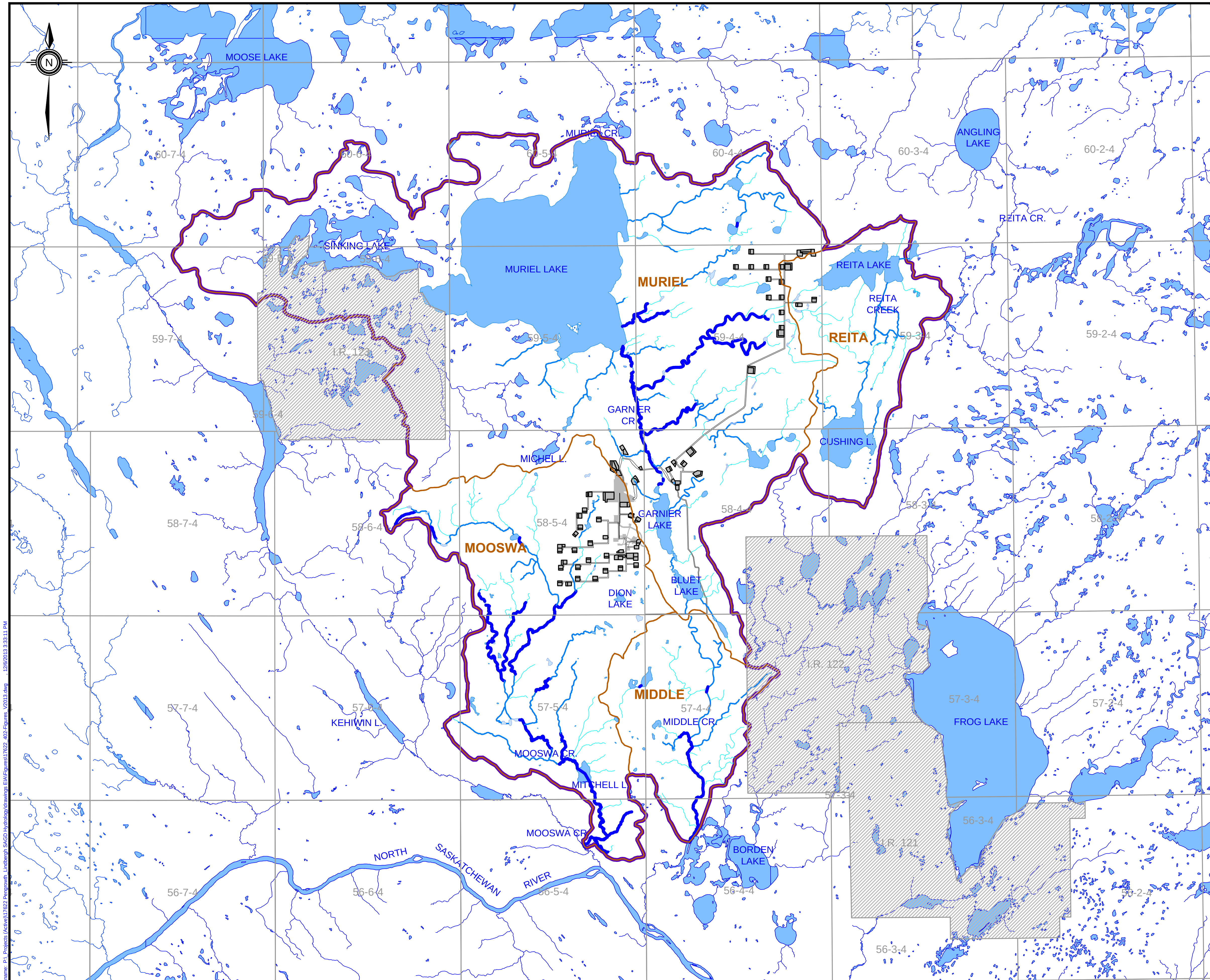

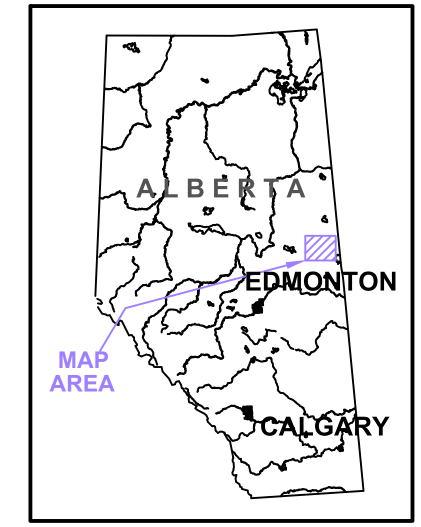

LEGEND

- REGIONAL STUDY AREA
- MAJOR WATERSHED BOUNDARIES
- STREAMS - PERMANENT
- STREAMS - EPHEMERAL
- DRAINAGE WITHOUT DEFINED CHANNELS
- LAKES & PONDS
- BEAVER POND
- ALBERTA TOWNSHIP GRID
- INDIAN RESERVE
- PROJECT FOOTPRINT

0 2 4 6 8 10 Km

SCALE 1:200,000

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LINDBERGH SAGD EXPANSION PROJECT
HYDROLOGY ASSESSMENT

REGIONAL STUDY AREA

Dwg. 7622-402	2013-12-01	**Figure 2**

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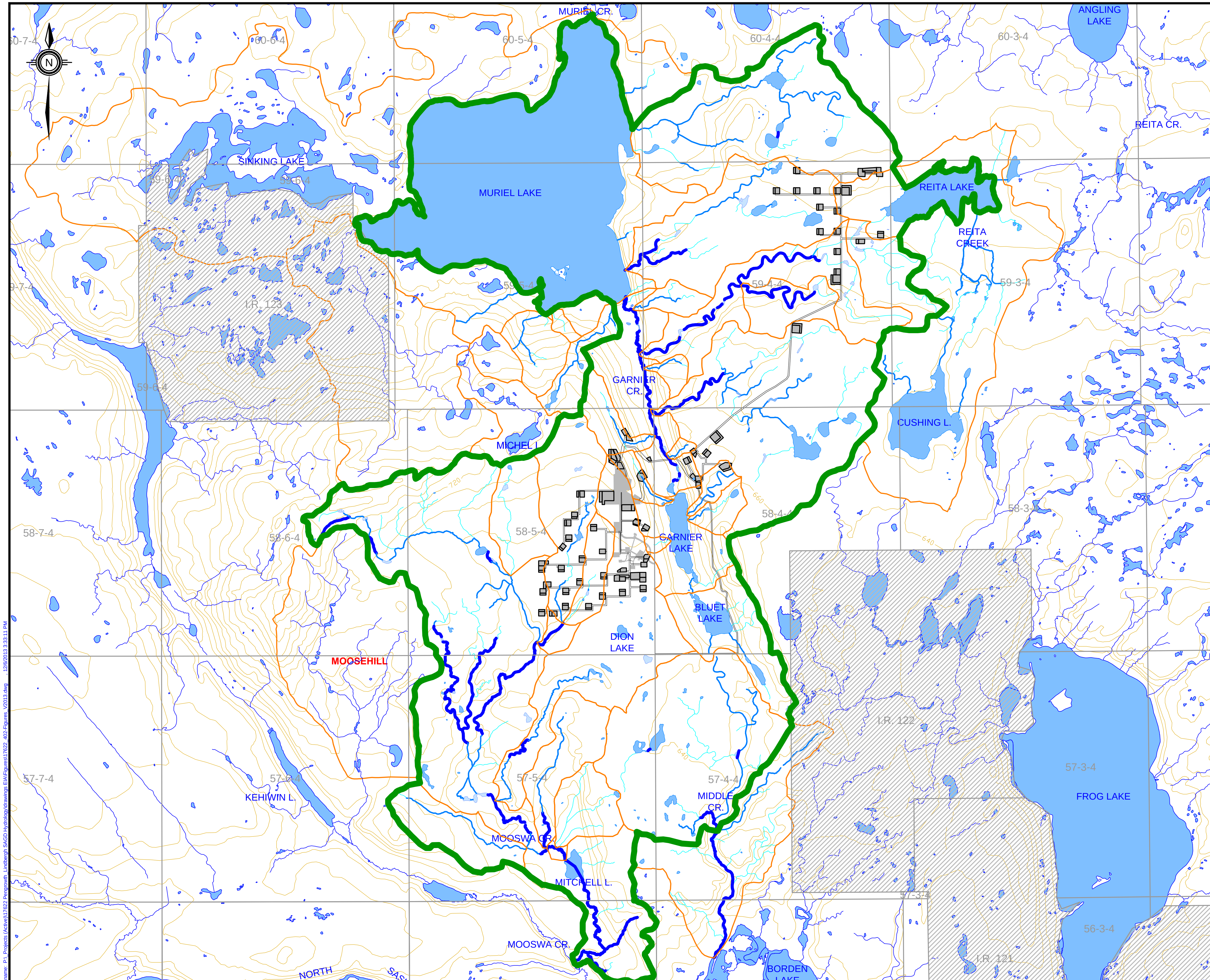

LEGEND

- LOCAL STUDY AREA
- WATERSHED BOUNDARIES
- STREAMS - PERMANENT
- STREAMS - EPHEMERAL
- DRAINAGE WITHOUT DEFINED CHANNELS
- LAKES & PONDS
- BEAVER POND
- ALBERTA TOWNSHIP GRID
- CONTOURS (20m INTERVAL)
- PROJECT FOOTPRINT

0 1.5 3 4.5 6 7.5 Km

SCALE 1:150,000

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LINDBERGH SAGD EXPANSION PROJECT
HYDROLOGY ASSESSMENT

LOCAL STUDY AREA

Dwg. 7622-402	2013-12-01	**Figure 3**

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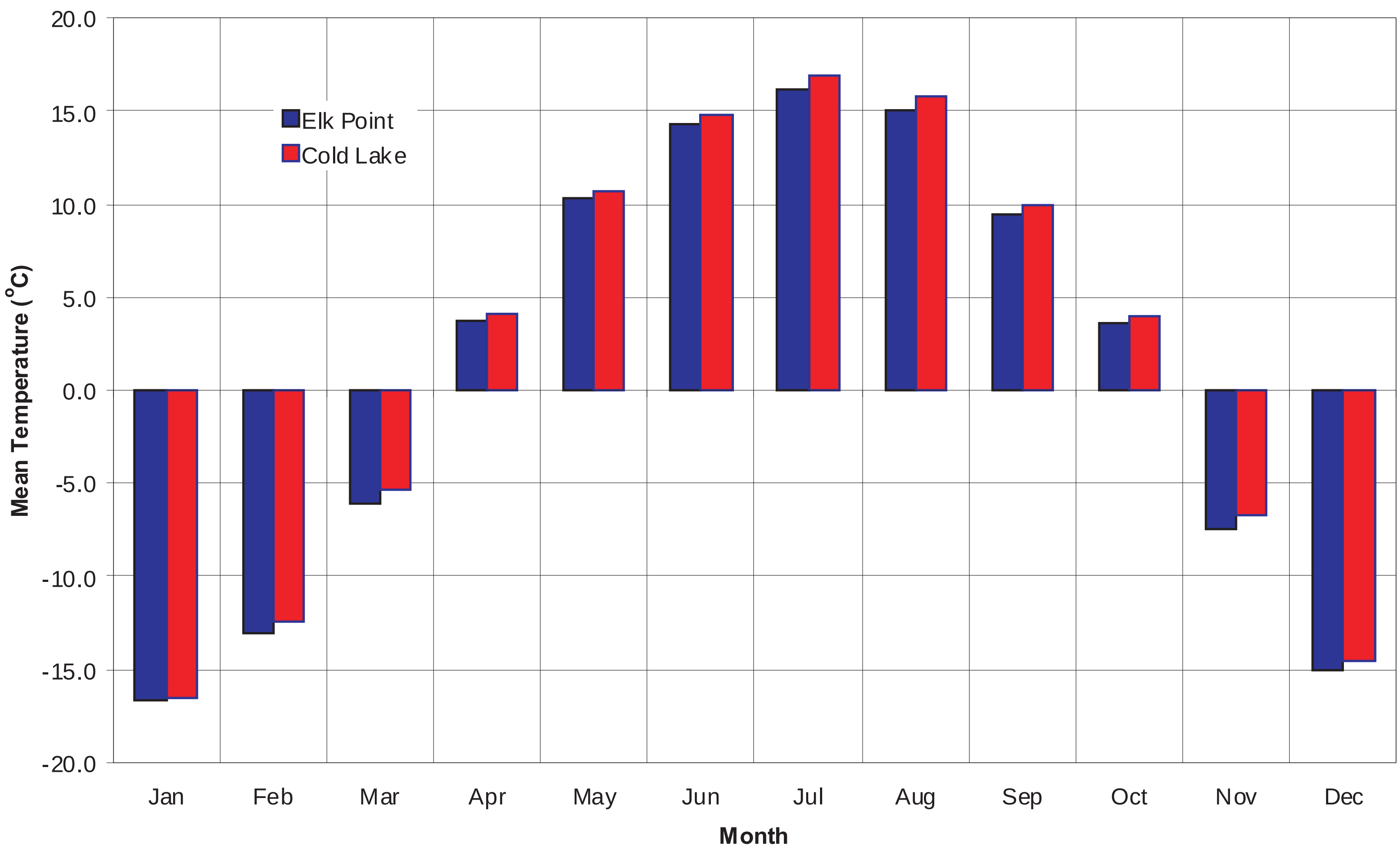
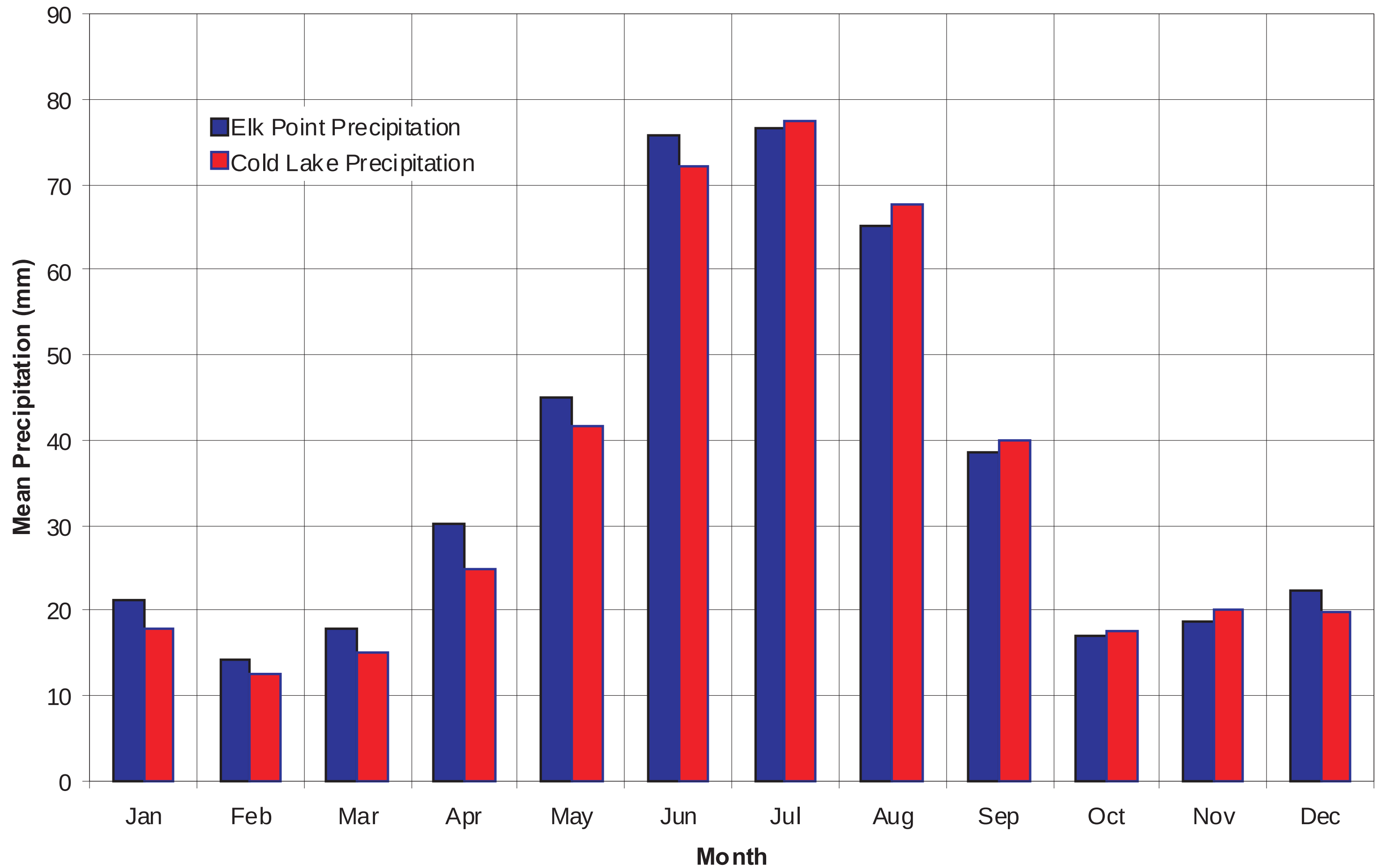


Based on climate normals from 1971-2000

PENGROWTH ENERGY CORPORATION		
LINDBERGH SAGD EXPANSION PROJECT HYDROLOGY ASSESSMENT **MONTHLY AIR TEMPERATURES**		
File 17622	2013-11-18	**Figure 4**
northwest hydraulic consultants ltd.		



Based on climate normals from 1971-2000

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LINDBERGH SAGD EXPANSION PROJECT
HYDROLOGY ASSESSMENT

MONTHLY PRECIPITATION

File 17622	2013-11-18	**Figure 5**

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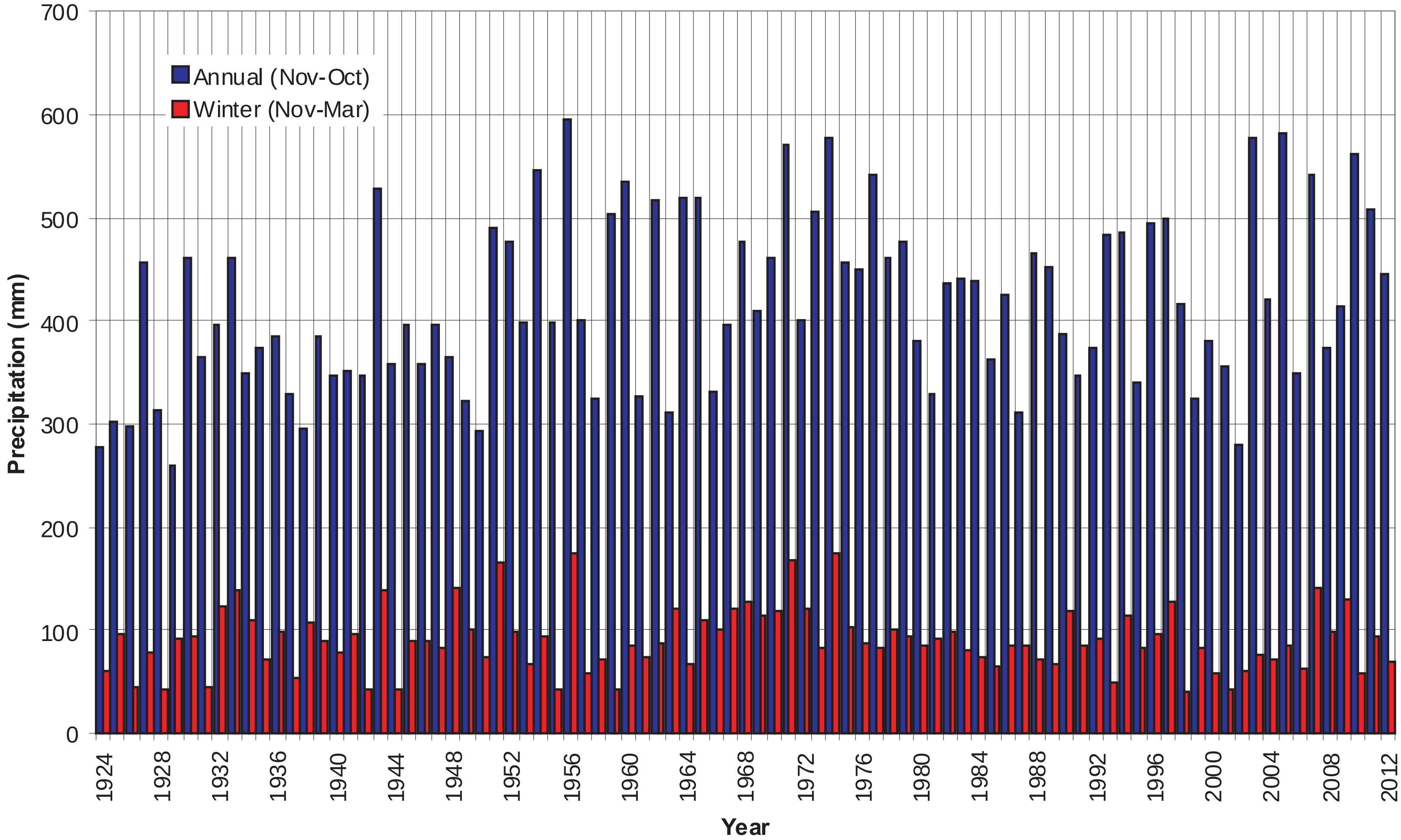

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LINDBERGH SAGD EXPANSION PROJECT
HYDROLOGY ASSESSMENT

ANNUAL PRECIPITATION AND WINTER SNOWFALL

File 17622	2013-11-18	**Figure 6**

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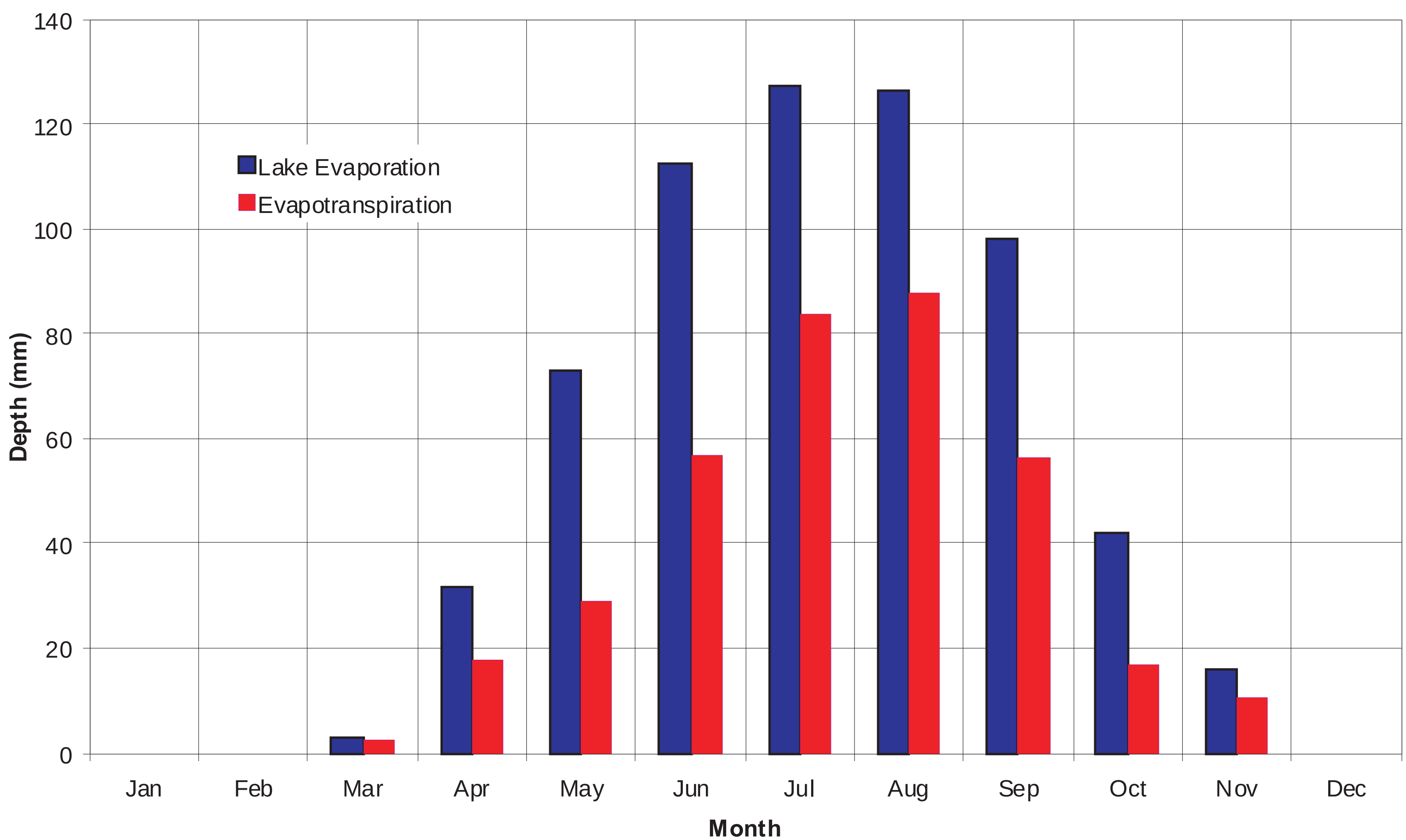

Based on climate normals from 1971-2000

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LINDBERGH SAGD EXPANSION PROJECT
HYDROLOGY ASSESSMENT

MONTHLY EVAPORATION AND EVAPOTRANSPIRATION

File 17622	2013-11-18	**Figure 7**

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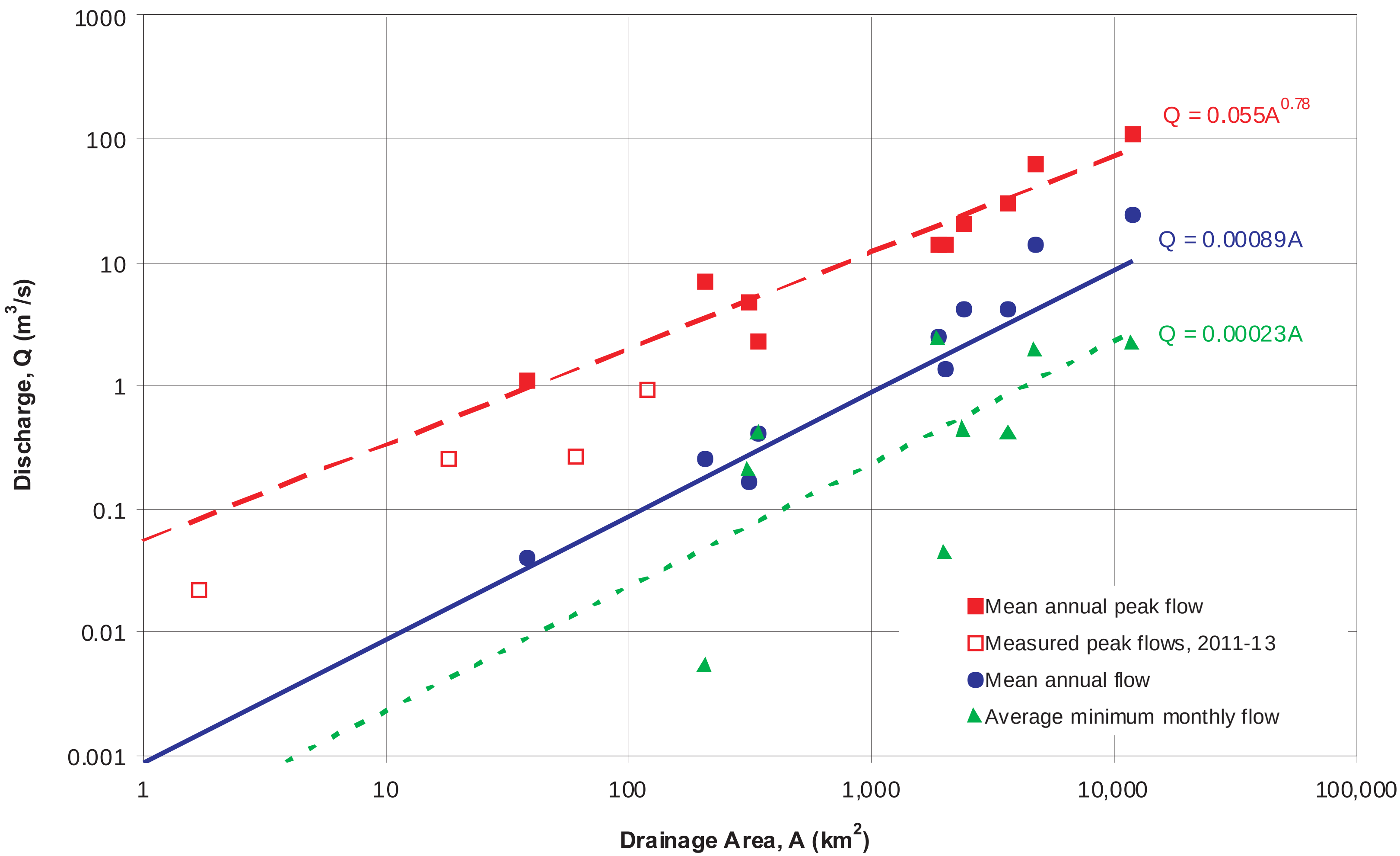
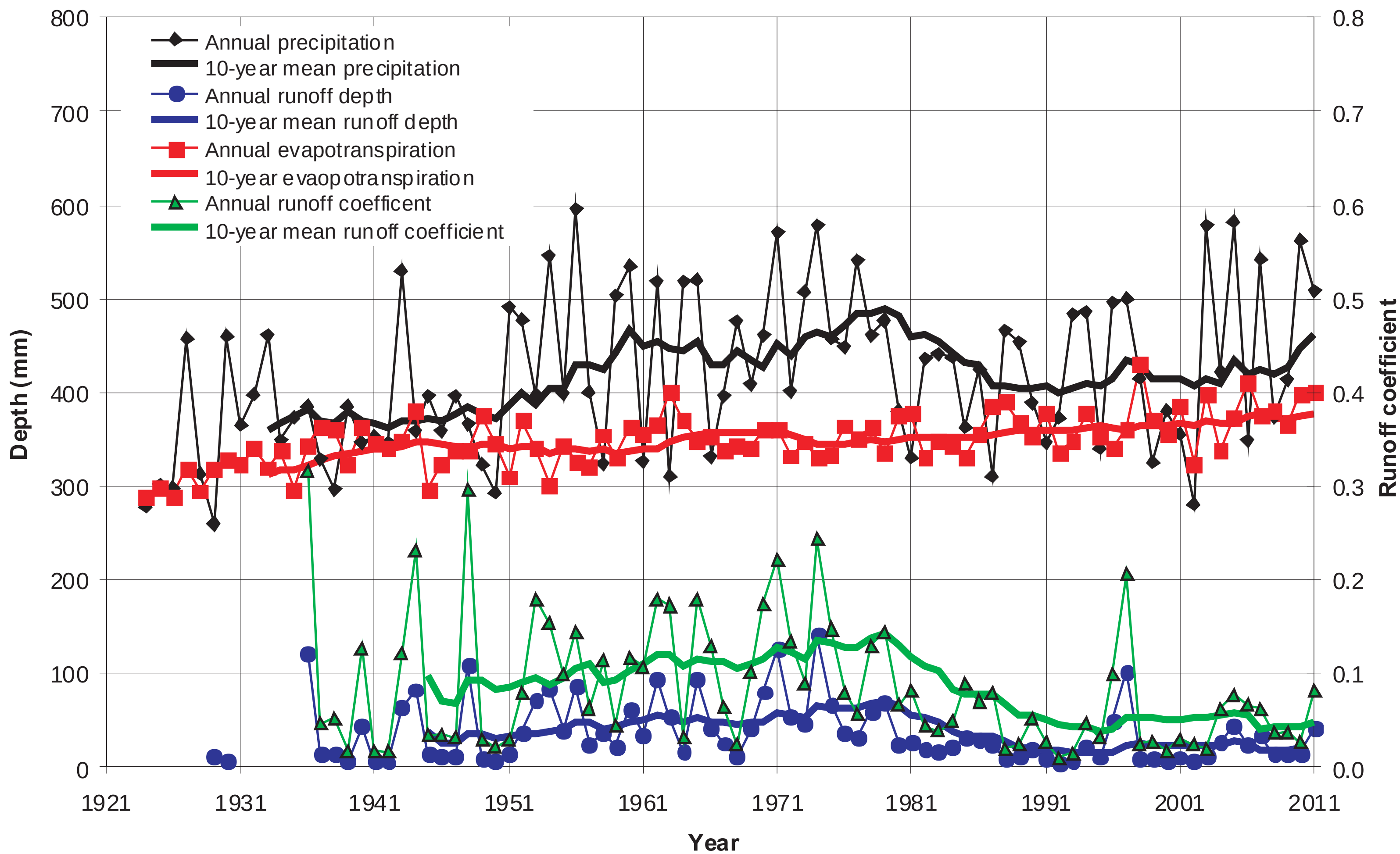


PENGROWTH ENERGY CORPORATION		
LINDBERGH SAGD EXPANSION PROJECT HYDROLOGY ASSESSMENT **VARIATION OF DISCHARGE WITH DRAINAGE AREA**		
File 17622	2013-11-18	**Figure 8**
northwest hydraulic consultants ltd.		



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LINDBERGH SAGD EXPANSION PROJECT
HYDROLOGY ASSESSMENT

COMPARISON OF ANNUAL PRECIPITATION, EVAPOTRANSPIRATION AND RUNOFF

File 17622	2013-11-18	**Figure 9**

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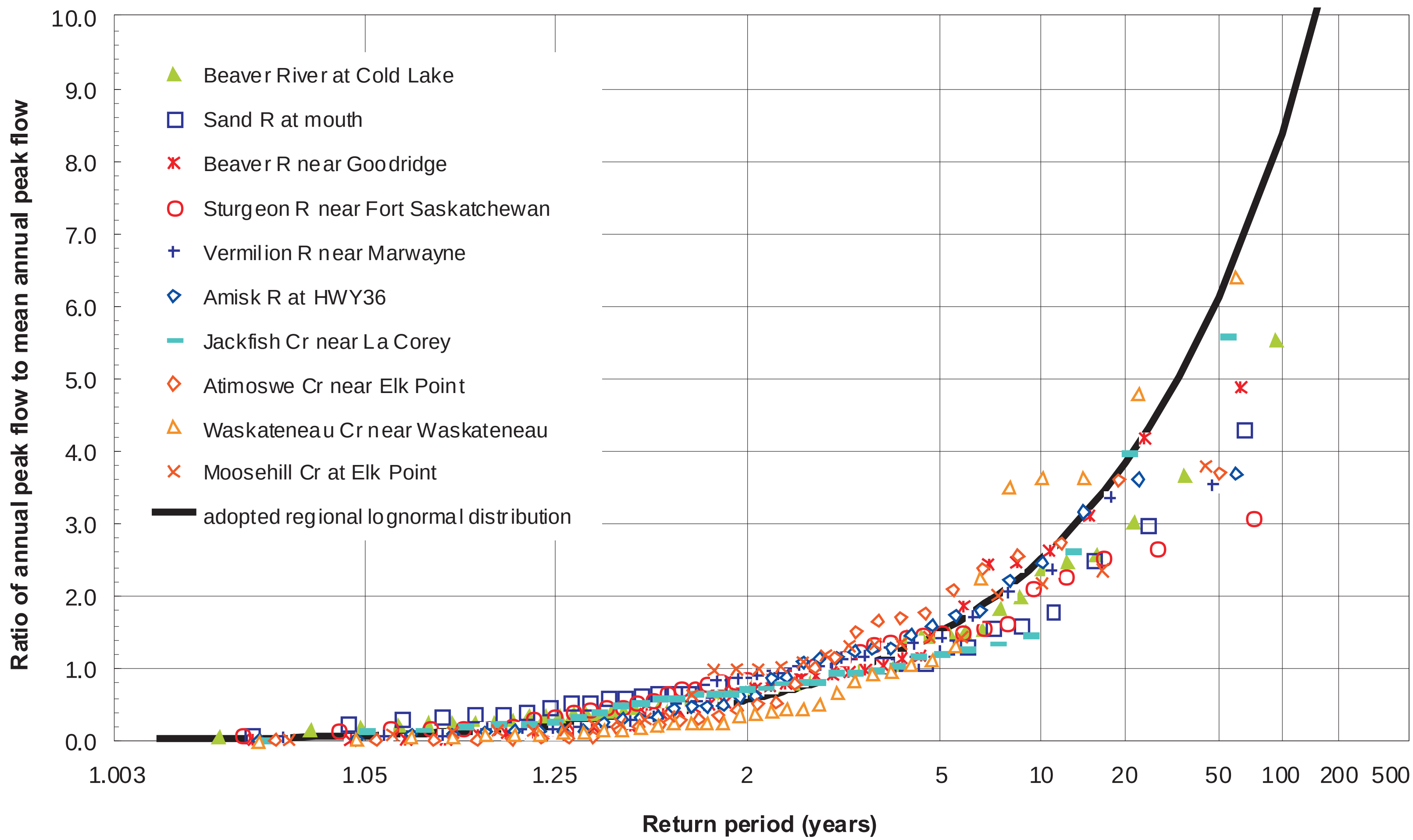

PENGROWTH ENERGY CORPORATION		
LINDBERGH SAGD EXPANSION PROJECT HYDROLOGY ASSESSMENT **REGIONAL FLOW FREQUENCY DISTRIBUTIONS**		
File 17622	2013-11-18	**Figure 10**
northwest hydraulic consultants ltd.		

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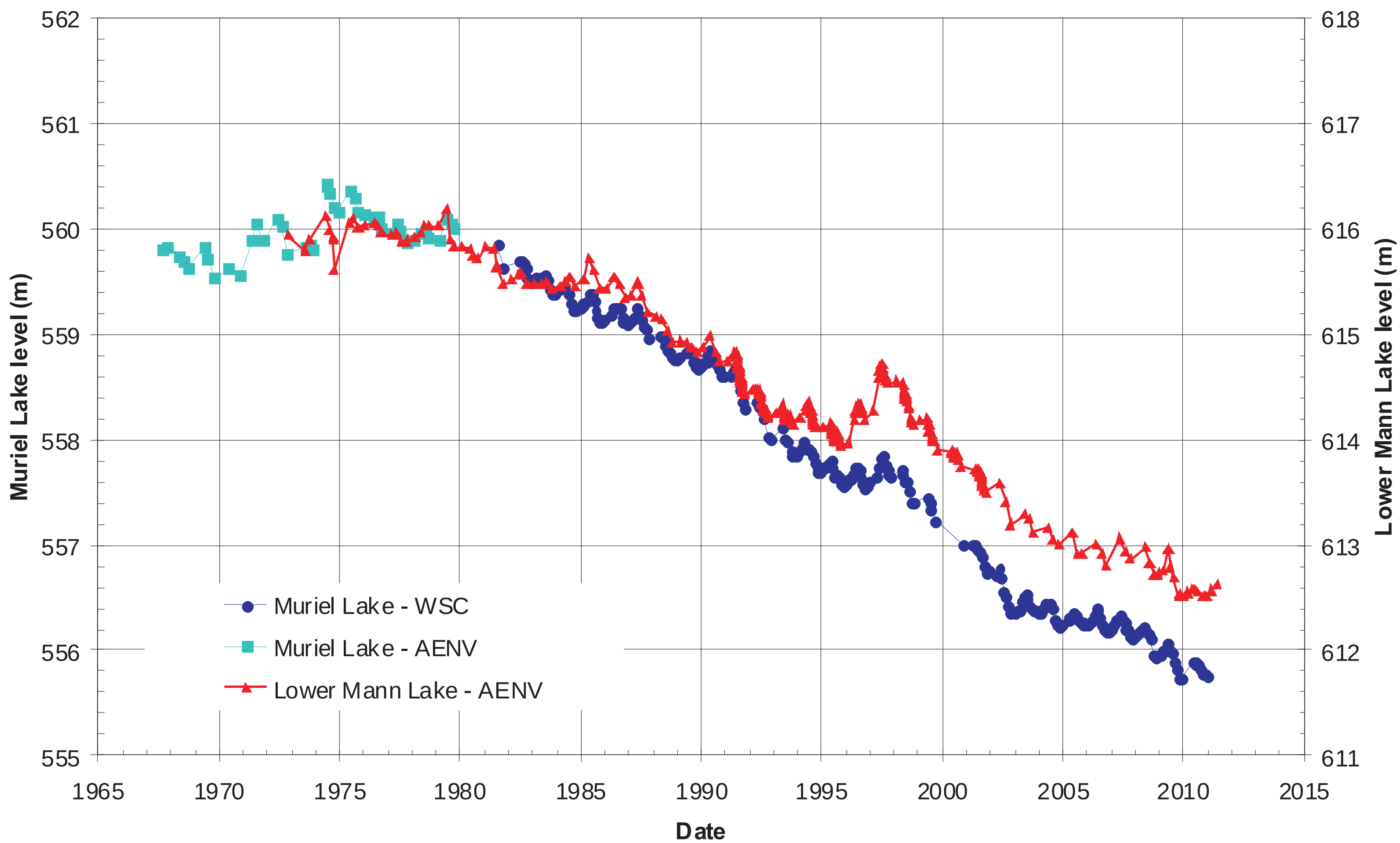

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LINDBERGH SAGD EXPANSION PROJECT
HYDROLOGY ASSESSMENT

WATER LEVEL VARIATIONS IN MURIEL AND LOWER MANN LAKES

File 17622	2013-11-18	**Figure 11**

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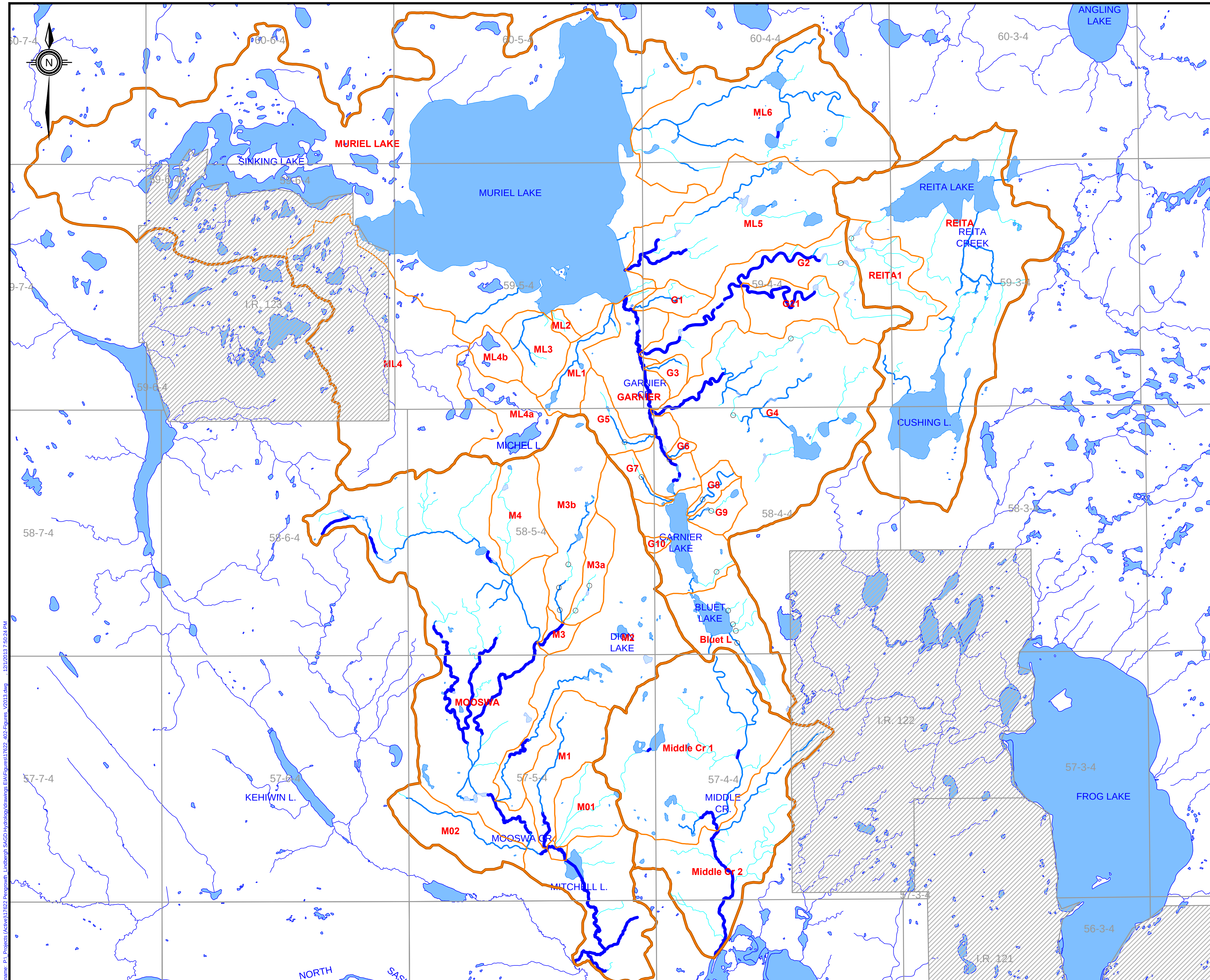

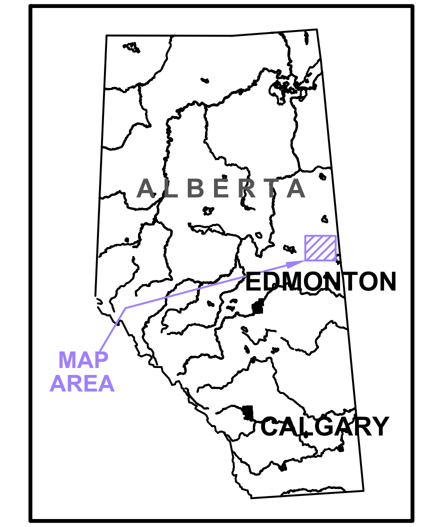

LEGEND

- MAJOR WATERSHED BOUNDARIES
- WATERSHED BOUNDARIES
- STREAMS - PERMANENT
- STREAMS - EPHEMERAL
- DRAINAGE WITHOUT DEFINED CHANNELS
- LAKES & PONDS
- BEAVER POND
- ALBERTA TOWNSHIP GRID

0 1.5 3 4.5 6 7.5 Km

SCALE 1:150,000

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LINDBERGH SAGD EXPANSION PROJECT
HYDROLOGY ASSESSMENT

LOCAL HYDROGRAPHY

Dwg. 7622-402	2013-12-01	**Figure 12**

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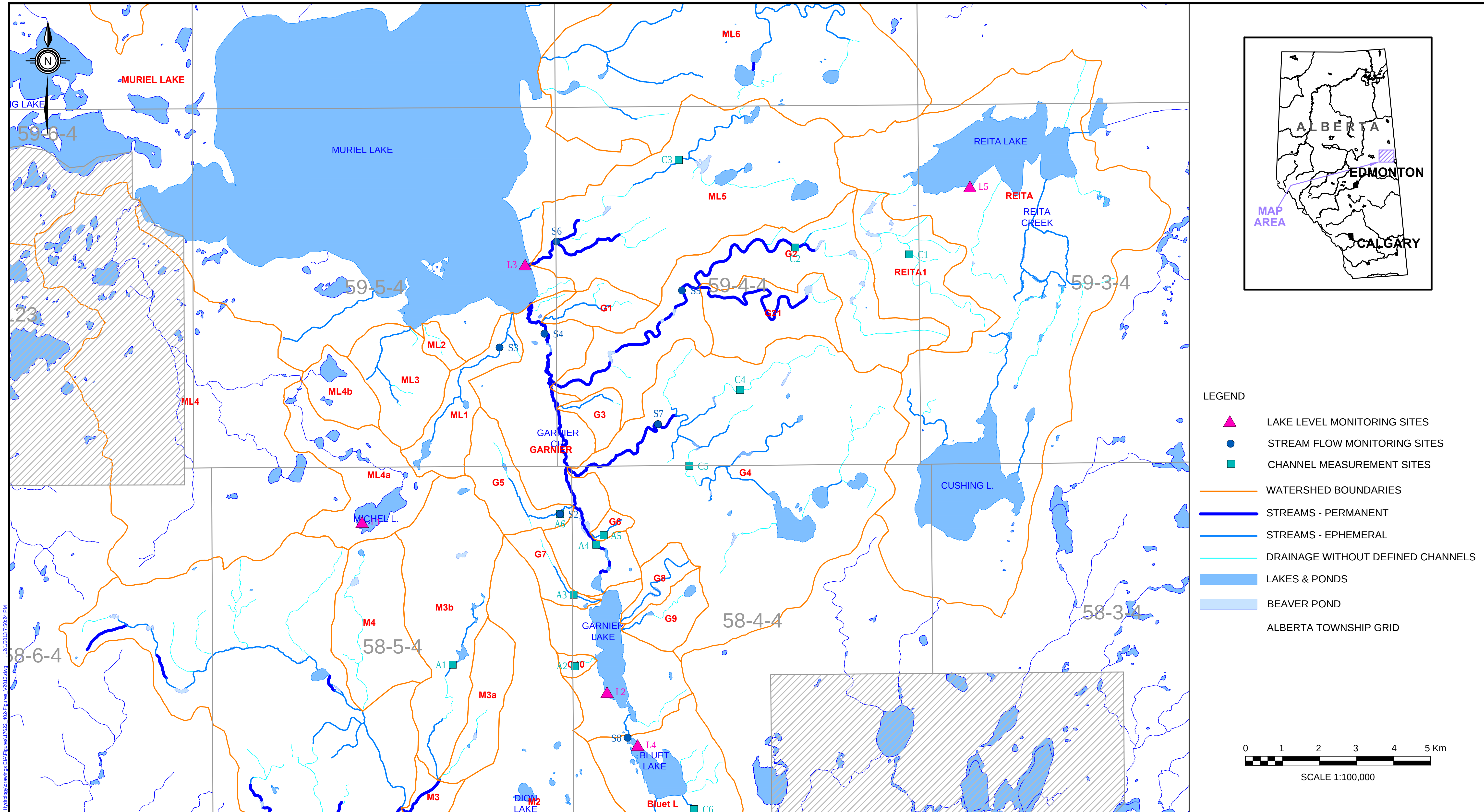

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LINDBERGH SAGD EXPANSION PROJECT
HYDROLOGY ASSESSMENT

LOCAL MONITORING SITE LOCATIONS

Dwg. 7622-402	2013-12-01	**Figure 13**

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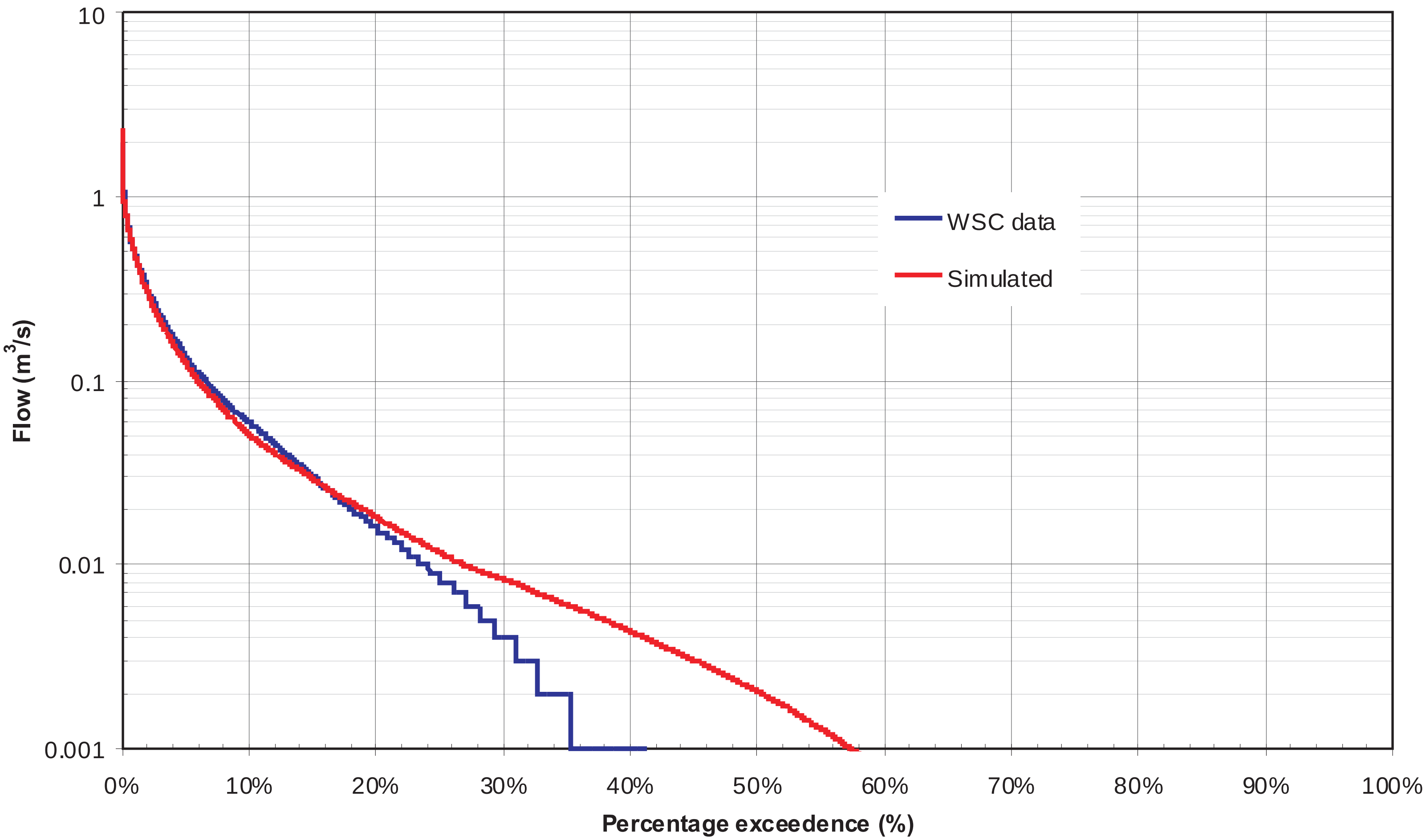

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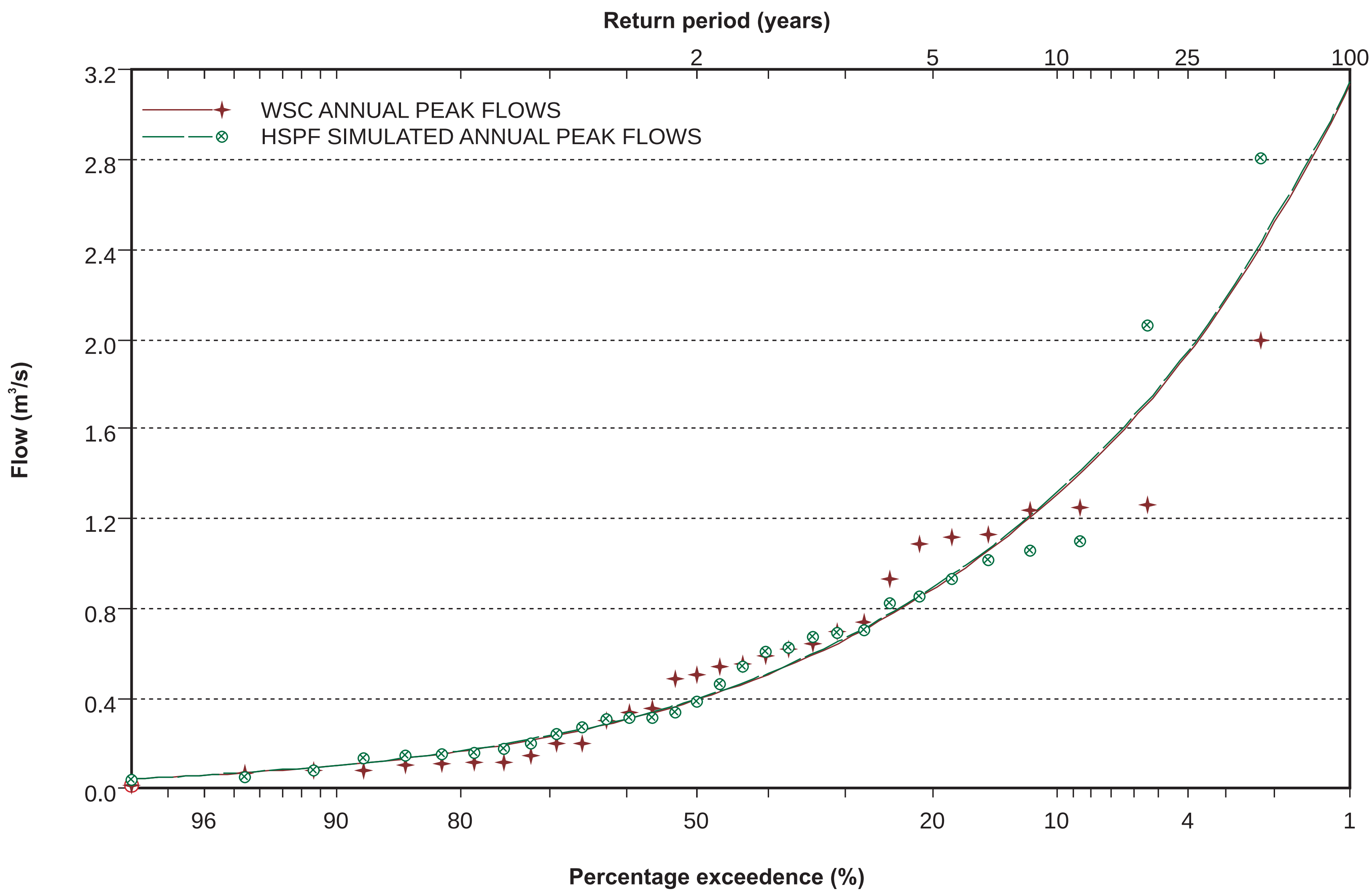
LINDBERGH SAGD EXPANSION PROJECT
HYDROLOGY ASSESSMENT

COMPARISON OF SIMULATED AND MEASURED FLOW DURATIONS FOR MOOSEHILLS CREEK

File 17622	2013-11-18	**Figure 14**

northwest hydraulic consultants ltd.



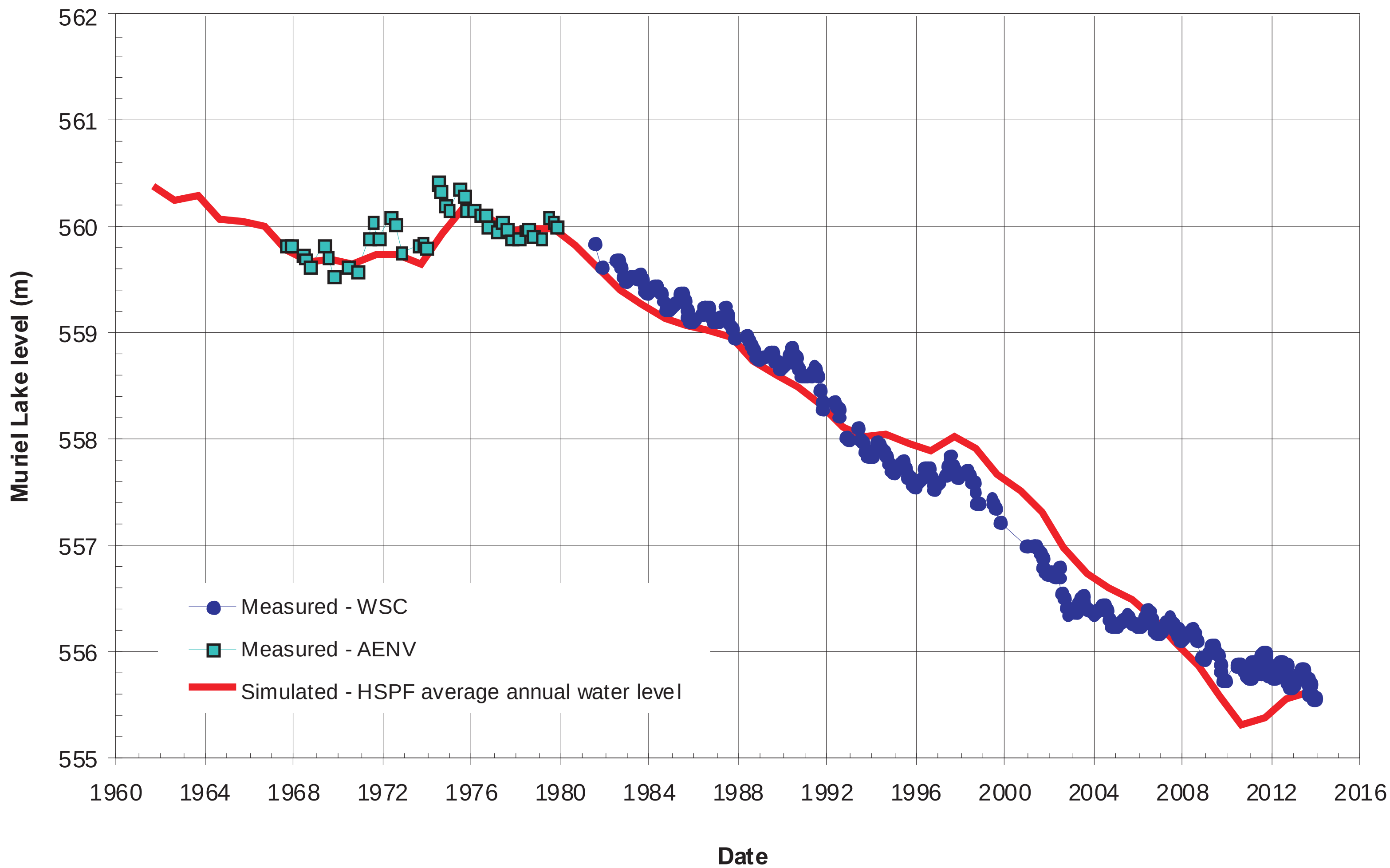
PENGROWTH ENERGY CORPORATION

LINDBERGH SAGD EXPANSION PROJECT
HYDROLOGY ASSESSMENT

COMPARISON OF SIMULATED AND MEASURED ANNUAL PEAK FLOWS FOR MOOSEHILLS CREEK

File 17622	2013-11-18	**Figure 15**

northwest hydraulic consultants ltd.



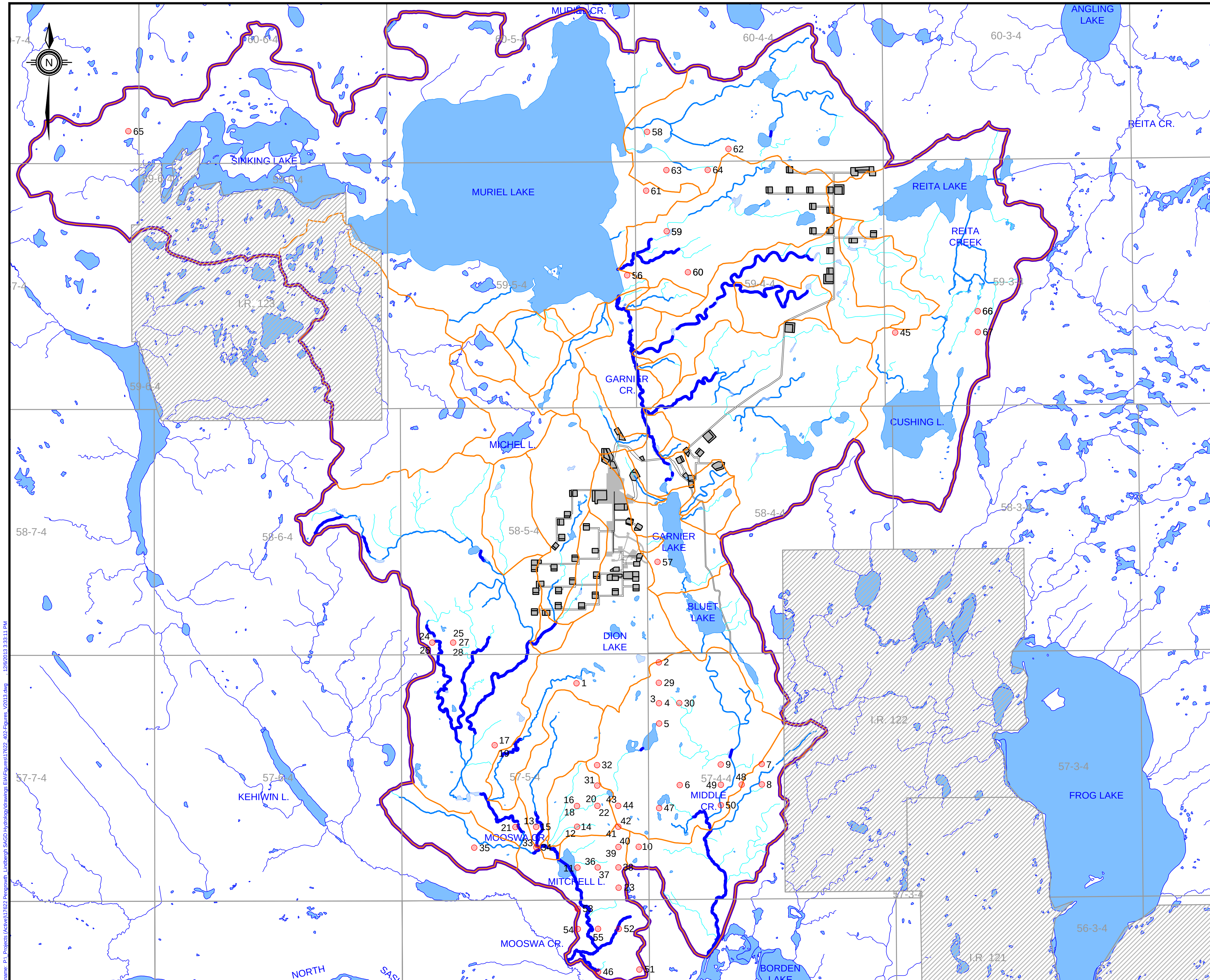
PENGROWTH ENERGY CORPORATION

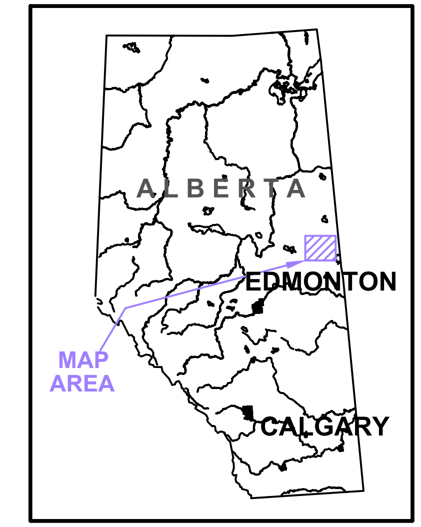
LINDBERGH SAGD EXPANSION PROJECT
HYDROLOGY ASSESSMENT

COMPARISON OF SIMULATED AND MEASURED WATER LEVELS IN MURIEL LAKE

File 17622	2013-11-18	**Figure 16**

northwest hydraulic consultants ltd.





LEGEND

- LOCATION OF WATER-RIGHTS HOLDERS
- REGIONAL STUDY AREA
- WATERSHED BOUNDARIES
- STREAMS - PERMANENT
- STREAMS - EPHEMERAL
- DRAINAGE WITHOUT DEFINED CHANNELS
- LAKES & PONDS
- BEAVER POND
- ALBERTA TOWNSHIP GRID
- PROJECT FOOTPRINT

0 1.5 3 4.5 6 7.5 Km

SCALE 1:150,000

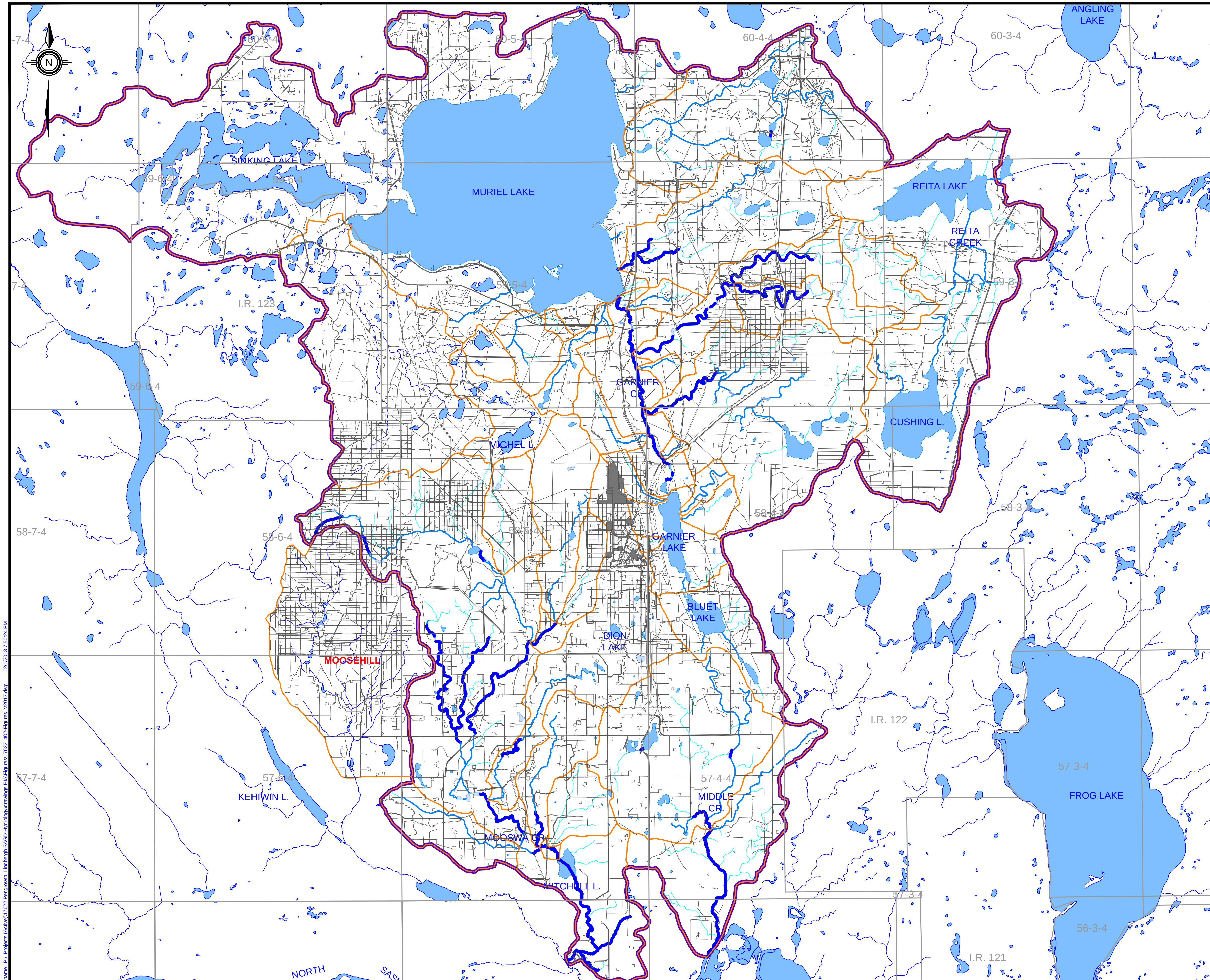
PENGROWTH ENERGY CORPORATION

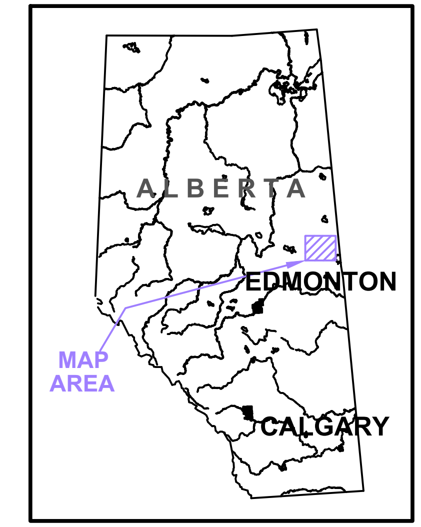
LINDBERGH SAGD EXPANSION PROJECT
HYDROLOGY ASSESSMENT

LOCATIONS OF EXISTING WATER RIGHTS HOLDERS WITHIN THE RSA

Dwg. 7622-402	2013-11-22	**Figure 17**

northwest hydraulic consultants





LEGEND

- REGIONAL STUDY AREA
- WATERSHED BOUNDARIES
- STREAMS - PERMANENT
- STREAMS - EPHEMERAL
- DRAINAGE WITHOUT DEFINED CHANNELS
- EXISTING AND APPROVED DEVELOPMENT (PILOT + PHASE 1)
- EXISTING DISTURBANCE IN RSA
- LAKES & PONDS
- BEAVER POND
- ALBERTA TOWNSHIP GRID

0 1.5 3 4.5 6 7.5 Km

SCALE 1:150,000

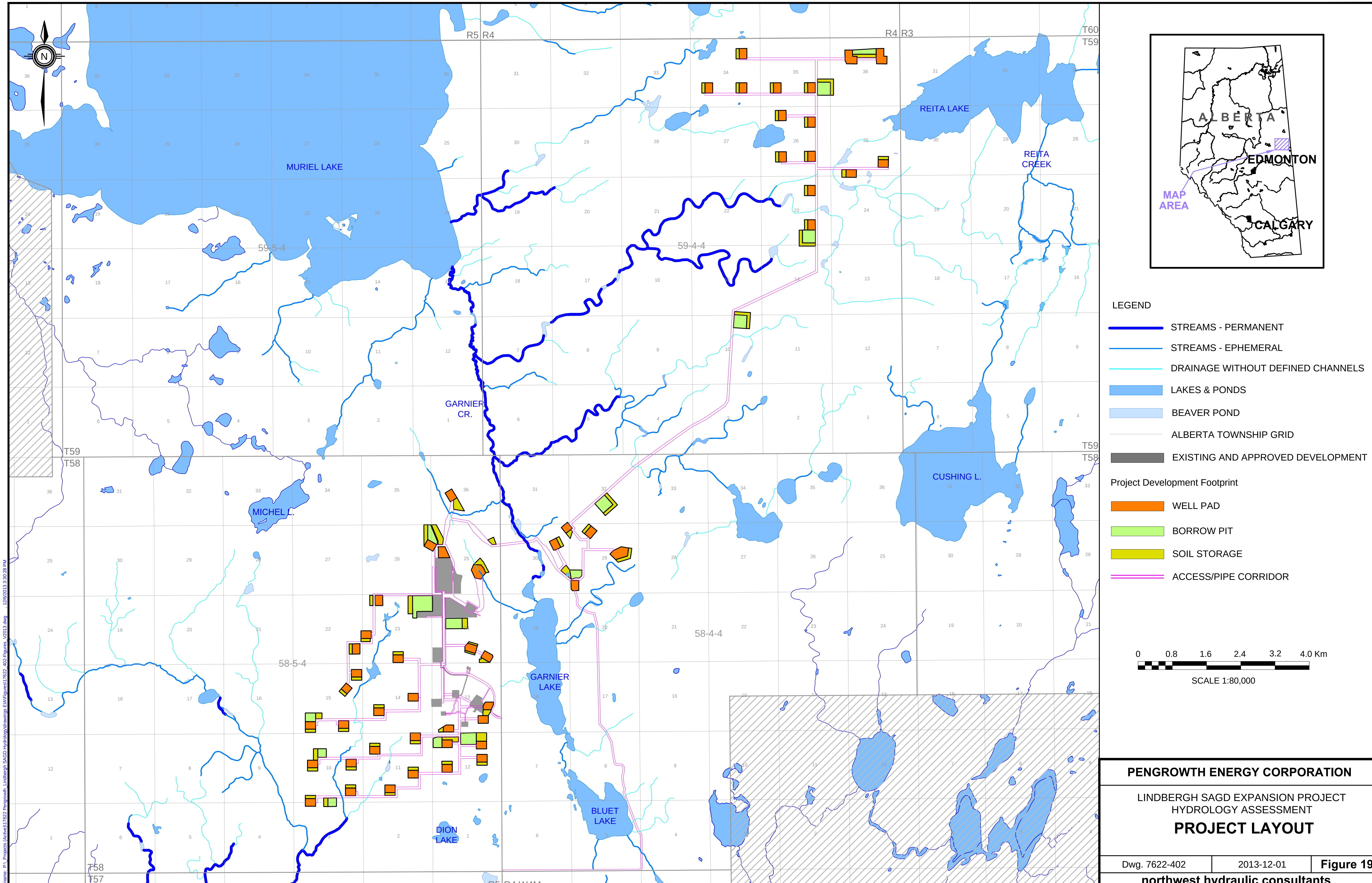
PENGROWTH ENERGY CORPORATION

LINDBERGH SAGD EXPANSION PROJECT
HYDROLOGY ASSESSMENT

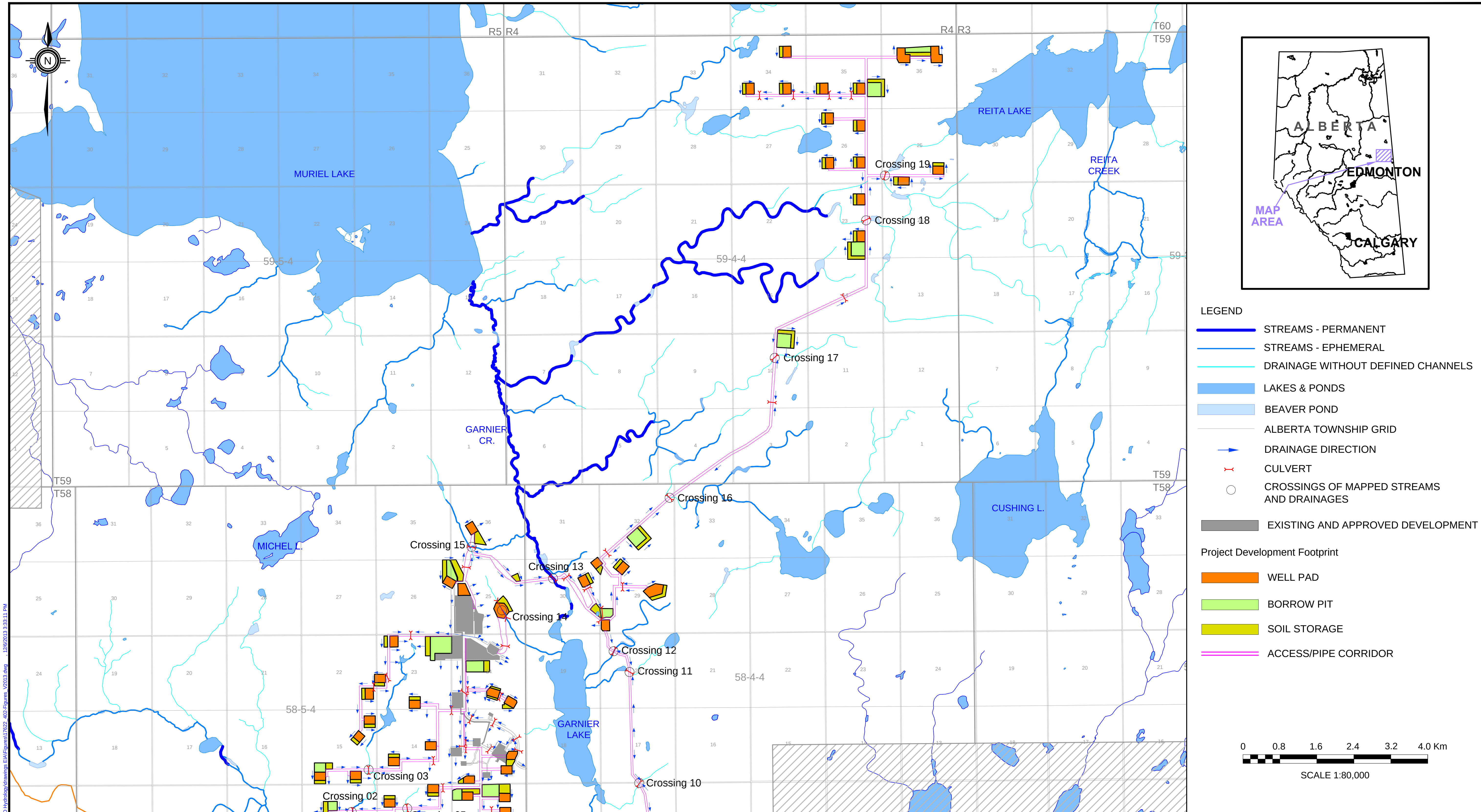
BASELINE DISTURBANCE CONDITIONS

Dwg. 7622-402	2013-12-01	**Figure 18**

northwest hydraulic consultants


R5 R4
R4 R3
T60
T59
MURIEL LAKE
REITA LAKE
REITA CREEK
59-5-4
59-4-4
GARNIER CR.
T59
T58
MICHEL L.
CUSHING L.
58-5-4
58-4-4
GARNIER LAKE
BLUET LAKE
DION LAKE
T58
T57
R5 R4 W4M
ALBERTA
EDMONTON
CALGARY
MAP AREA
LEGEND
STREAMS - PERMANENT
STREAMS - EPHEMERAL
DRAINAGE WITHOUT DEFINED CHANNELS
LAKES & PONDS
BEAVER POND
ALBERTA TOWNSHIP GRID
EXISTING AND APPROVED DEVELOPMENT
Project Development Footprint
WELL PAD
BORROW PIT
SOIL STORAGE
ACCESS/PIPE CORRIDOR
0 0.8 1.6 2.4 3.2 4.0 Km
SCALE 1:80,000
PENGROWTH ENERGY CORPORATION
LINDBERGH SAGD EXPANSION PROJECT
HYDROLOGY ASSESSMENT
PROJECT LAYOUT
Dwg. 7622-402
2013-12-01
Figure 19
northwest hydraulic consultants

Previous View Main Menu Search



PENGROWTH ENERGY CORPORATION

LINDBERGH SAGD EXPANSION PROJECT
HYDROLOGY ASSESSMENT

DRAINAGE OF PROJECT DEVELOPMENT

Dwg. 7622-402	2013-12-01	**Figure 20**

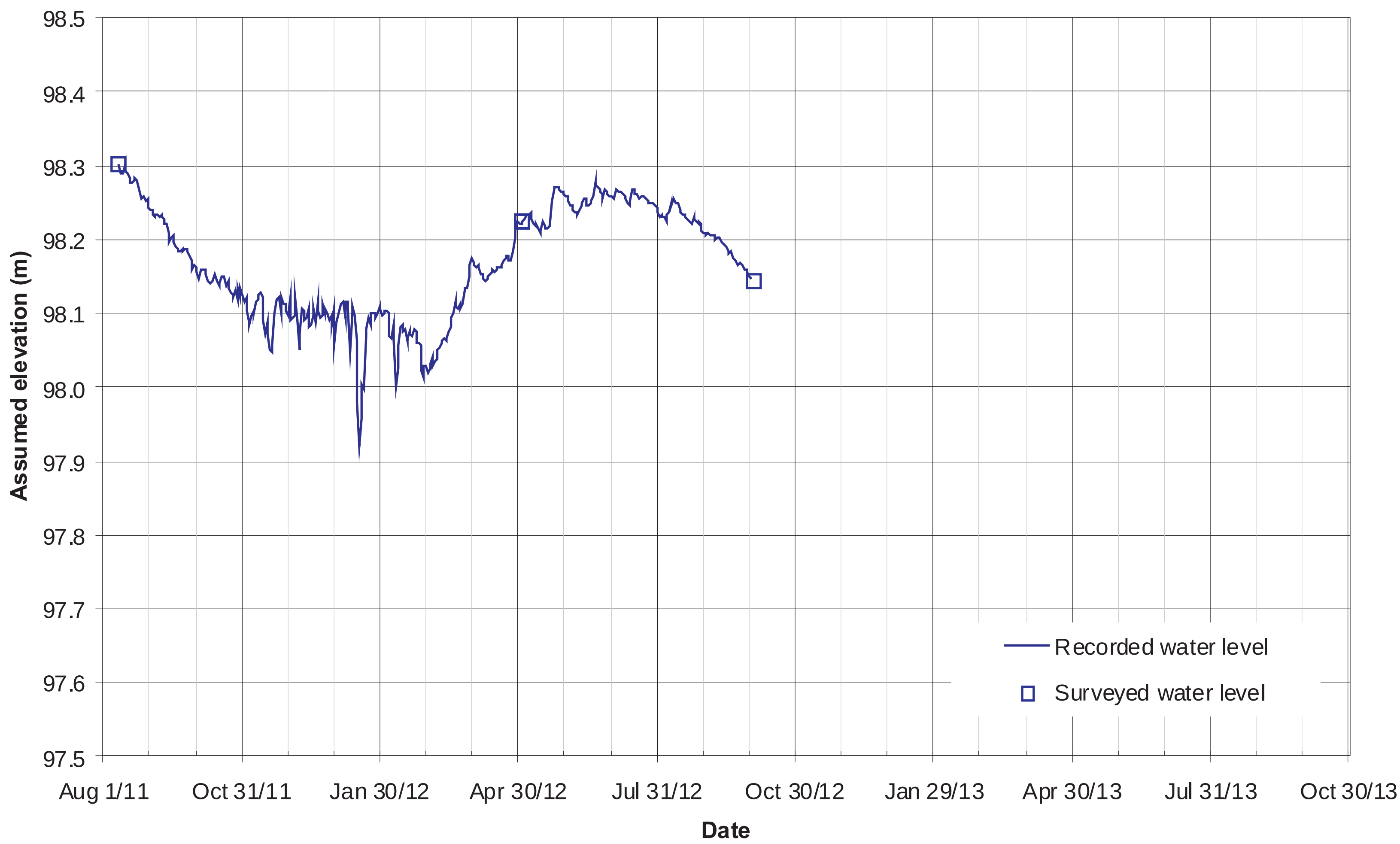
northwest hydraulic consultants

APPENDIX A

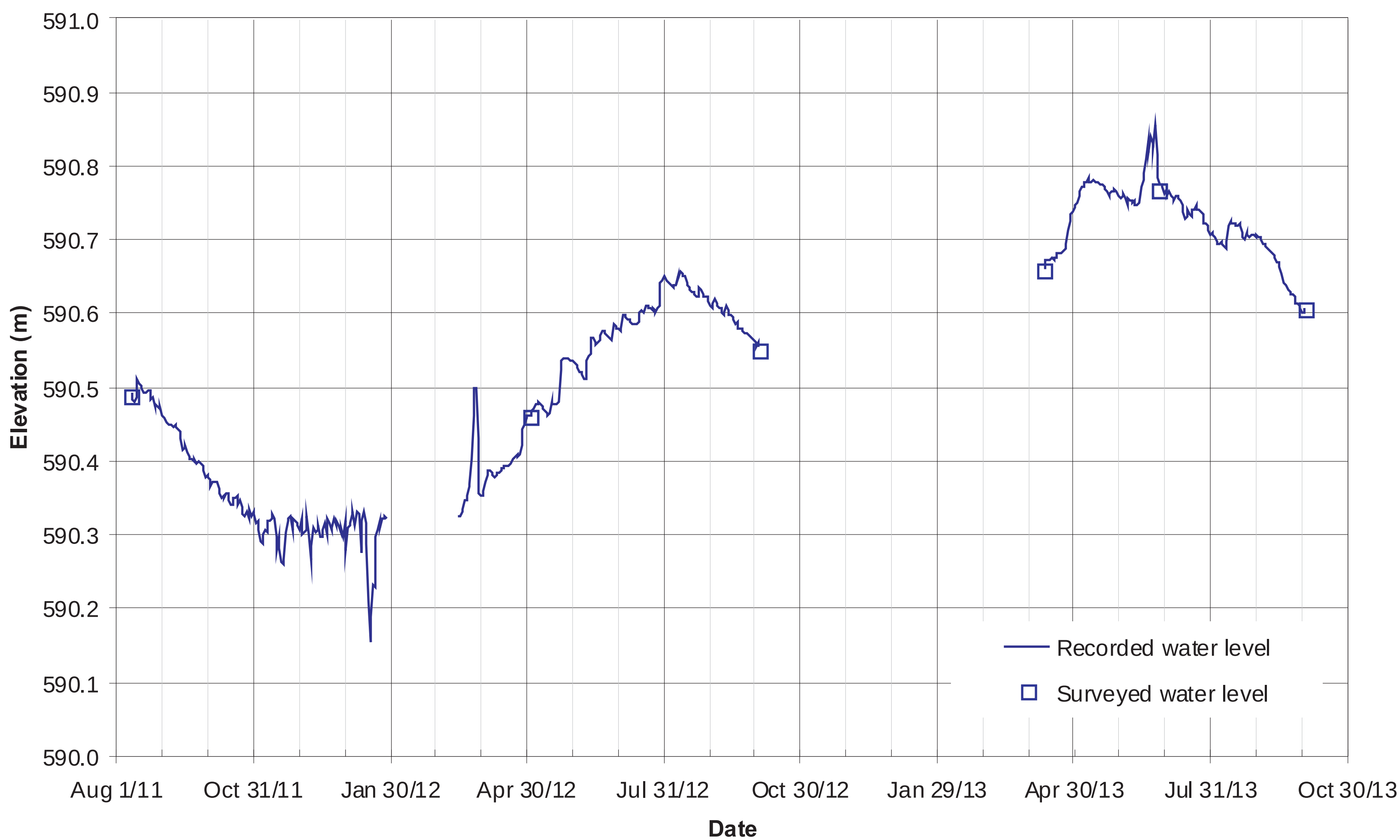
WATER LEVEL MEASUREMENTS

IN LOCAL LAKES

Previous View Main Menu Search

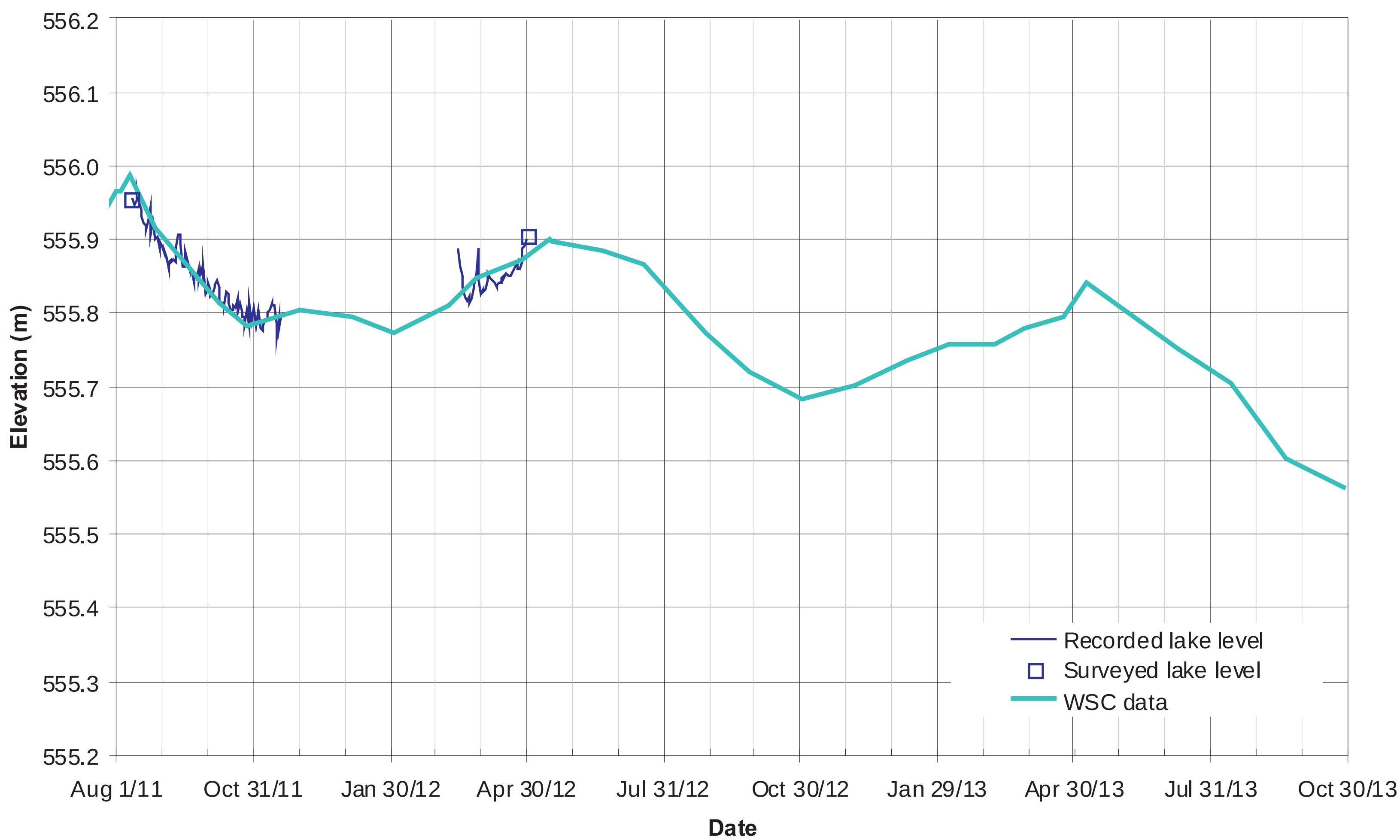


PENGROWTH ENERGY CORPORATION		
LINDBERGH SAGD EXPANSION PROJECT HYDROLOGY ASSESSMENT **MEASURED WATER LEVELS AT SITE L1 - MICHEL LAKE**		
File 17622	2013-11-19	**Figure A1**
northwest hydraulic consultants ltd.		

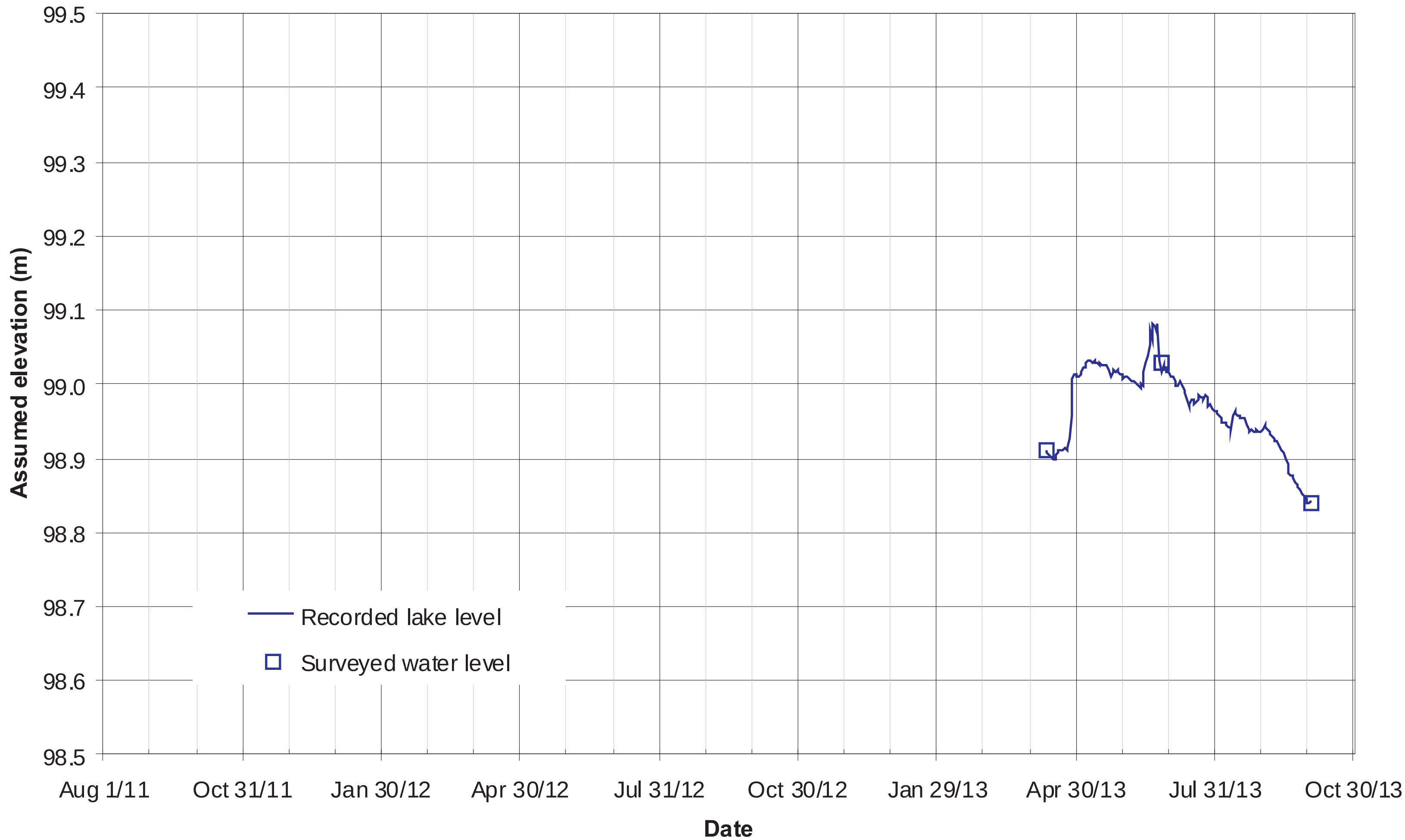


PENGROWTH ENERGY CORPORATION		
LINDBERGH SAGD EXPANSION PROJECT HYDROLOGY ASSESSMENT **MEASURED WATER LEVELS AT SITE L2 - GARNIER LAKE**		
File 17622	2013-11-19	**Figure A2**
northwest hydraulic consultants ltd.		

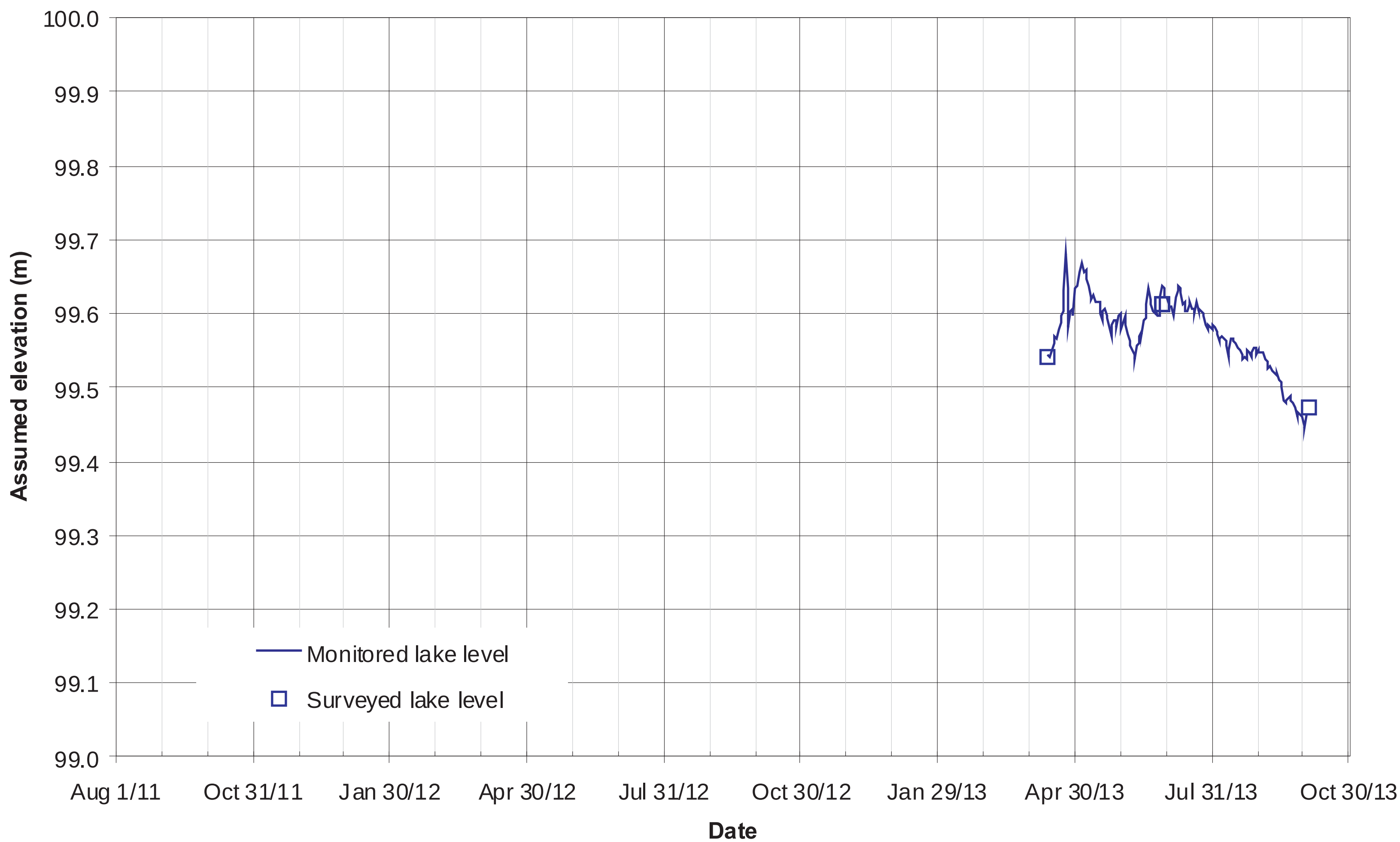
Previous View Main Menu Search



PENGROWTH ENERGY CORPORATION		
LINDBERGH SAGD EXPANSION PROJECT HYDROLOGY ASSESSMENT **MEASURED WATER LEVELS AT SITE L3 - MURIEL LAKE**		
File 17622	2013-11-19	**Figure A3**
northwest hydraulic consultants ltd.		



PENGROWTH ENERGY CORPORATION		
LINDBERGH SAGD EXPANSION PROJECT HYDROLOGY ASSESSMENT **MEASURED WATER LEVELS AT SITE L4 - BLUET LAKE**		
File 17622	2013-11-19	**Figure A4**
northwest hydraulic consultants ltd.		

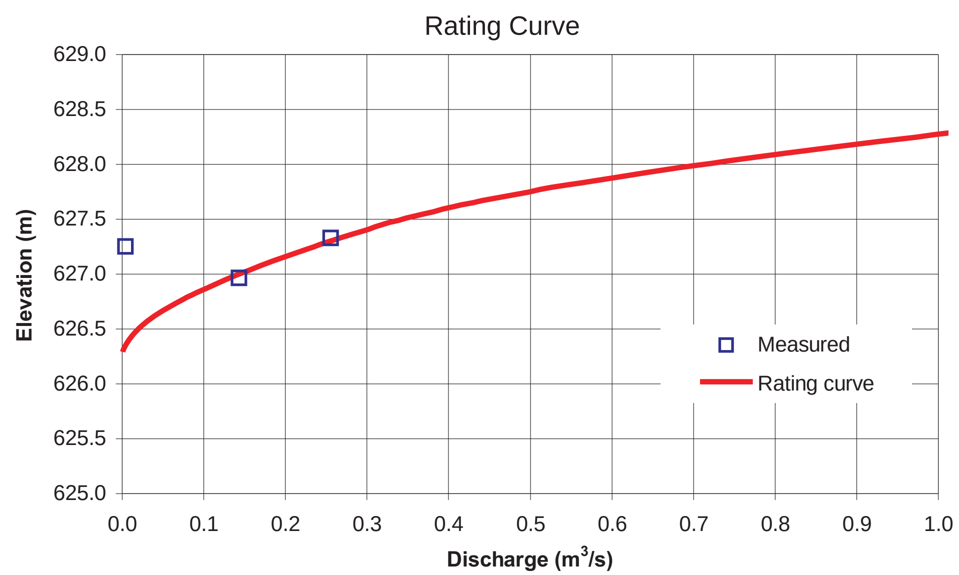


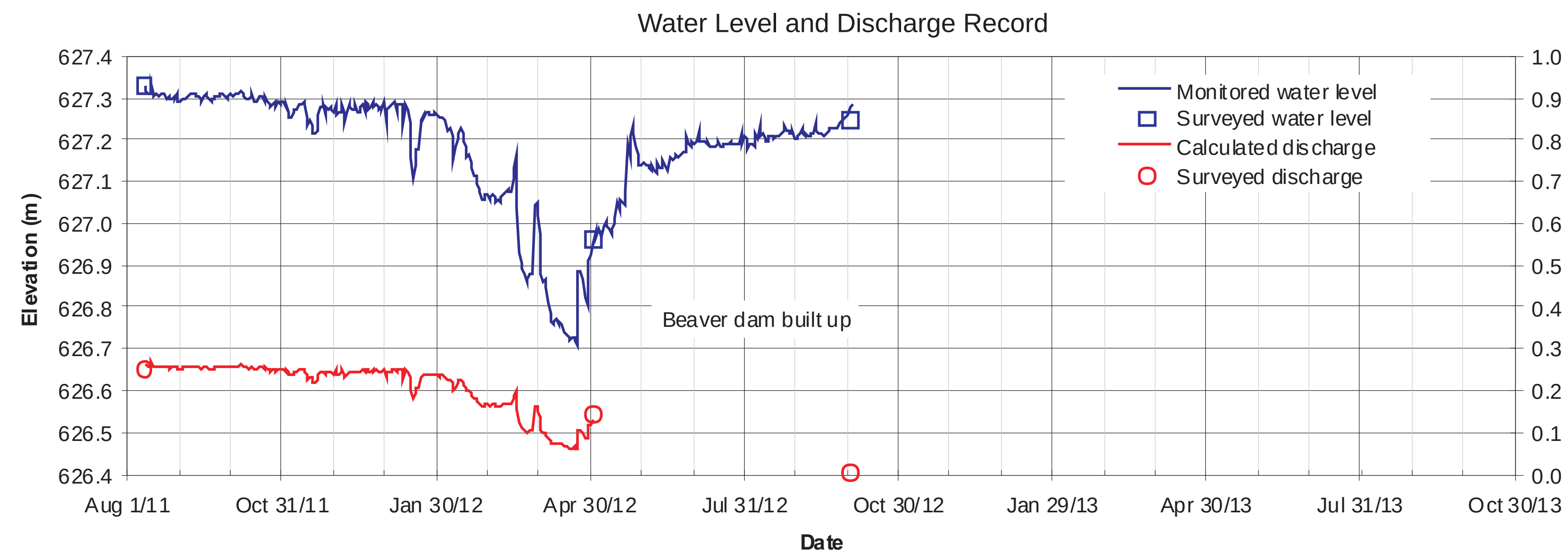
PENGROWTH ENERGY CORPORATION		
LINDBERGH SAGD EXPANSION PROJECT HYDROLOGY ASSESSMENT **MEASURED WATER LEVELS AT SITE L5 - REITA LAKE**		
File 17622	2013-11-19	**Figure A5**
northwest hydraulic consultants ltd.		

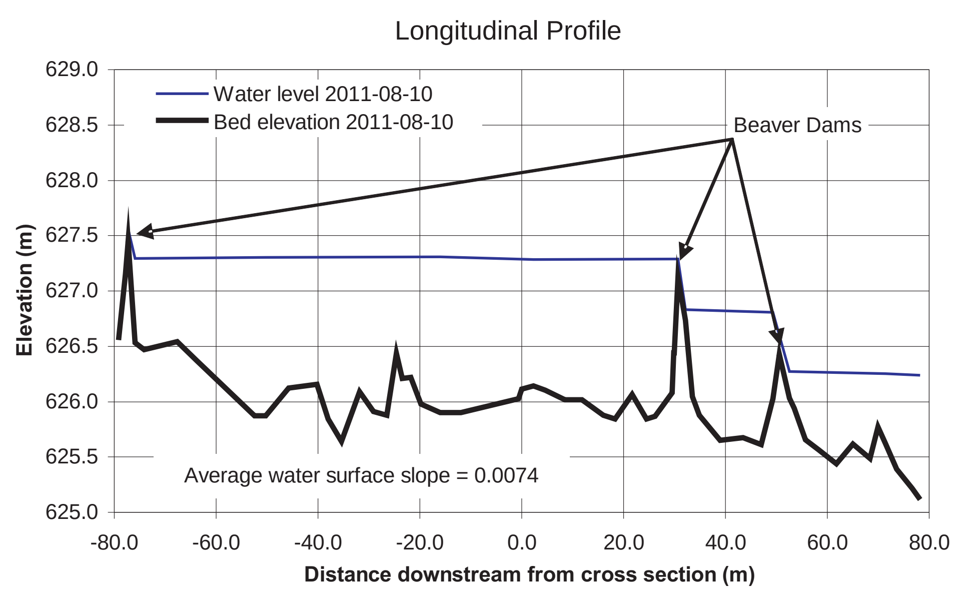
APPENDIX B

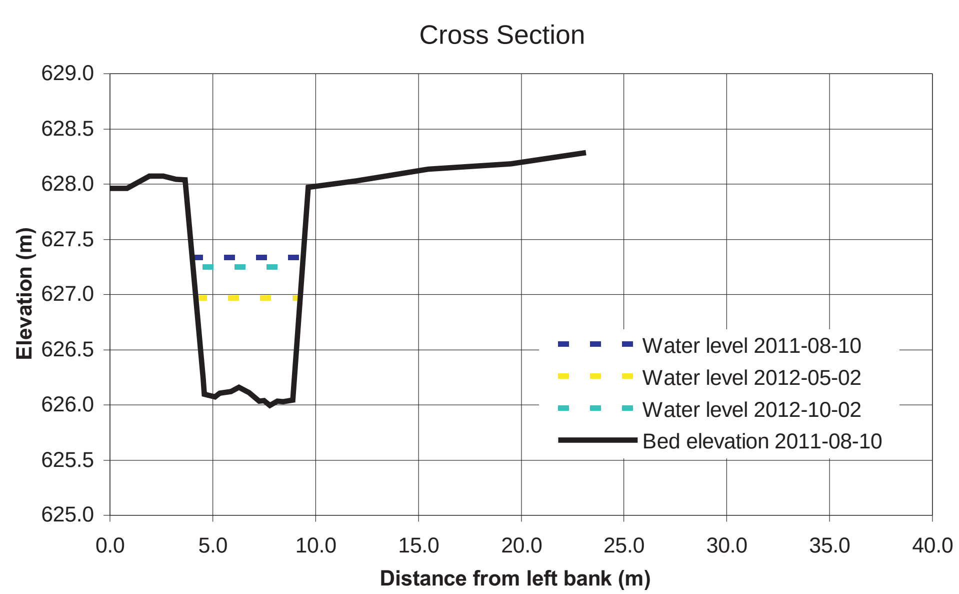
FLOW CHARACTERISTICS

IN LOCAL STREAMS









View of cross section upstream of bridge

View downstream of cross section

View upstream of cross section

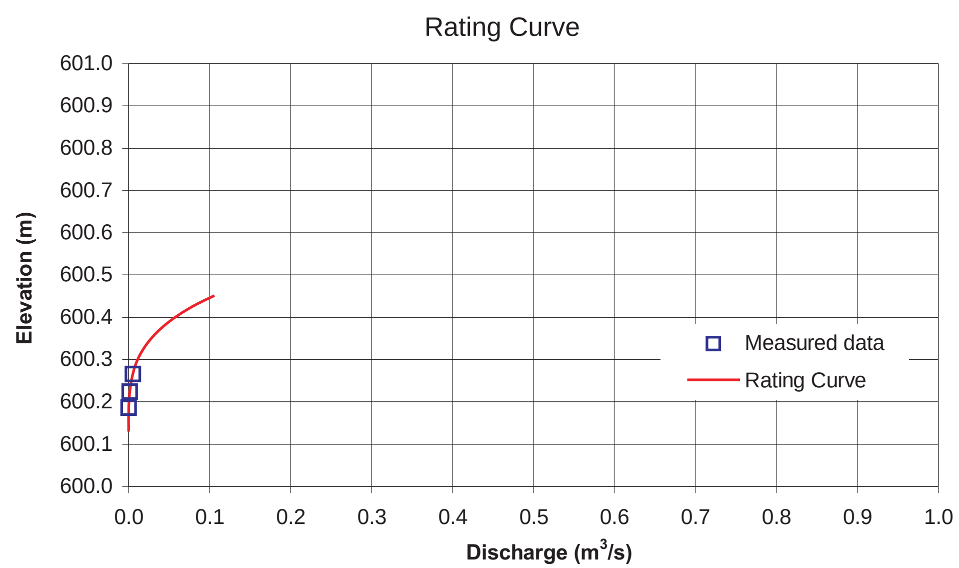
PENGROWTH ENERGY CORPORATION

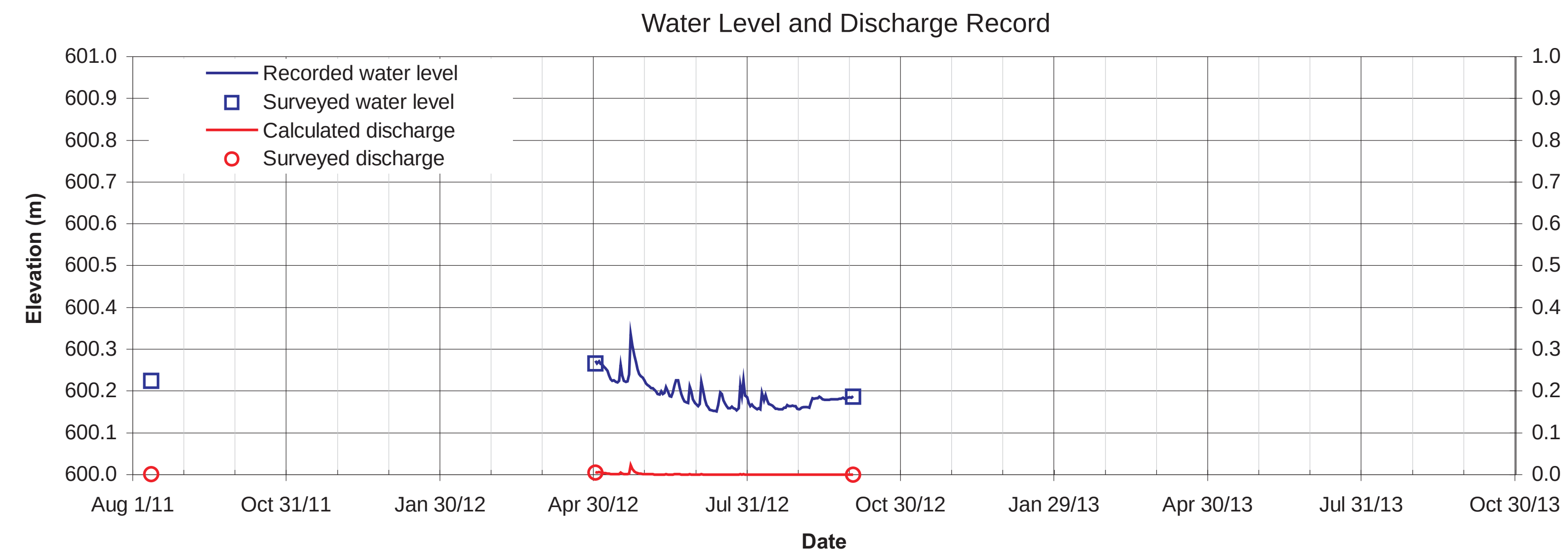
LINDBERGH SAGD EXPANSION PROJECT
HYDROLOGY ASSESSMENT

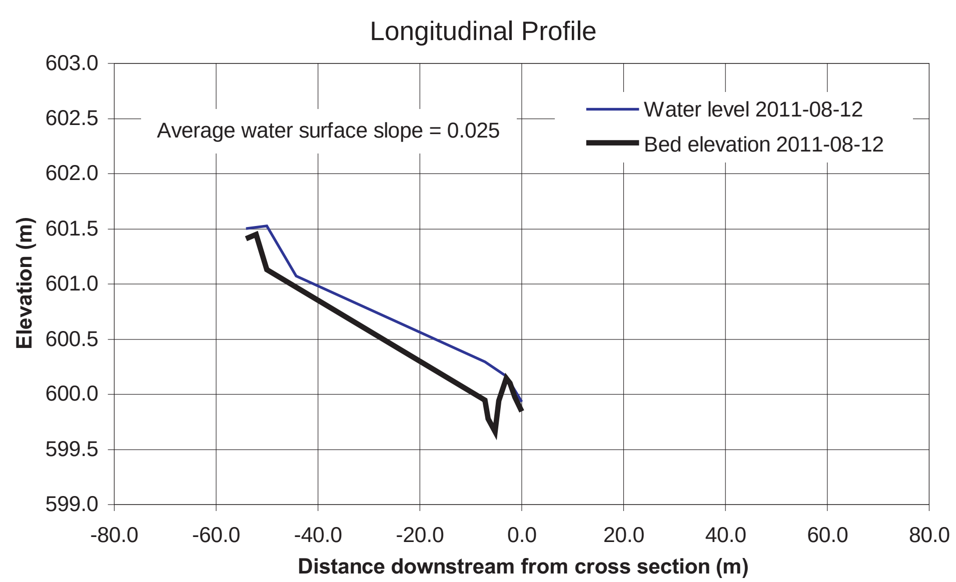
HYDRAULIC CHARACTERISTICS AT SITE S1 (MOOSWA CREEK)

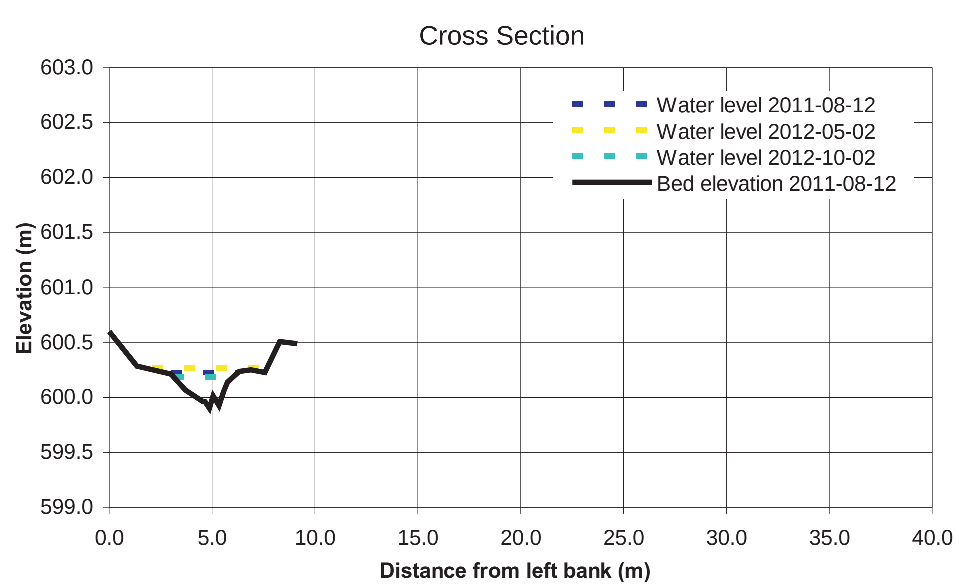
File 17622	2013-11-20	**Figure B1**

northwest hydraulic consultants ltd.










Cross section


View downstream of cross section


Culvert upstream of cross section

PENGROWTH ENERGY CORPORATION

LINDBERGH SAGD EXPANSION PROJECT
HYDROLOGY ASSESSMENT

HYDRAULIC CHARACTERISTICS AT SITE S2 (WATERSHED G5)

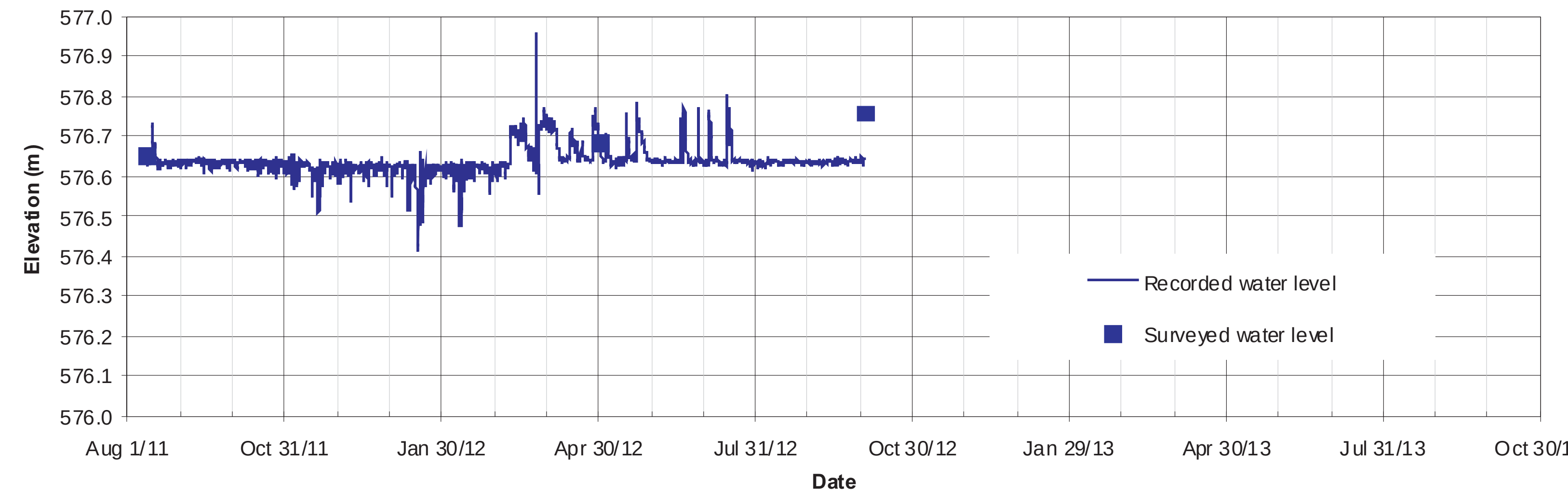
File 17622	2013-12-06	**Figure B2**

northwest hydraulic consultants ltd.

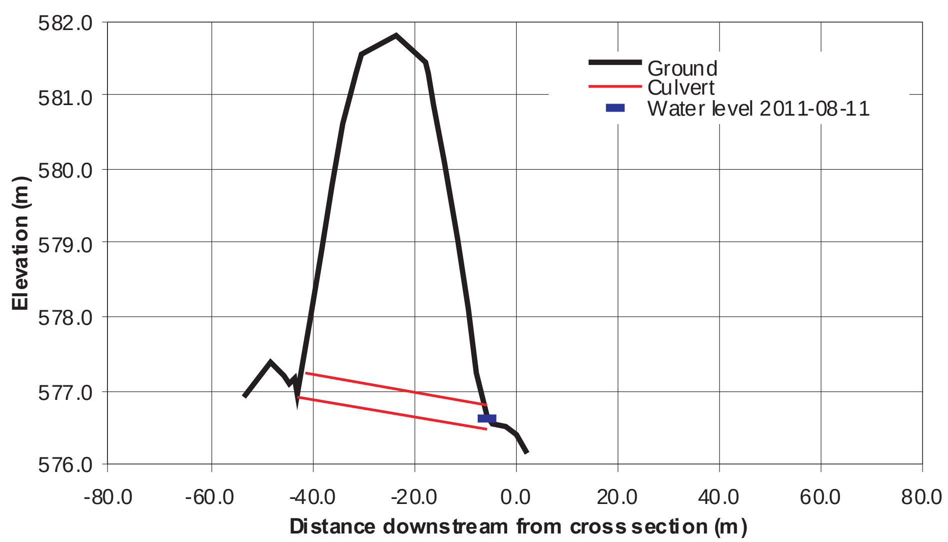
Rating Curve

No detectable flows

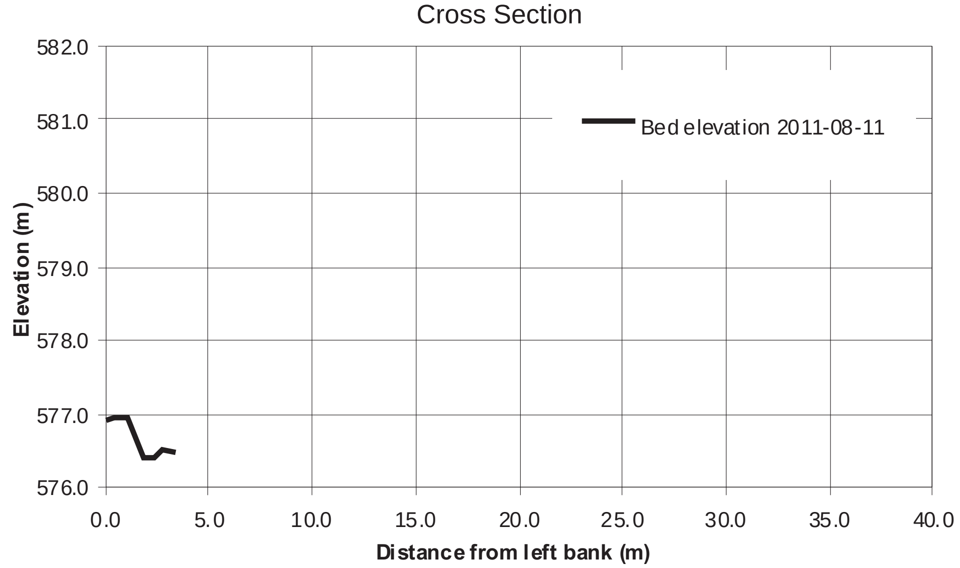
Water Level and Discharge Record



Longitudinal Profile



Cross Section




Cross section downstream of culvert


View downstream of cross section


Culvert upstream of road

PENGROWTH ENERGY CORPORATION

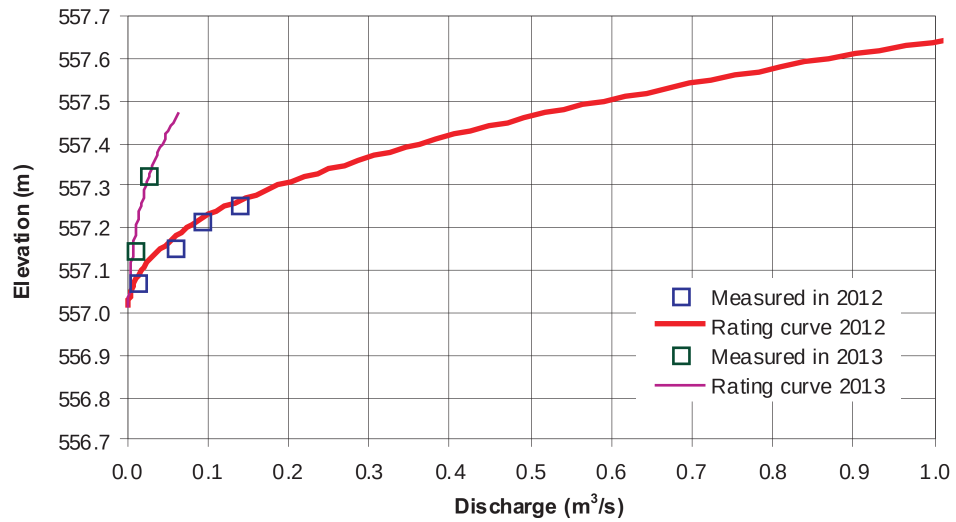
LINDBERGH SAGD EXPANSION PROJECT
HYDROLOGY ASSESSMENT

HYDRAULIC CHARACTERISTICS AT SITE S3 (WATERSHED ML1)

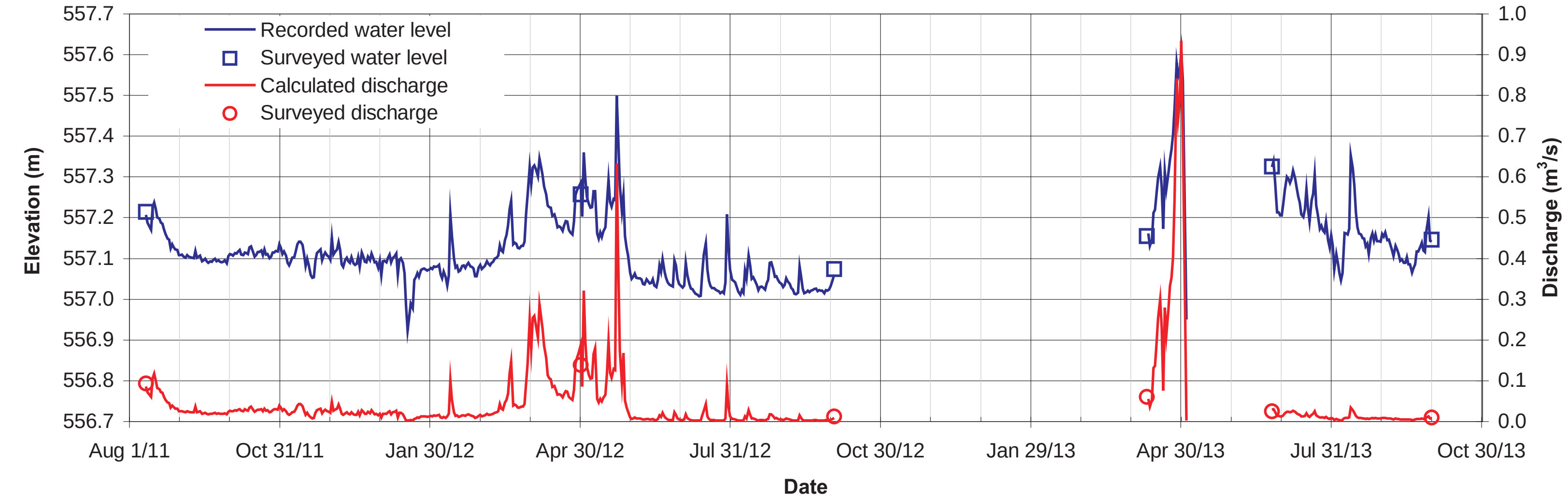
File 17622	2013-12-06	**Figure B3**

northwest hydraulic consultants ltd.

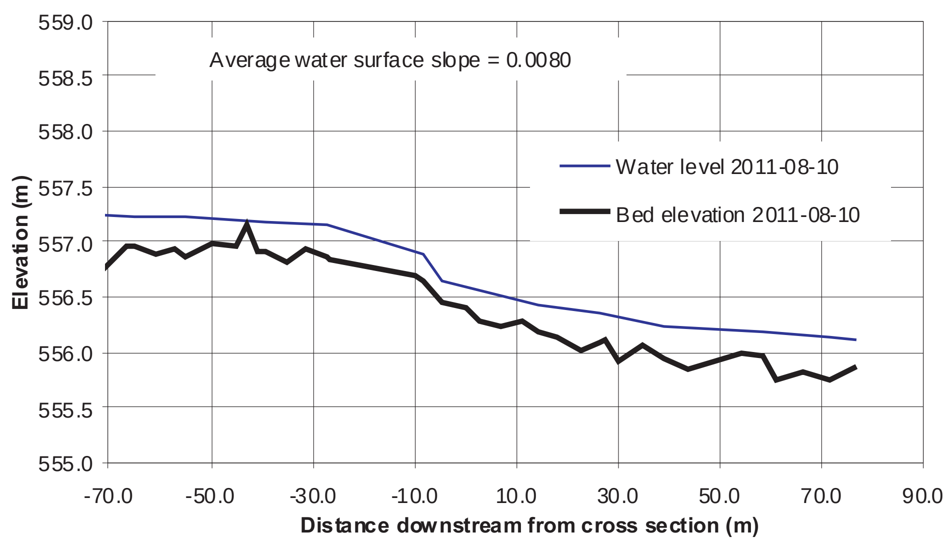
Rating Curve



Water Level and Discharge Record



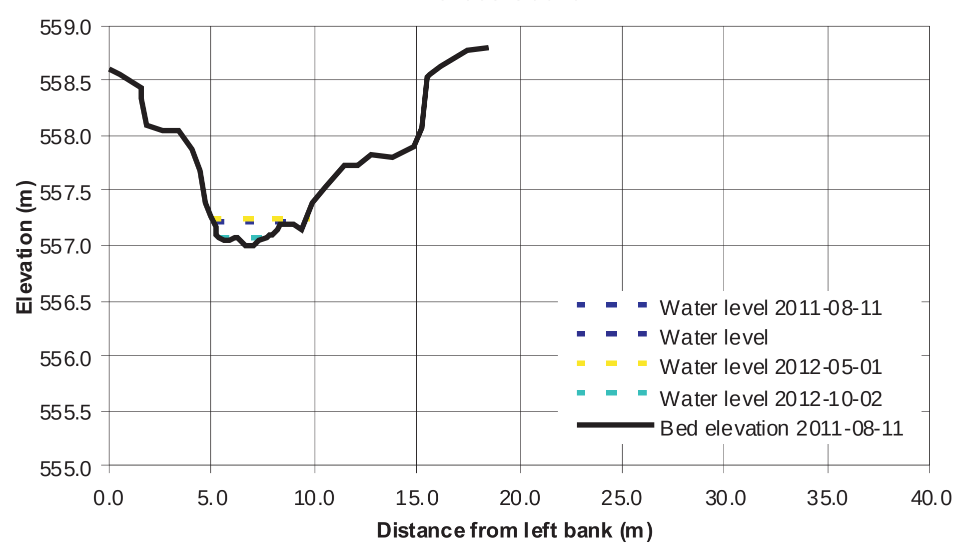
Longitudinal Profile



Aerial view of site

View downstream of cross section

Cross Section



View upstream of cross section

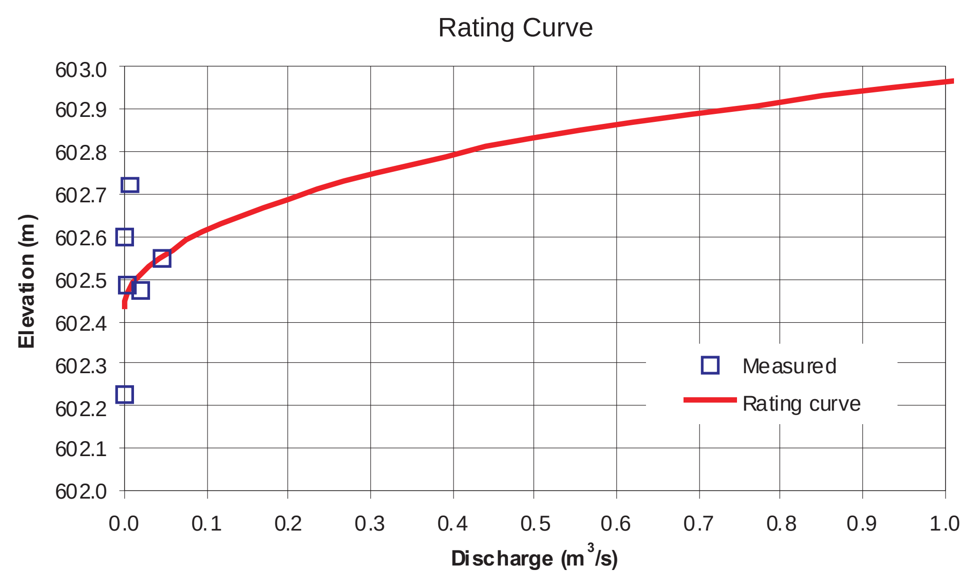
PENGROWTH ENERGY CORPORATION

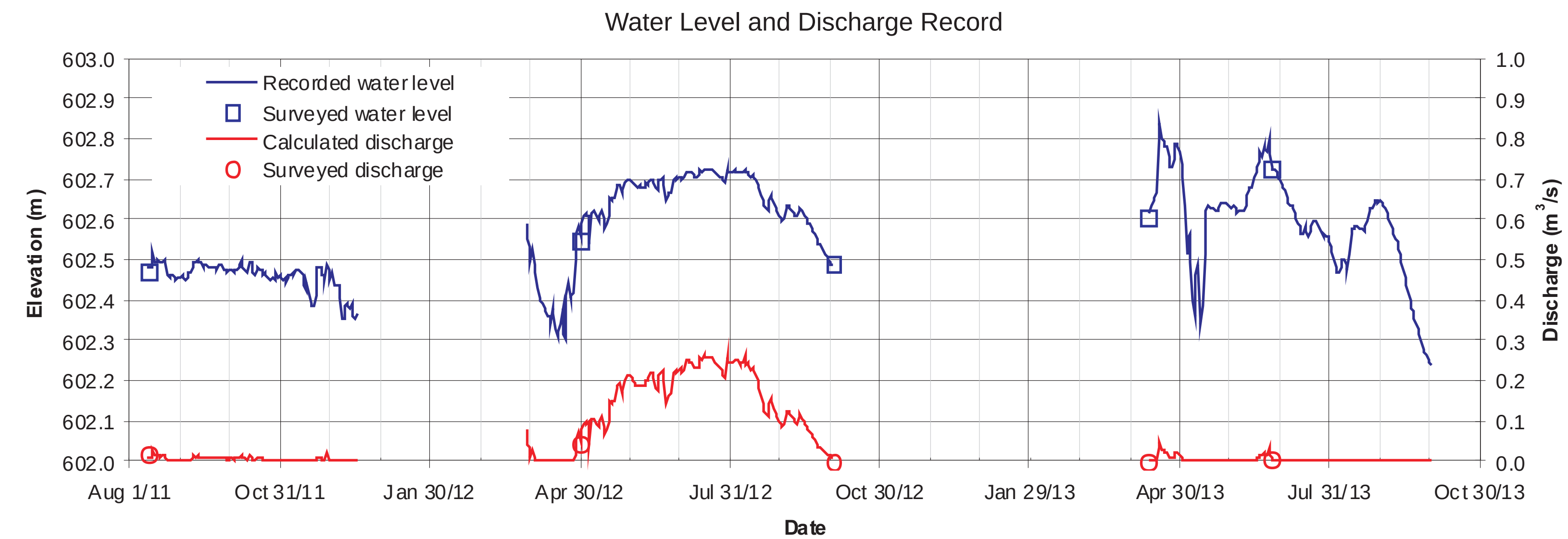
LINDBERGH SAGD EXPANSION PROJECT
HYDROLOGY ASSESSMENT

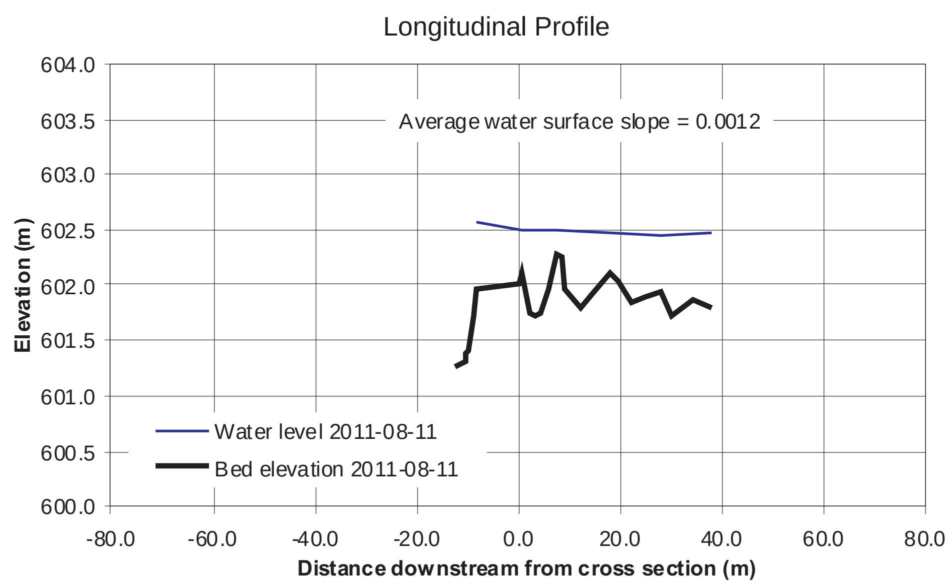
HYDRAULIC CHARACTERISTICS AT SITE S4 (GARNIER CREEK)

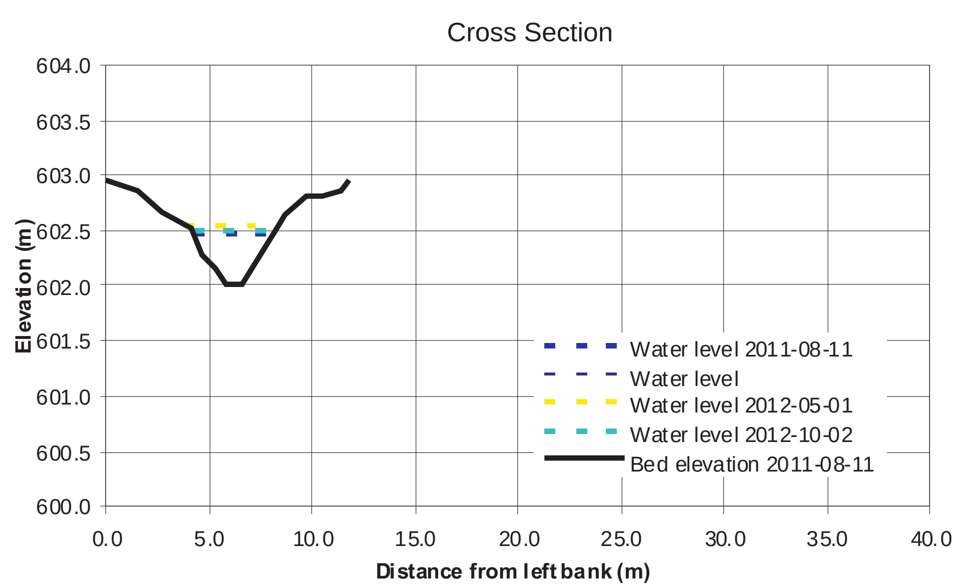
File 17622	2013-12-06	**Figure B4**

northwest hydraulic consultants ltd.










View of cross section


View downstream of cross section


View upstream of cross section

PENGROWTH ENERGY CORPORATION

LINDBERGH SAGD EXPANSION PROJECT
HYDROLOGY ASSESSMENT

HYDRAULIC CHARACTERISTICS AT SITE S5 (WATERSHED G2)

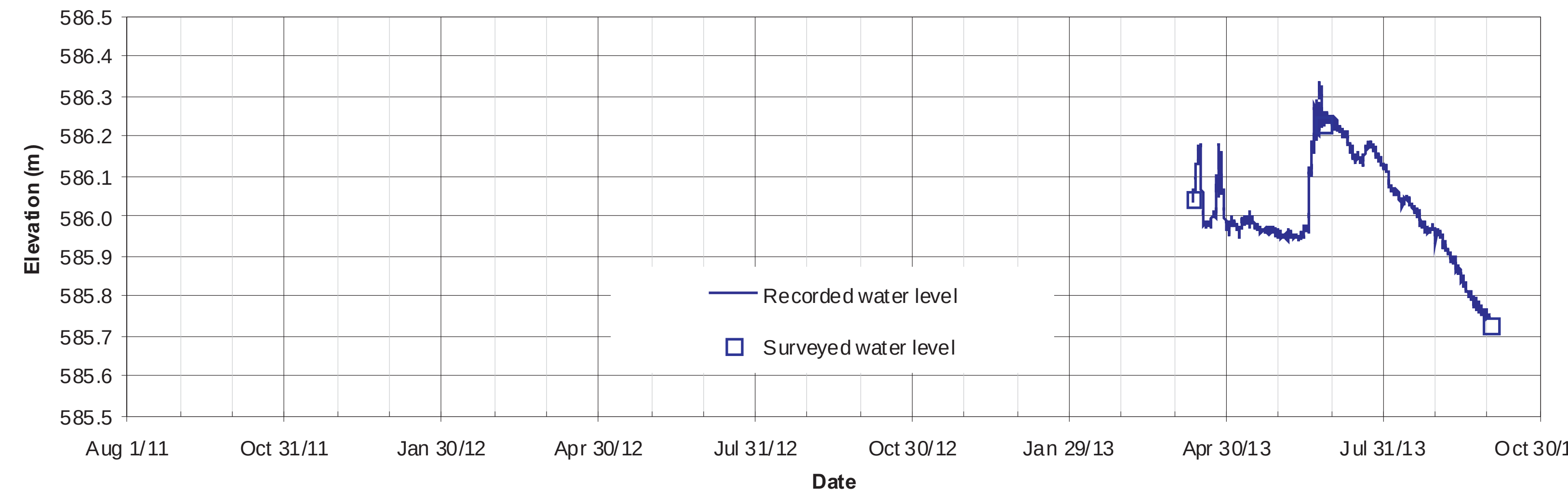
File 17622	2013-12-06	**Figure B5**

northwest hydraulic consultants ltd.

Rating Curve

No detectable flows

Water Level and Discharge Record

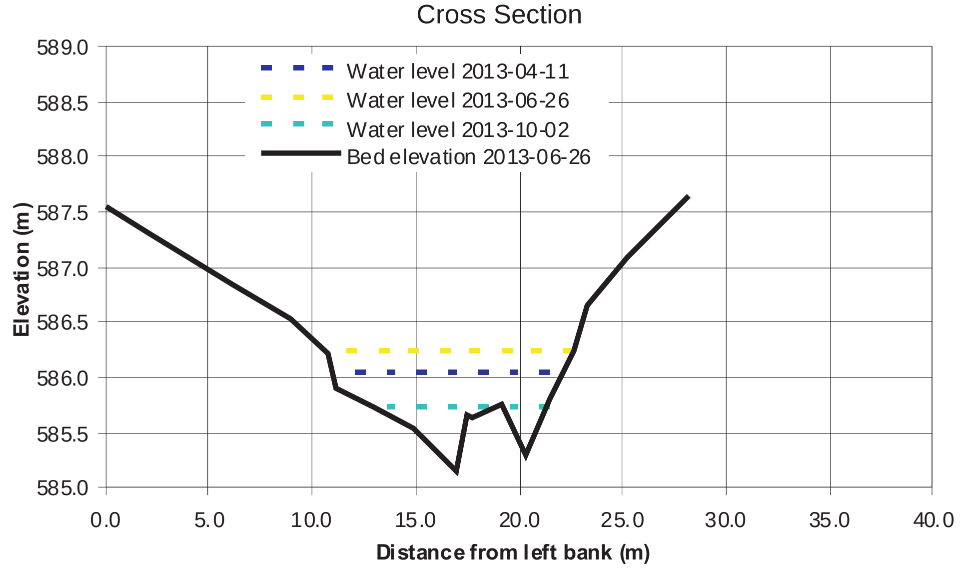


Aerial view of cross section

Cross section

View downstream of cross section

Cross Section



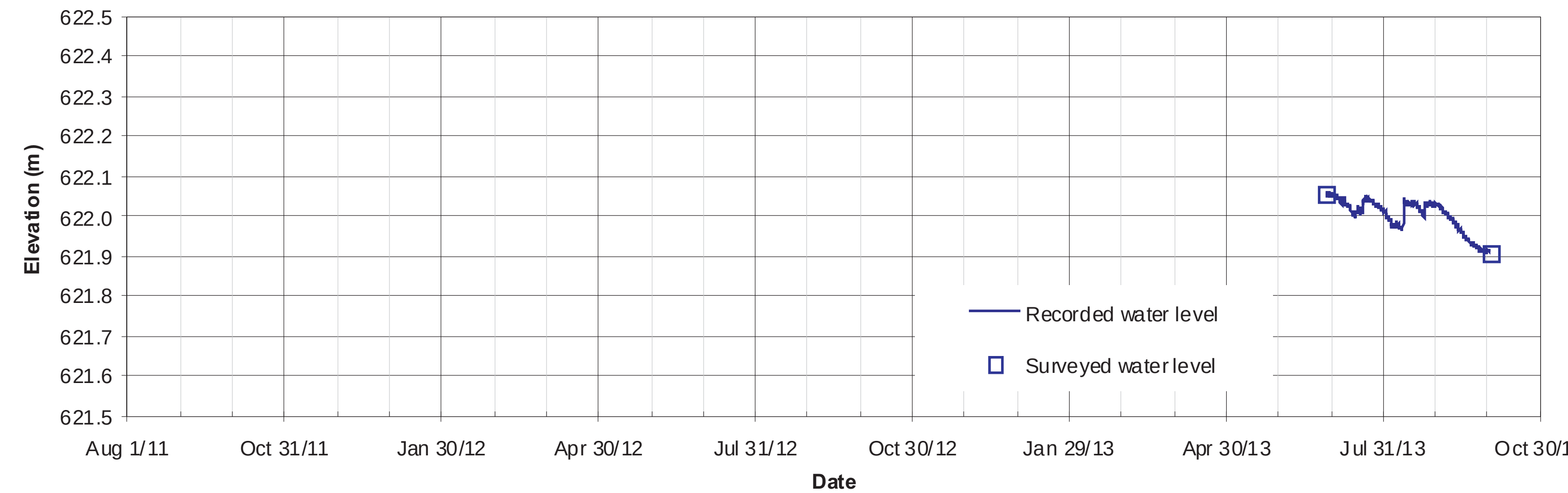
Culvert upstream of cross section

PENGROWTH ENERGY CORPORATION		
LINDBERGH SAGD EXPANSION PROJECT HYDROLOGY ASSESSMENT		
HYDRAULIC CHARACTERISTICS AT SITE S6 (WATERSHED ML5)		
File 17622	2013-12-06	**Figure B6**
northwest hydraulic consultants ltd.		

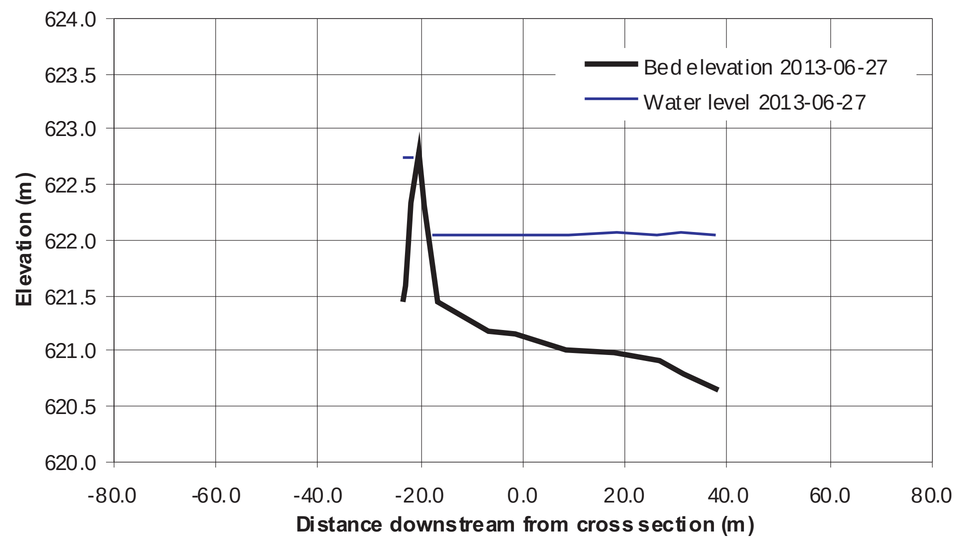
Rating Curve

No detectable flows

Water Level and Discharge Record



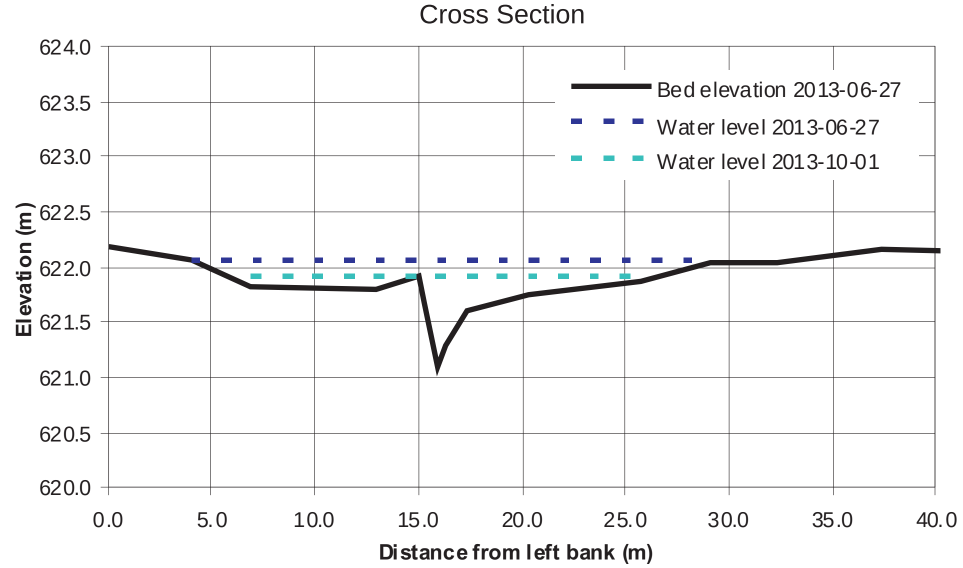
Longitudinal Profile




Cross section


View downstream of cross section

Cross Section




View upstream of cross section

PENGROWTH ENERGY CORPORATION

LINDBERGH SAGD EXPANSION PROJECT
HYDROLOGY ASSESSMENT

HYDRAULIC CHARACTERISTICS AT SITE S7 (WATERSHED G4)

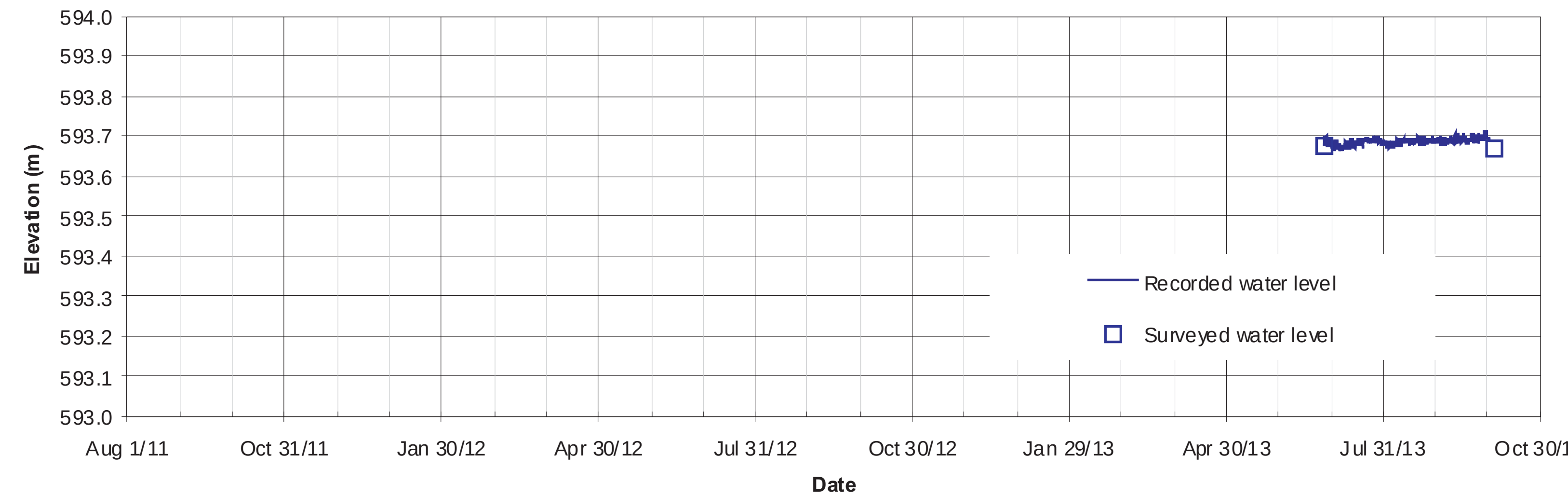
File 17622	2013-12-06	**Figure B7**

northwest hydraulic consultants ltd.

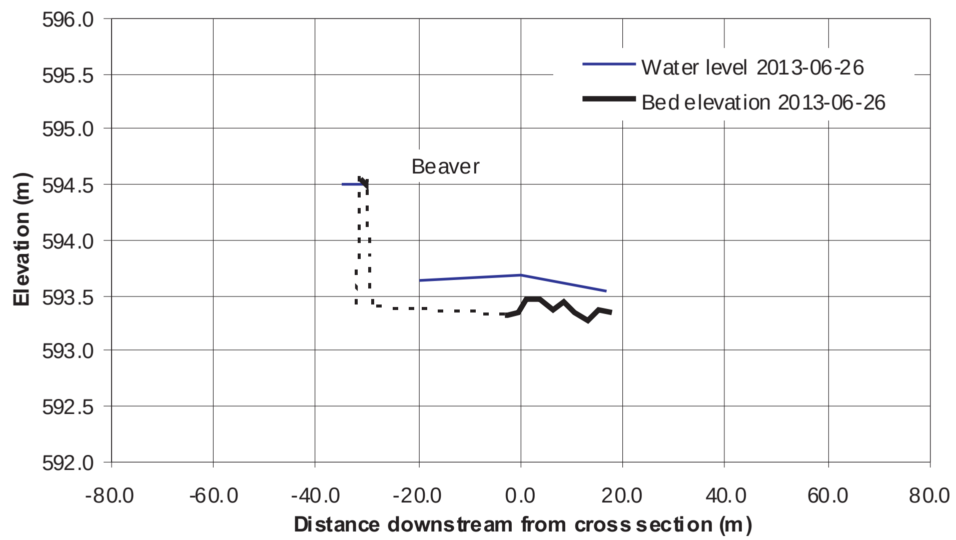
Rating Curve

No detectable flows

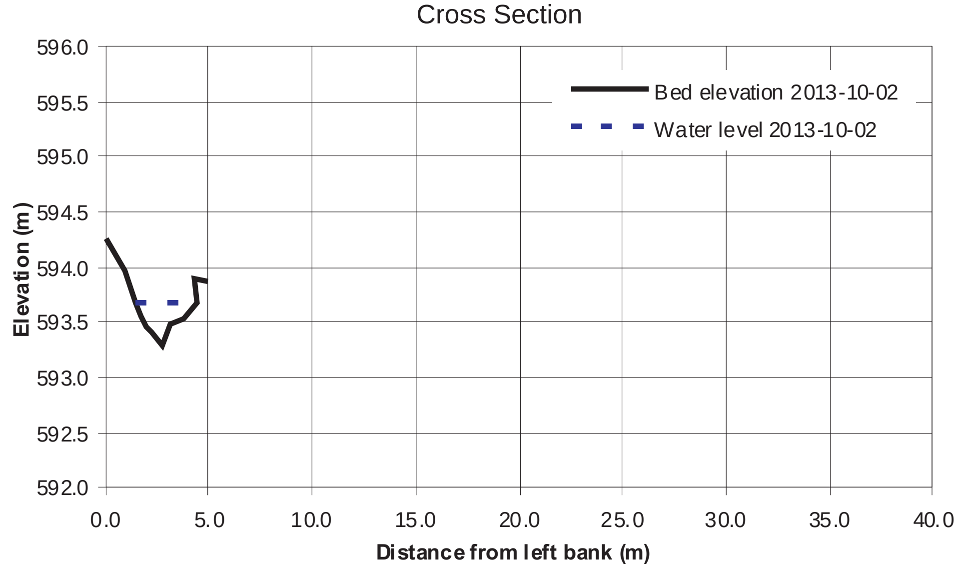
Water Level and Discharge Record



Longitudinal Profile



Cross Section



Cross section

View downstream of cross section

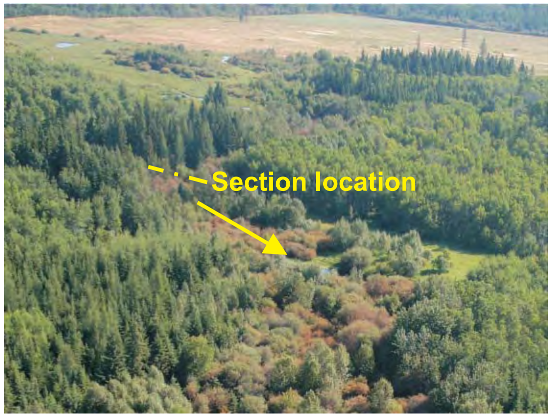
Beaver dam upstream of cross section

PENGROWTH ENERGY CORPORATION		
LINDBERGH SAGD EXPANSION PROJECT HYDROLOGY ASSESSMENT		
HYDRAULIC CHARACTERISTICS AT SITE S8 (BLUET LAKE WATERSHED)		
File 17622	2013-12-06	**Figure B8**
northwest hydraulic consultants ltd.		

APPENDIX C

CHARACTERISTICS OF

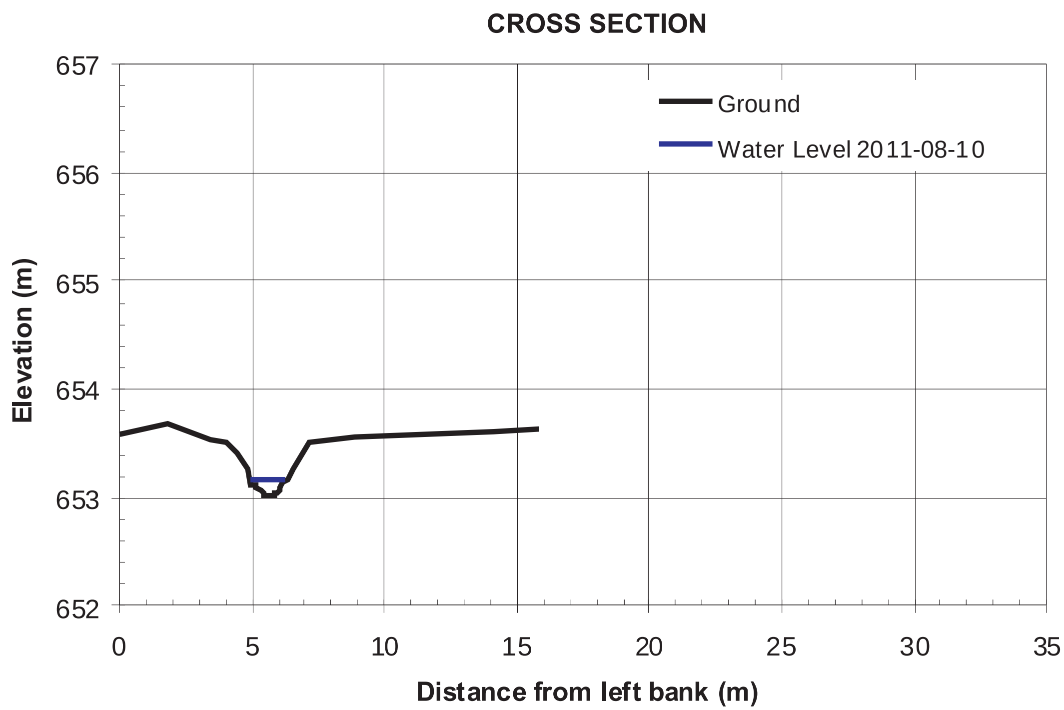
LOCAL CHANNELS AND DRAINAGES



Aerial view of site looking upstream

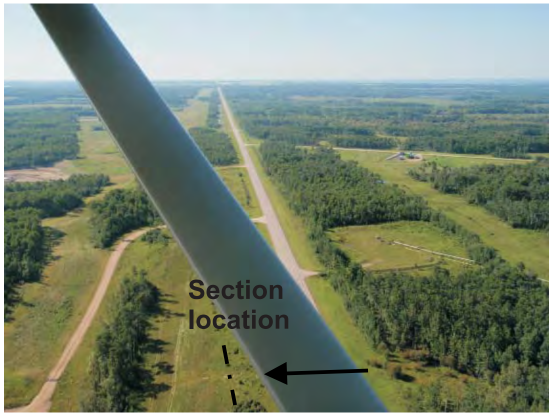
View of section from left bank

View downstream of section



View upstream of section

PENGROWTH ENERGY CORPORATION		
LINDBERGH SAGD EXPANSION PROJECT HYDROLOGY ASSESSMENT		
DRAINAGE CHARACTERISTICS AT SITE A1 (WATERSHED M3b)		
File 17622	2013-12-06	**Figure C1**
northwest hydraulic consultants ltd.		

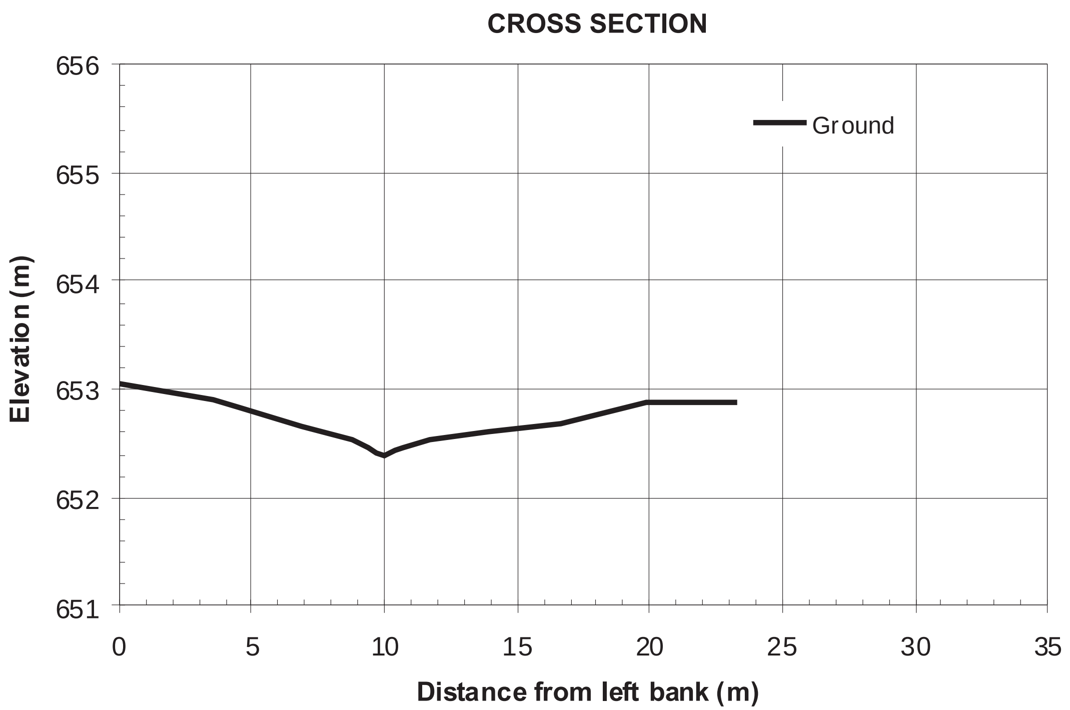


Aerial view of site


View downstream of highway


View upstream of highway


View of culvert looking upstream



PENGROWTH ENERGY CORPORATION

LINDBERGH SAGD EXPANSION PROJECT
HYDROLOGY ASSESSMENT

DRAINAGE CHARACTERISTICS AT SITE A2 (WATERSHED G10)

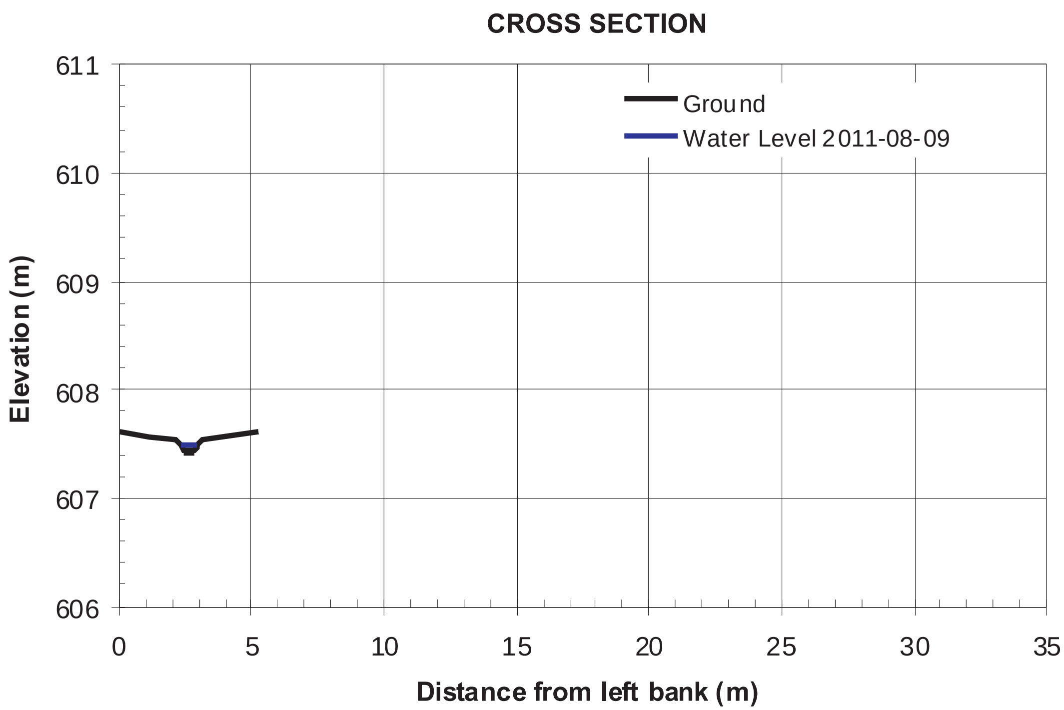
File 17622	2013-12-06	**Figure C2**

northwest hydraulic consultants ltd.

Aerial view of site

View downstream of site

View of flow measurement section



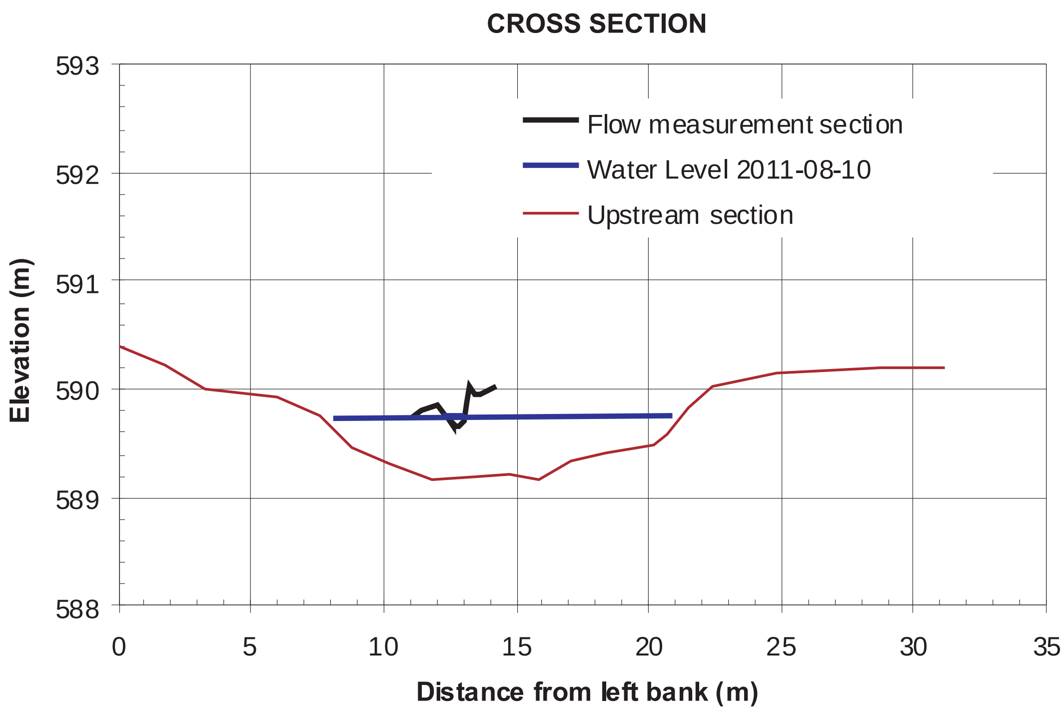
View upstream of highway

PENGROWTH ENERGY CORPORATION		
LINDBERGH SAGD EXPANSION PROJECT HYDROLOGY ASSESSMENT **DRAINAGE CHARACTERISTICS AT SITE A3 (WATERSHED G7)**		
File 17622	2013-12-06	**Figure C3**
northwest hydraulic consultants ltd.		

Aerial view of site

View of section from right bank

View upstream of section



View downstream of section

PENGROWTH ENERGY CORPORATION.

LINDBERGH SAGD EXPANSION PROJECT
HYDROLOGY ASSESSMENT

DRAINAGE CHARACTERISTICS AT SITE A4 (GARNIER CREEK)

File 17622	2013-12-06	**Figure C4**

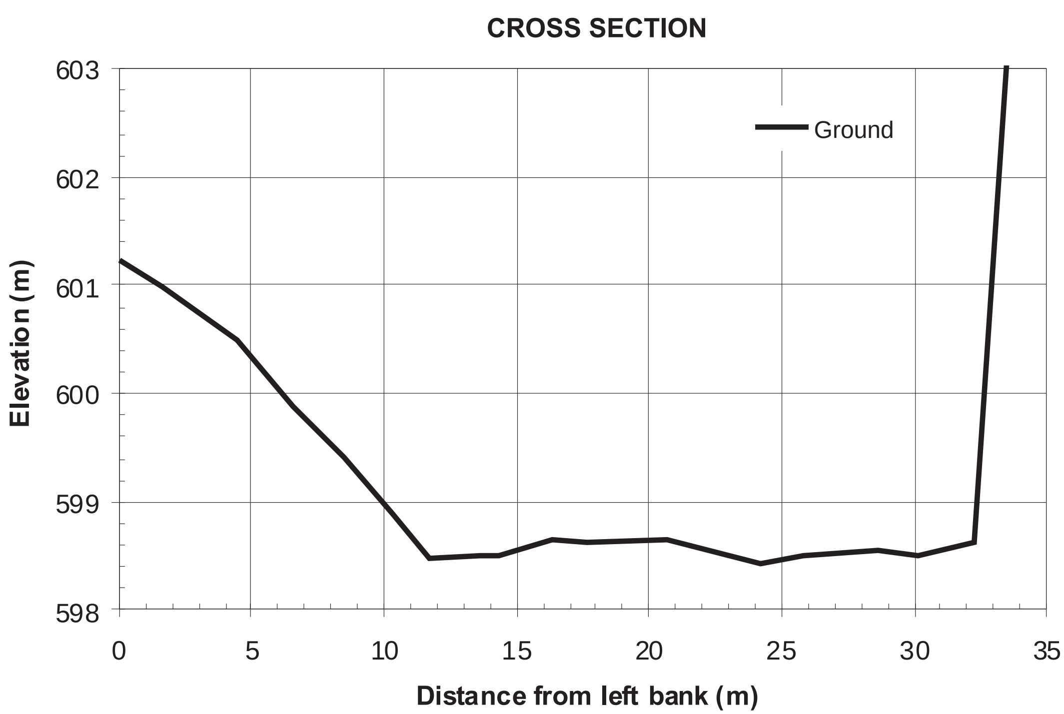
northwest hydraulic consultants ltd.

Previous View Main Menu Search

Aerial view of site


View downstream of section


View downstream of section



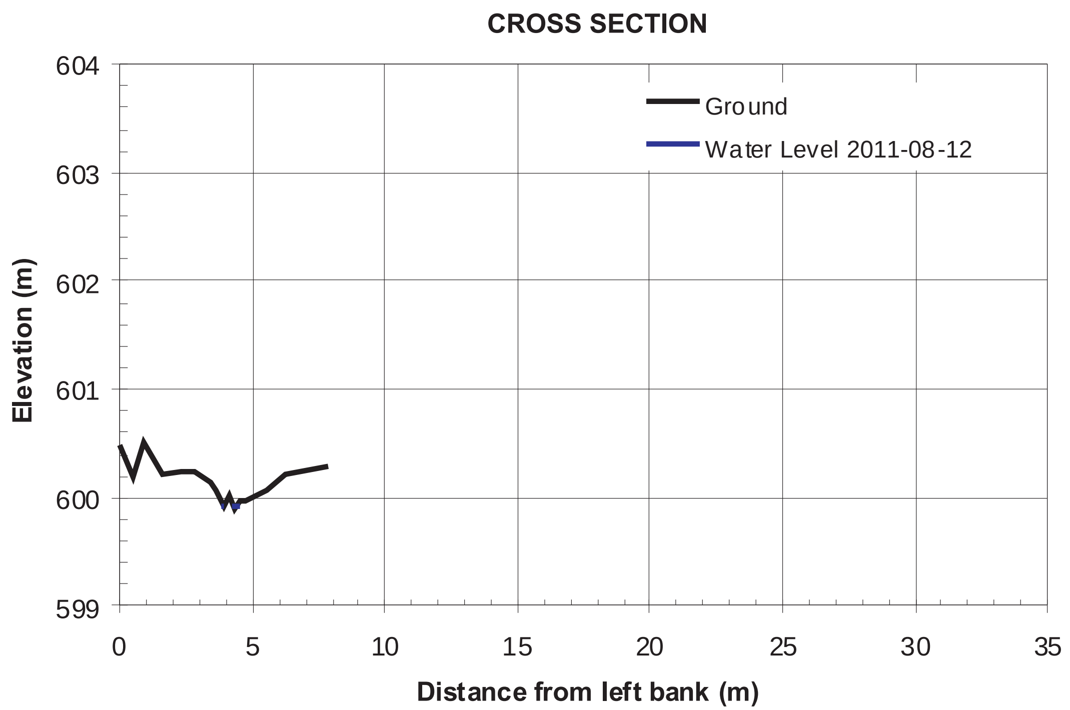

View of section from left

PENGROWTH ENERGY CORPORATION		
LINDBERGH SAGD EXPANSION PROJECT HYDROLOGY ASSESSMENT **DRAINAGE CHARACTERISTICS AT SITE A5 (WATERSHED G6)**		
File 17622	2013-12-06	**Figure C5**
northwest hydraulic consultants ltd.		

Aerial view of site


View of culvert at site


View looking upstream




View from section looking downstream

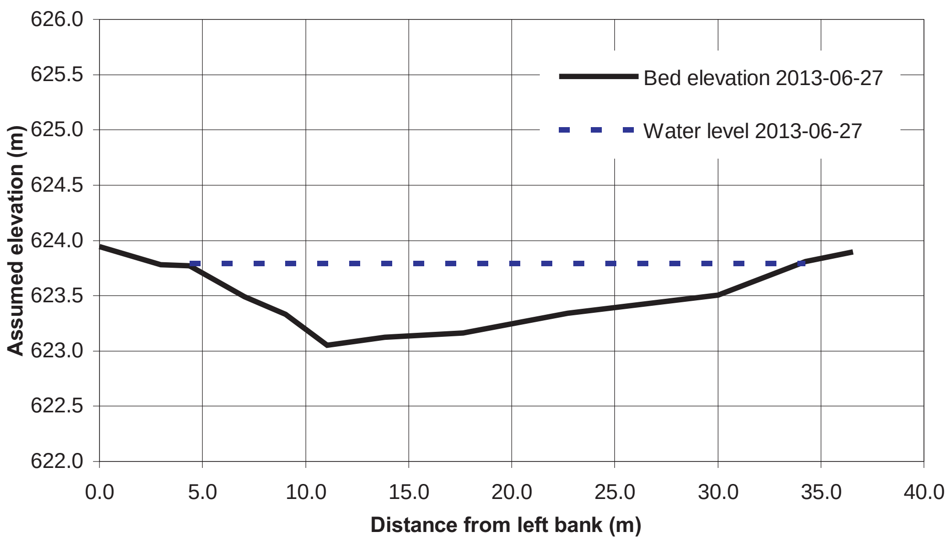
PENGROWTH ENERGY CORPORATION		
LINDBERGH SAGD EXPANSION PROJECT HYDROLOGY ASSESSMENT **DRAINAGE CHARACTERISTICS AT SITE A6 (WATERSHED G5)**		
File 17622	2013-12-06	**Figure C6**
northwest hydraulic consultants ltd.		


View downstream


View upstream


View of beaver dam

CROSS SECTION



PENGROWTH ENERGY CORPORATION		
LINDBERGH SAGD EXPANSION PROJECT HYDROLOGY ASSESSMENT **DRAINAGE CHARACTERISTICS AT SITE C1 (WATERSHED REITA1)**		
File 17622	2013-12-06	**Figure C7**
northwest hydraulic consultants ltd.		

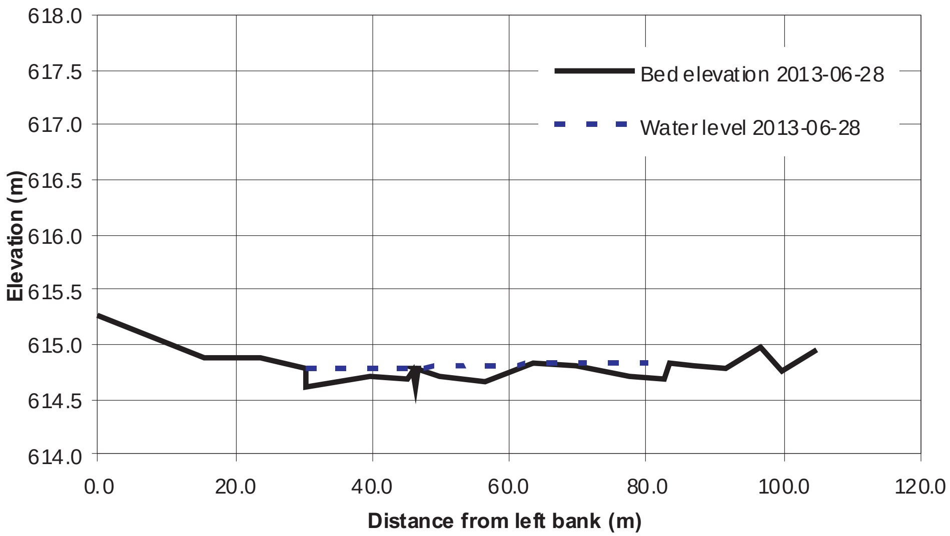
Aerial view upstream of site

View of site

View looking upstream

View looking downstream

CROSS SECTION

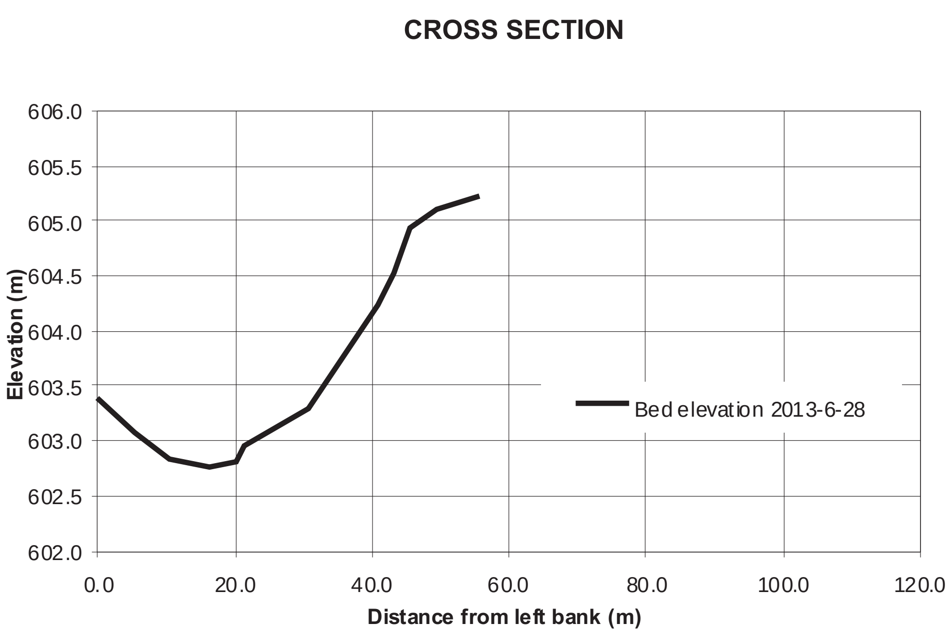


PENGROWTH ENERGY CORPORATION		
LINDBERGH SAGD EXPANSION PROJECT HYDROLOGY ASSESSMENT **DRAINAGE CHARACTERISTICS AT SITE C2 (WATERSHED G2)**		
File 17622	2013-12-06	**Figure C8**
northwest hydraulic consultants ltd.		


View looking upstream


View looking downstream


View of site



PENGROWTH ENERGY CORPORATION

LINDBERGH SAGD EXPANSION PROJECT
HYDROLOGY ASSESSMENT

DRAINAGE CHARACTERISTICS AT SITE C3 (WATERSHED ML5)

File 17622	2013-12-06	**Figure C9**

northwest hydraulic consultants ltd.


View looking upstream


View looking downstream


View of channel bed

PENGROWTH ENERGY CORPORATION		
LINDBERGH SAGD EXPANSION PROJECT HYDROLOGY ASSESSMENT **DRAINAGE CHARACTERISTICS AT SITE C4 (WATERSHED G4)**		
File 17622	2013-12-06	**Figure C10**
northwest hydraulic consultants ltd.		


View looking upstream


View looking downstream


View of culvert inlet

PENGROWTH ENERGY CORPORATION

LINDBERGH SAGD EXPANSION PROJECT
HYDROLOGY ASSESSMENT

DRAINAGE CHARACTERISTICS AT SITE C5 (WATERSHED G4)

File 17622	2013-12-06	**Figure C11**

northwest hydraulic consultants ltd.

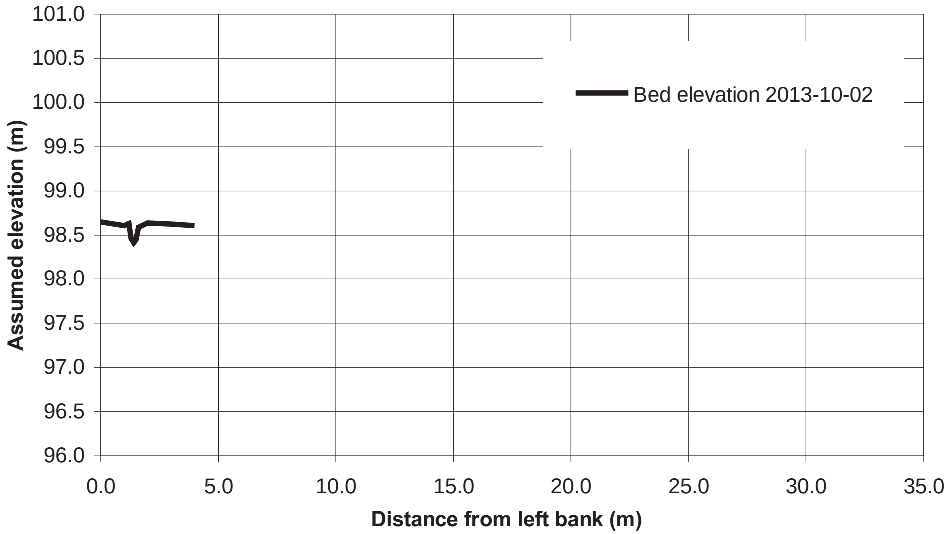
Aerial view of site

View of culvert at site

View looking downstream

View looking upstream

CROSS SECTION



PENGROWTH ENERGY CORPORATION

LINDBERGH SAGD EXPANSION PROJECT
HYDROLOGY ASSESSMENT

DRAINAGE CHARACTERISTICS AT SITE C6 (BLUET LAKE WATERSHED)

File 17622	2013-12-06	**Figure C12**

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