Yukon Energy Corporation

Yukon's Hydroelectric Resources
Yukon Energy Charrette Background Paper

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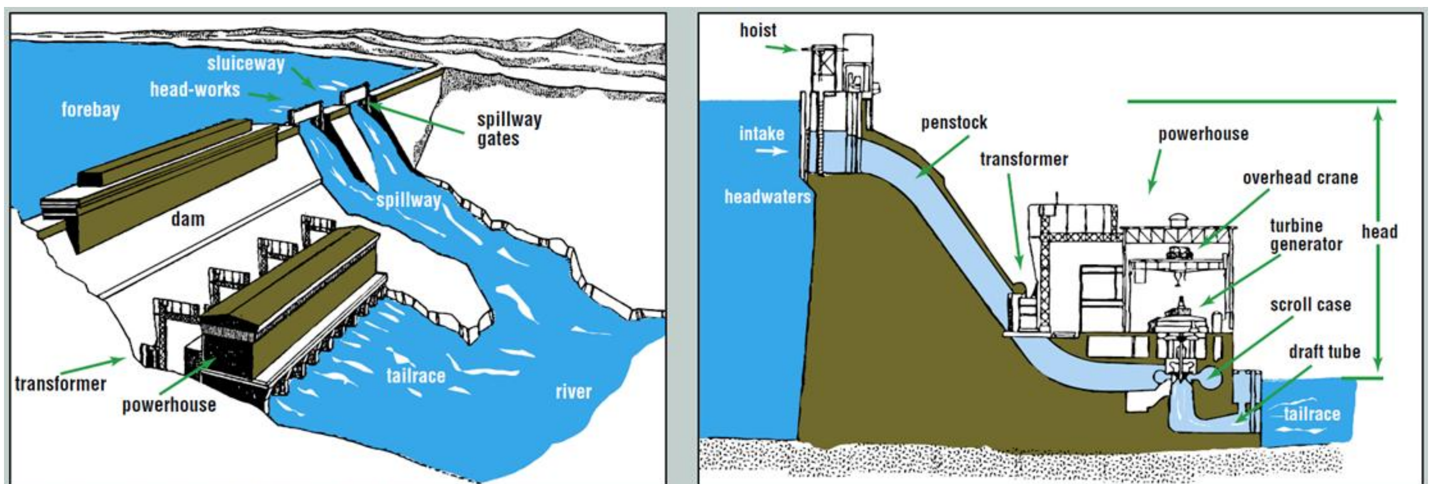
AECOM

1. Hydropower Background
1.1 How Hydropower Works

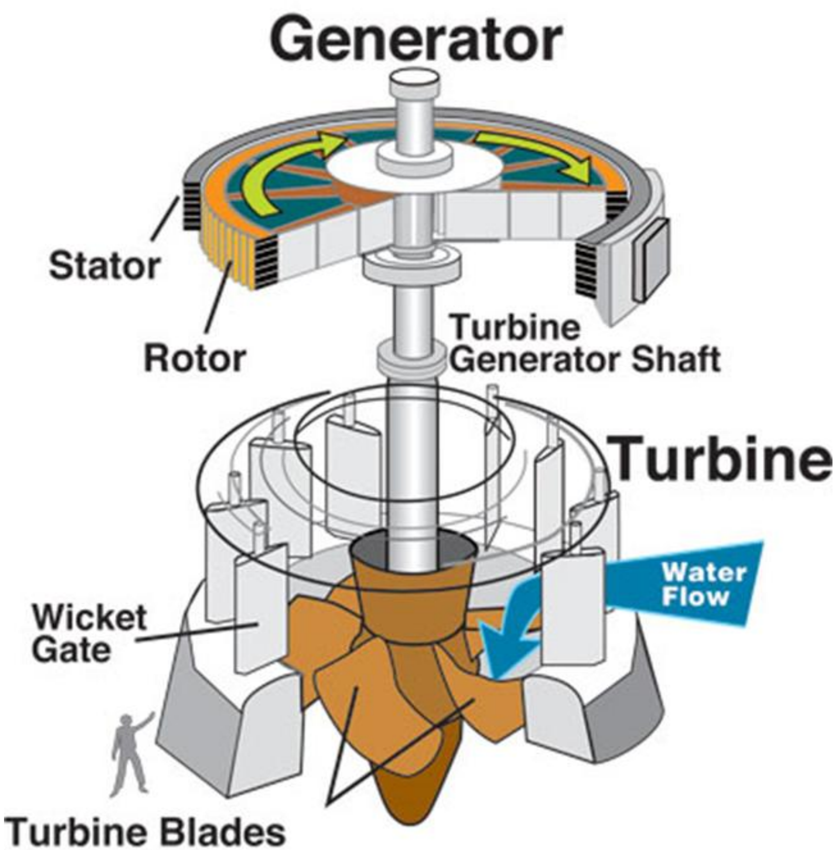
Hydroelectricity is the production of electrical power through the use of the gravitational force of falling or flowing water.



Both drawings adapted from December 1999 report of the Canadian Electricity Association

(from Yukon Development Corp. 2001)

Hydroelectric generation requires a flow of water and a drop, or “head”. A large drop (high head) with low flow can generate a similar amount of energy as a small drop (low head) and high flow.



Electricity is generated by water spinning a turbine and generator.

Hydroelectric generation is a relatively simple, mature technology that is robust. Hydro has been in use since the late 19th century for electrical generation.

Hydropower It is the most widely used form of renewable energy worldwide (REN21 2010). Hydroelectric generation produces very low amounts of green house gasses (GHGs) and no local air or noise pollution.

1.2 History of Hydro in Yukon

Hydropower has played a key role in the Yukon's history over the last century. Milestones in hydropower development in the Yukon:

- 1907 to 1920 – The Yukon's first hydro-plant was the 1.2MW Twelve-Mile River developed to power the dredges near Dawson City.
- 1911 to 1966 - North Fork Klondike River hydro plant.
- 1950 - the 1.6MW Fish Lake hydro scheme was developed near Whitehorse.
- 1952 – Mayo hydro developed to serve the Keno and Elsa mines. 2.5 MW, expanded in 1957 to 5.1 MW
- 1956 – Whitehorse Rapid hydro plant developed to provide electricity for Whitehorse. Initially 11MW, expanded to 19.5 MW in 1966, and then 40 MW in 1985.
- 1966 – Transmission line built from Whitehorse to Faro to service the Faro mine.
- 1974 – 30MW Aishihik Lake hydro developed to keep pace with rising electrical demand in Yukon
- 2003 – Mayo-Dawson transmission line completed to provide hydroelectricity to Dawson City from the Mayo dam.

Whitehorse dam under construction in 1957 (Lister 2008)

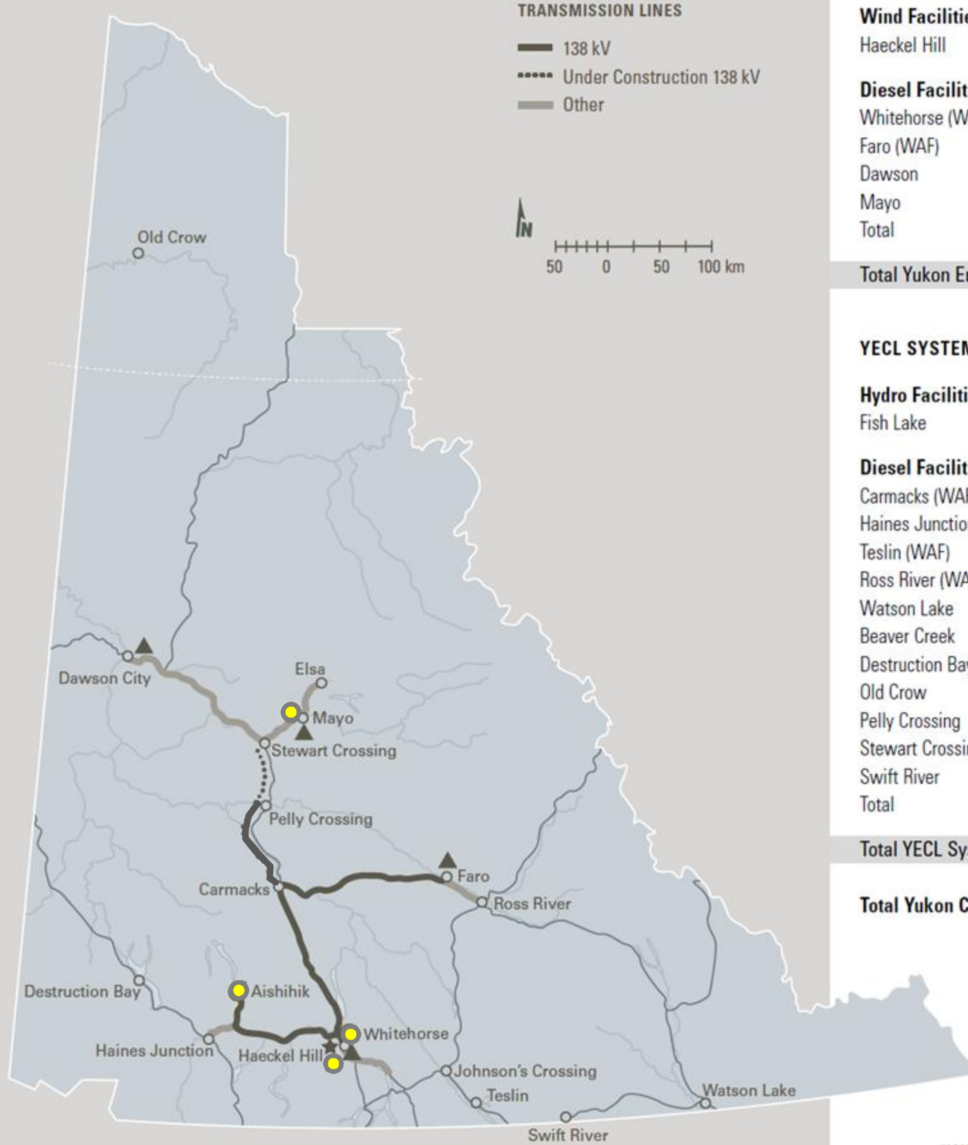
(from The Power of Water, *Yukon Development Corp. 2001)*

2. Hydro Resource Capacity

2.1 Current Hydro Facilities in Yukon

There are four hydroelectric generation facilities in the Yukon that supply the public energy grid:

1. Aishihik
2. Whitehorse
3. Mayo
4. Fish Lake



(adapted from Yukon Energy Corp. 2008)

YUKON ENERGY SYSTEM	(IN MW)
Hydro Facilities	
Whitehorse (WAF) *	40.0
Aishihik	30.0
Mayo	5.4
Total	75.4
Wind Facilities	
Haeckel Hill	0.8
Diesel Facilities	
Whitehorse (WAF)	25.0
Faro (WAF)	5.4
Dawson	6.0
Mayo	2.0
Total	38.4
Total Yukon Energy System	114.6

YECL SYSTEM	(IN MW)
Hydro Facilities	
Fish Lake	1.3
Diesel Facilities	
Carmacks (WAF)	1.3
Haines Junction (WAF)	1.3
Teslin (WAF)	1.3
Ross River (WAF)	1.0
Watson Lake	5.0
Beaver Creek	0.9
Destruction Bay	0.9
Old Crow	0.7
Pelly Crossing	0.7
Stewart Crossing	0.3
Swift River	0.3
Total	13.7
Total YECL System	15.0
Total Yukon Capacity	**129.6**

*WAF: Whitehorse-Aishihik-Faro interconnected grid

2. 2 Current Hydro Development

Current capacity and annual energy from the Yukon's hydro infrastructure is listed below. Additionally, two projects are currently under construction that will enhance the capacity and energy from these facilities:

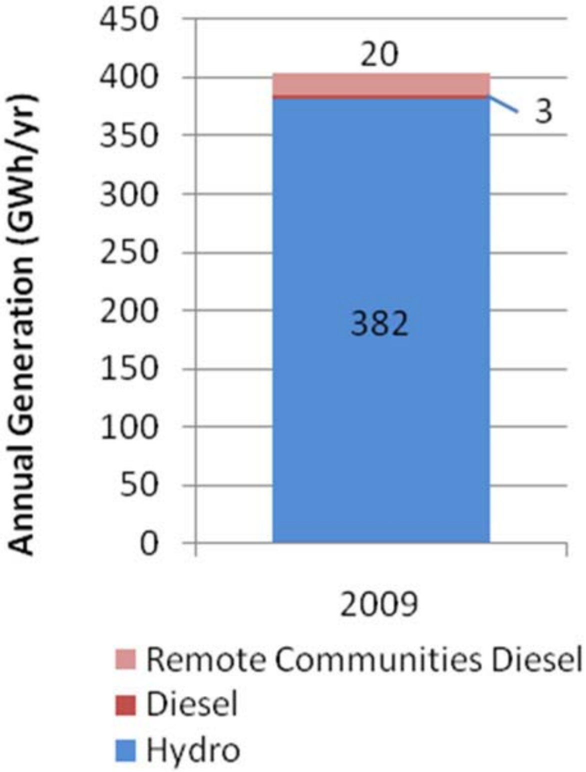
1. Mayo B – 10 MW additional capacity
2. Aishihik 3rd Turbine – 7 MW additional capacity

Facility	Currently Installed Capacity, MW	Annual Energy, GWh/yr (Current)	Enhanced Capacity, MW	Enhanced Annual Energy, GWh/yr
Whitehorse	40	245	40	245
Aishihik	30	105	**37**	**110**
Mayo	5.4	40	**15**	**76**
Fish Lake	1.3	7	1.3	7
Total	76.7	397	93.3	438

2.3 Current Role of Hydro in Yukon

94% of all the Yukon electricity in 2009 was generated from hydropower. 99% of electricity on the Whitehorse, Aishihik, Faro (WAF) and Mayo-Dawson grids is provided by hydropower.

Yukon has enjoyed the lowest GHG emissions per capita in Canada . This emission rate was 10.5 tonnes of CO_2/year/person in 2008 (National Inventory Report 1990–2008: Greenhouse Gas Sources and Sinks in Canada (Environment Canada 2010) and is partially because of our renewable-based electric generating system.



(compiled from Yukon Energy Corp. 2010 and Yukon Bureau of Statistics, 2010)

3. Energy Potential

3.1 Overview of Hydro Potential in the Yukon

Much of the Yukon has mountainous terrain and abundant water, creating numerous hydropower opportunities. However, there are few “easy” hydropower sites. Few sites exist in the Yukon with a significant drop in elevation (head) and with significant flow, especially during winter months.

The Yukon’s existing hydro facilities have taken advantage of natural lakes to provide storage during winter months. Many of the potential new hydropower sites require creation of a reservoir to store water.

Run-of-river hydropower schemes are of lower value because they provide significantly less power during winter months, when the power is needed the most.

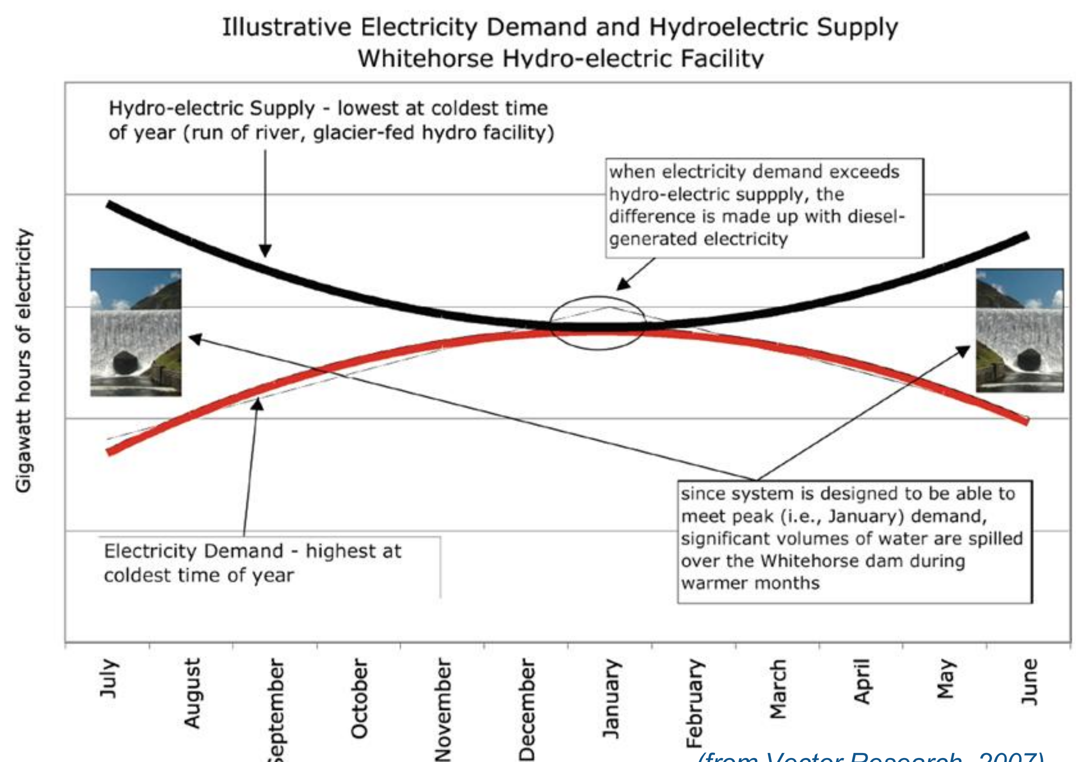
Hoole Canyon on the Pelly R.

3.2 Hydropower – Seasonal Considerations

Energy demand is highest during winter months in Yukon, however stream flow is lowest during winter months.

Accordingly, hydropower needs storage to generate energy during winter months. This makes run-of-river projects (i.e. Hydro projects without storage) of reduced value in Yukon.

Additionally, year-to-year hydrology (stream flow) can vary significantly, making generation variable each year. However, to date we have not seen long-term declining or increasing stream flow trends.

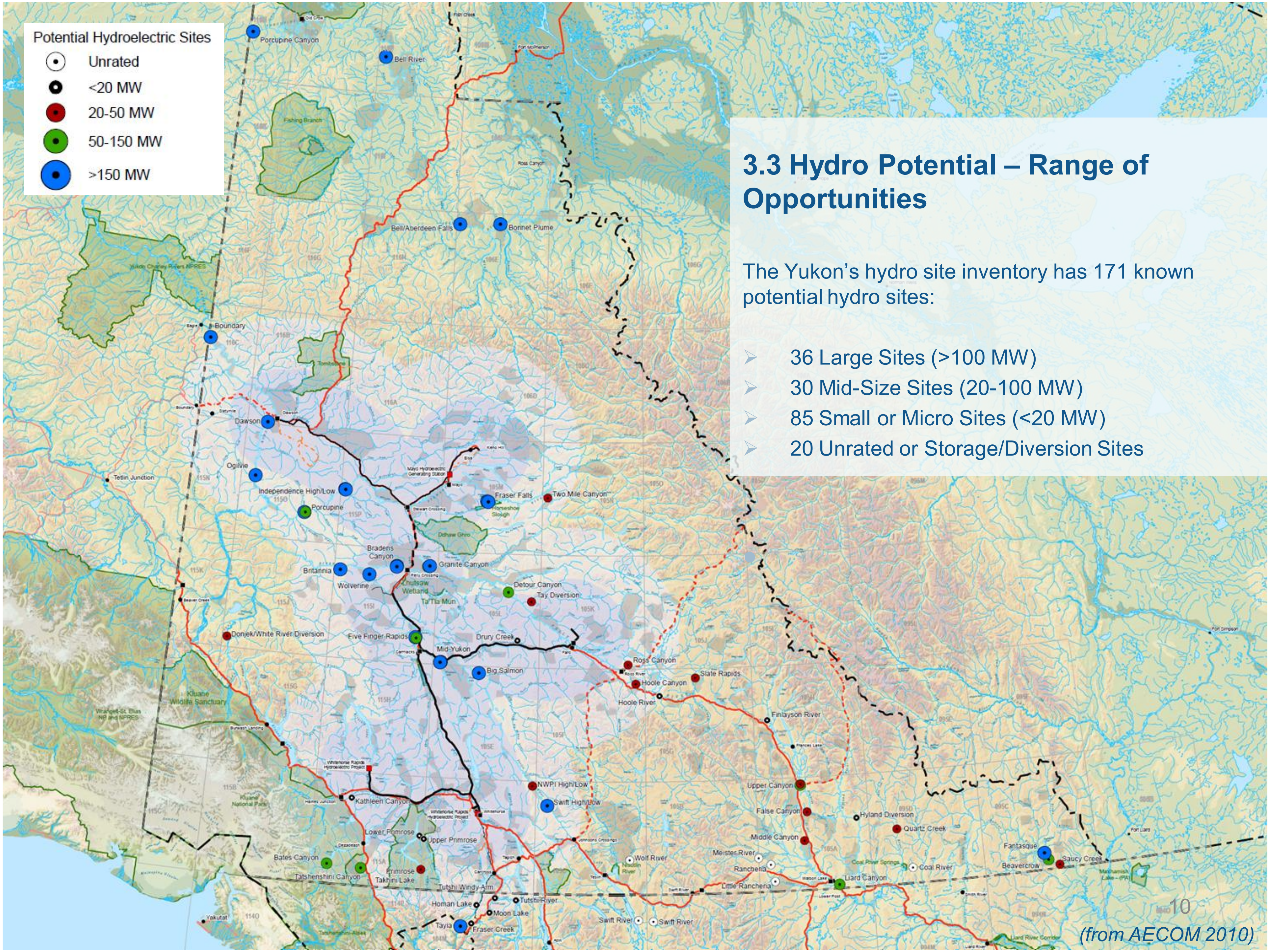


(from Vector Research, 2007)

3.3 Hydro Potential – Range of Opportunities

The Yukon’s hydro site inventory has 171 known potential hydro sites:

- 36 Large Sites (>100 MW)
- 30 Mid-Size Sites (20-100 MW)
- 85 Small or Micro Sites (<20 MW)
- 20 Unrated or Storage/Diversion Sites



(from AECOM 2010)

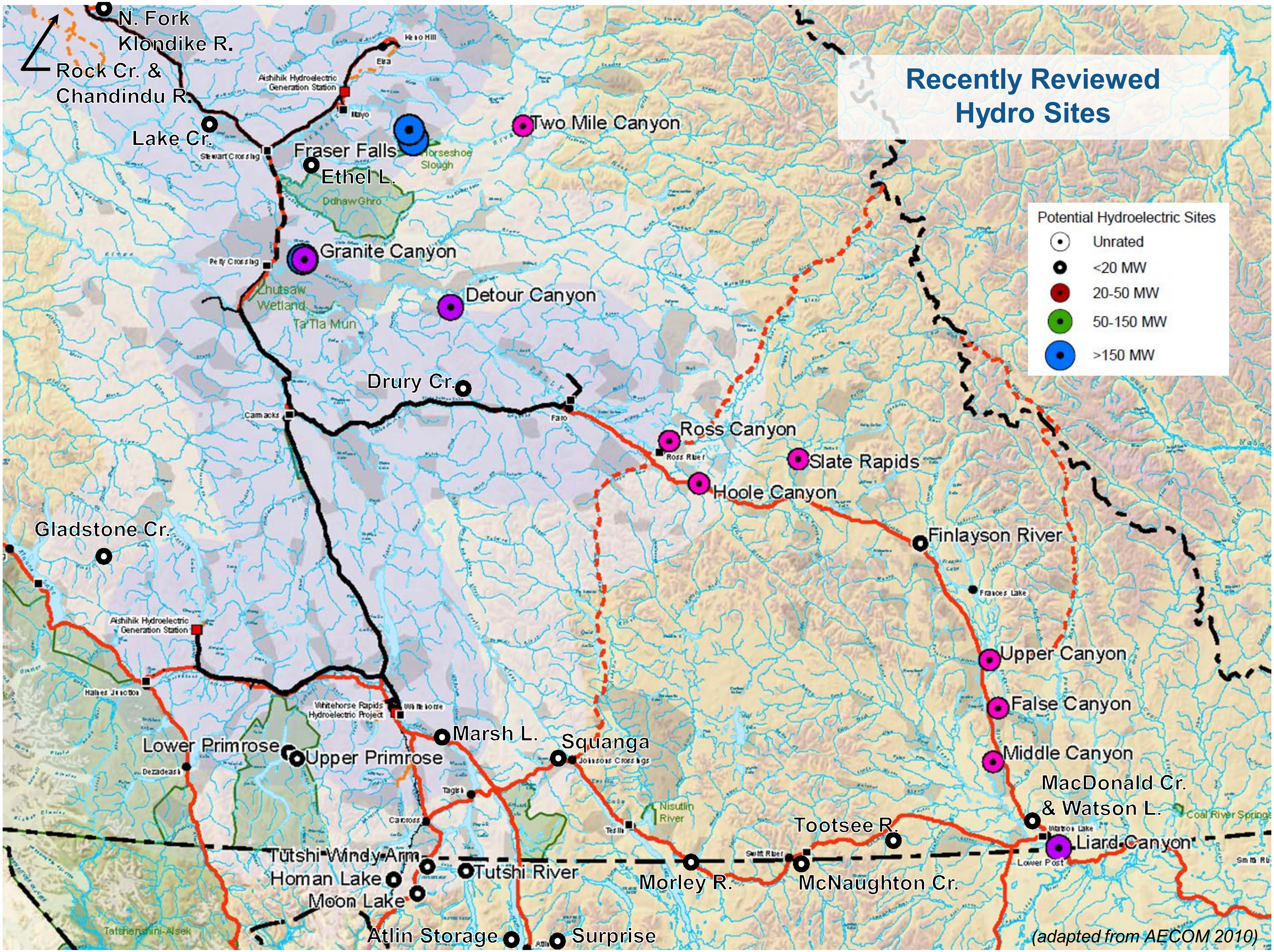
3.4 Hydro Opportunities – Site Screening

Many of known hydro “sites” in the Yukon have not undergone detailed or recent assessment, and therefore the viability of many hydro sites in the Yukon is uncertain.

Four studies have been conducted in the last 10 years that reviewed or evaluated some of the known hydro sites for potential viability:

1. Watson-Teslin area – BC Hydro 2003 – 7 sites
2. Mayo-Dawson area – BC Hydro 2003 – 6 sites
3. Potential Hydro Sites Assessment – KGS 2008 – 8 sites
4. Large Hydro Initial Evaluation – AECOM 2010 – 21 preferred sites

Between these four studies, a total of 29 potentially viable known sites have been looked at recently, including the hydro enhancement projects (Marsh Lake, Atlin Storage and Gladstone Diversion). The location of these sites is shown on the following map.


Recently Reviewed Hydro Sites
Potential Hydroelectric Sites
Unrated
<20 MW
20-50 MW
50-150 MW
>150 MW
N. Fork Klondike R.
Rock Cr. & Chandindu R.
Lake Cr.
Fraser Falls
Ethel L.
Two Mile Canyon
Granite Canyon
Detour Canyon
Drury Cr.
Ross Canyon
Slate Rapids
Hoole Canyon
Finlayson River
Gladstone Cr.
Upper Canyon
False Canyon
Middle Canyon
MacDonald Cr. & Watson L.
Liard Canyon
Tootsee R.
McNaughton Cr.
Morley R.
Squanga
Marsh L.
Lower Primrose
Upper Primrose
Tutshi-Windy Arm
Homan Lake
Moon Lake
Tutshi River
Atlin Storage
Surprise
Aishihik Hydroelectric Generation Station
Whitehorse Rapids Hydroelectric Project
Horseshoe Slough
Lhutsaw Wetland
Ta'Tla Mun
Nisutlin River
Coal River Springs
(adapted from AECOM 2010)

3.5 Large Hydro Initial Evaluation

In 2009/2010 an initial evaluation of known large hydro sites was completed by AECOM to identify preferred sites for further study. The evaluation used a sustainability based evaluation criteria, evaluating known sites relative to each other to identify the relatively best site(s). The qualitative, equally weighted evaluation considered:

1. Economic,
2. Environmental, and
3. Social aspects.

The objective of the Large Hydro Initial Evaluation was to identify a set of preferred hydro sites:

- 2 sites in the 20-40 MW range;
- 1 site in the 100 MW range; and
- 1 site in the 200 MW range.

Large Hydro Initial Evaluation – General Approach

Data Compilation (175 Hydro Schemes)

↓

Pre-Screening (58 Hydro Schemes)

↓

Preferred Sites (25 Hydro Schemes)

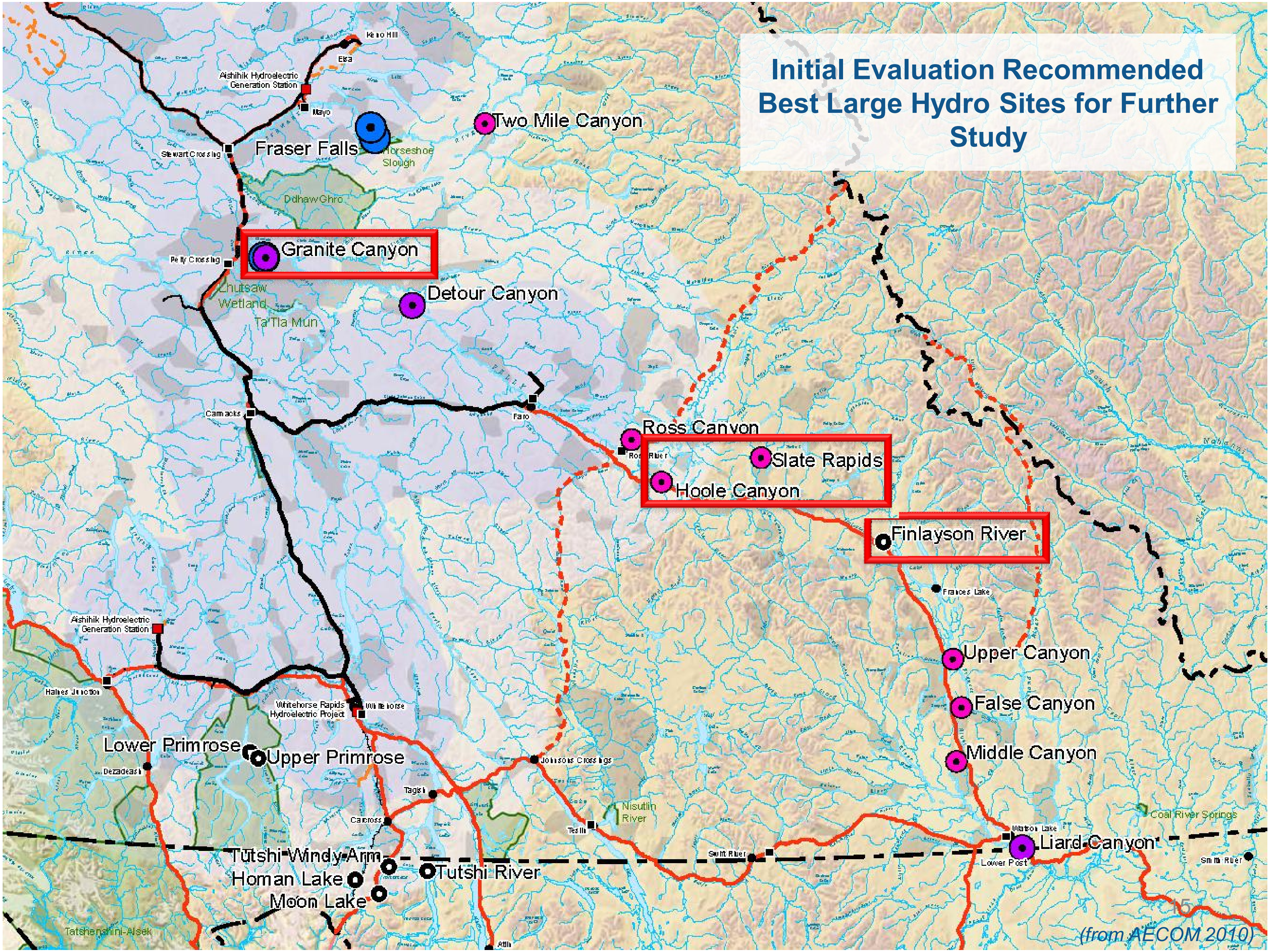
↓

Recommendations for further study (4 Hydro Schemes)

Note:

- Only previously proposed projects were considered in this study
- The study consisted of a contemporary review earlier works

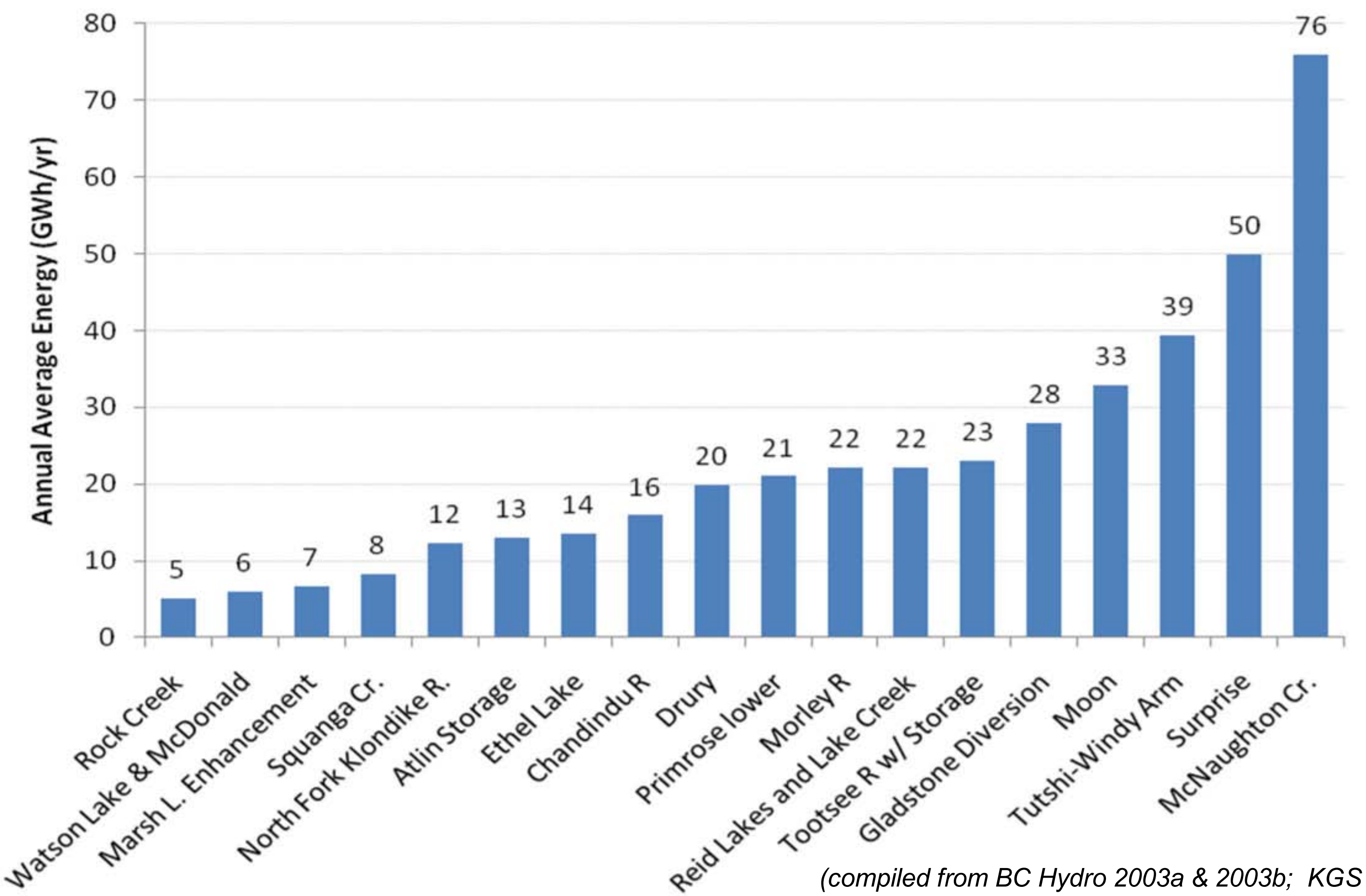
Initial Evaluation Recommended Best Large Hydro Sites for Further Study



(from AECOM 2010)

3.6 Hydro Potential – Annual Average Energy Small Sites (<10 MW)

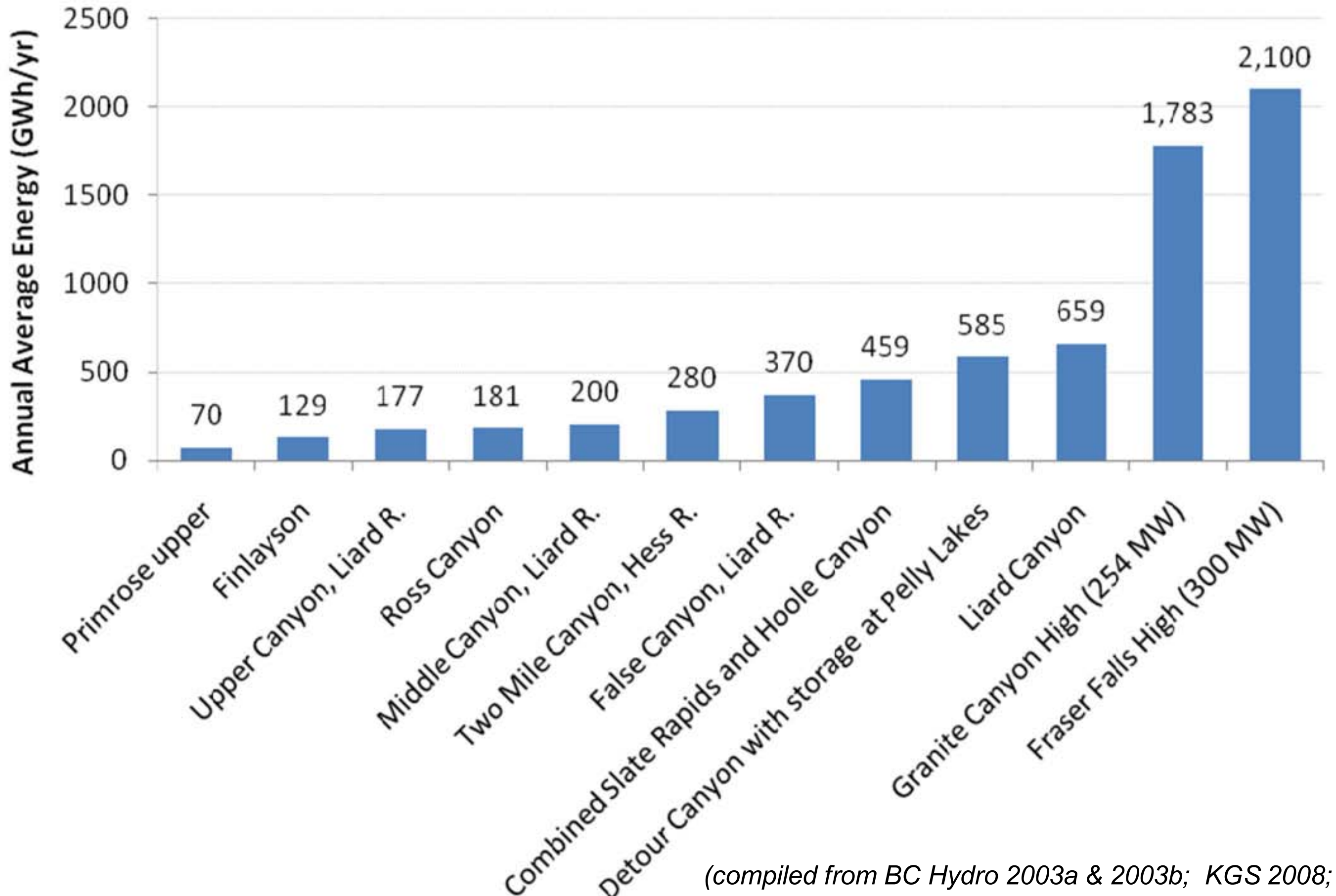
This figure shows the current estimated annual average energy potential for small hydro sites (<10MW) that have been reviewed in the last 10 years.



(compiled from BC Hydro 2003a & 2003b; KGS 2008; AECOM 2010)

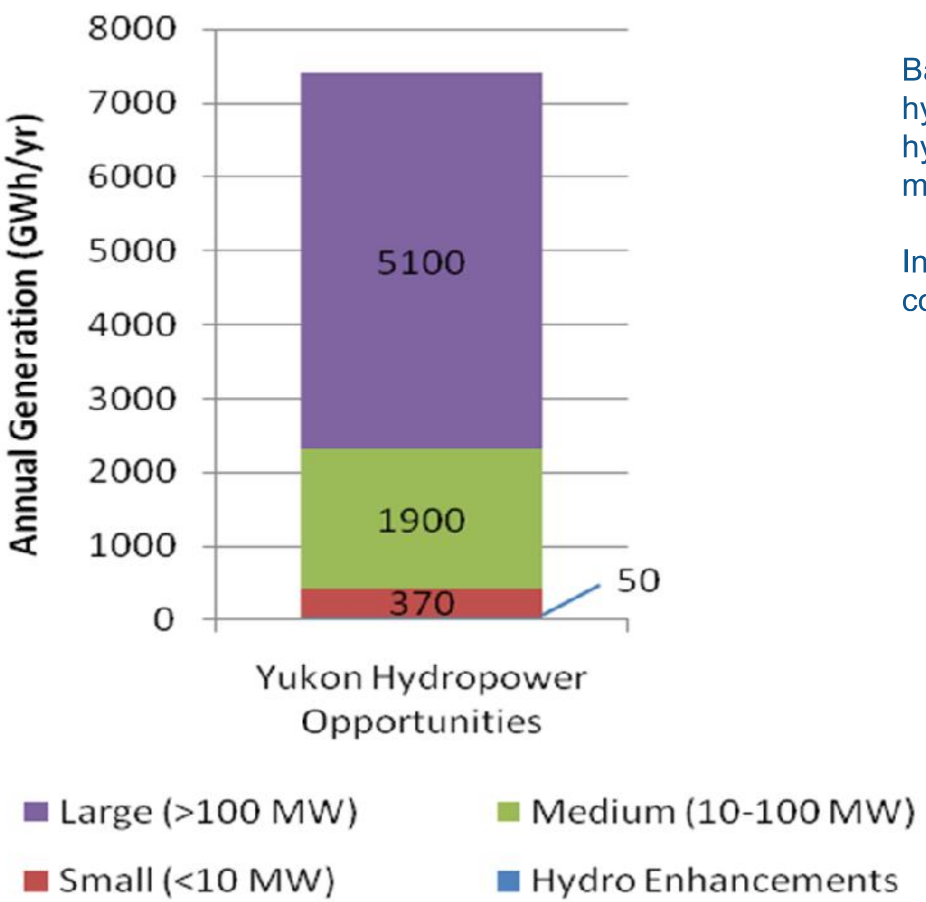
3.7 Hydro Potential – Annual Average Energy Medium & Large Sites (>10 MW)

This figure shows the current estimated annual average energy potential for medium and large hydro sites (>10MW) that have been reviewed in the last 10 years.



(compiled from BC Hydro 2003a & 2003b; KGS 2008; AECOM 2010)

3.8 Hydro Potential – Total Annual Energy Potential of Evaluated Hydro Sites



Based on the known sites that are likely viable hydropower sites, there is over 10 times more hydroelectric potential in the Yukon than required to meet the Yukon's current energy demands.

In other words, all of the Yukon's electricity needs could be met with hydroelectricity.

(compiled from BC Hydro 2003a & 2003b; KGS 2008; AECOM 2010)



4. Energy Costs

4.1 Yukon Potential Hydroelectric Projects – Energy Costs

	Annual Energy Range / Site (GWh/yr)	Levelized Cost of Energy, LCOE Range[1,3] ($2009)	Weighted Average LCOE[2]
Hydro Enhancements	6.7 to 28	$0.068 to $0.09 / kWh	$0.068 / kWh
Small Hydro (<10 MW)	5 to 76	$0.07 to $0.31 / kWh	$0.137 / kWh
Medium Hydro (10-100 MW)	70 - 659	$0.06 to $0.19 / kWh	$0.095 / kWh
Large Hydro (>100 MW)	585 - 2100	$0.05 to $0.11 / kWh	$0.065 / kWh

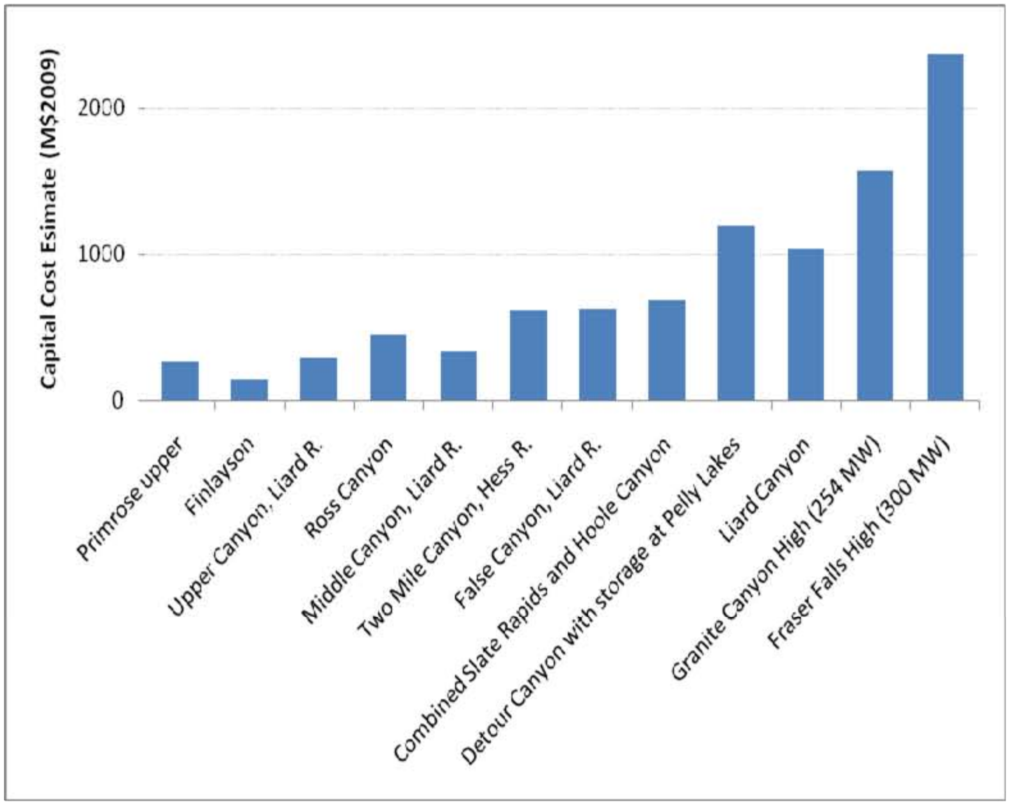
Hydroelectric energy costs are largely controlled by the construction cost of the project (capital expenditure) and the amount of energy produced. Operation and maintenance costs are relatively low and there are no ongoing fuel requirements.

Energy costs vary considerably from project-to-project, but generally large projects produce lower cost energy than smaller projects.

4.2 Yukon Potential Hydroelectric Projects – Capital Costs

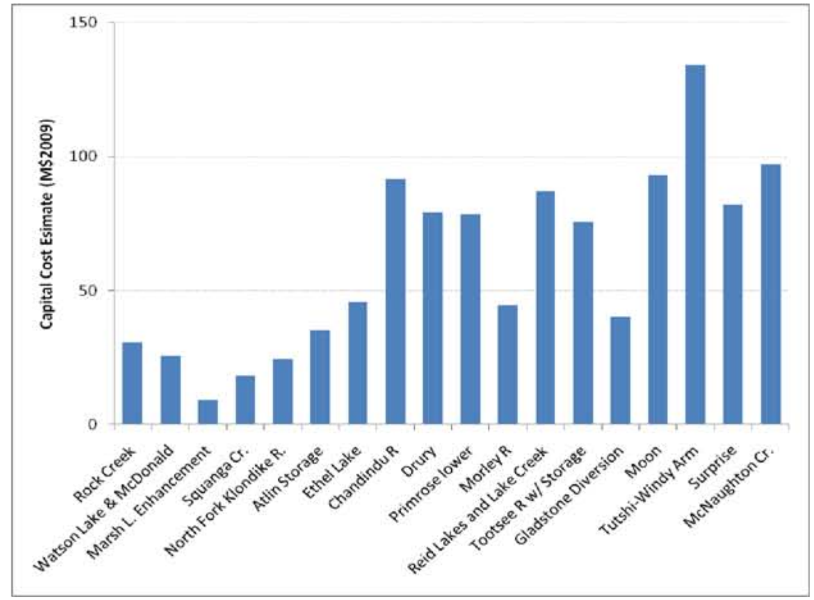
Hydropower development is capital intensive to develop, but has a very long service life (>60 years) and relatively low ongoing costs (low operation and maintenance).

Medium and Large Sites (>10 MW)



(compiled from BC Hydro 2003a & 2003b; KGS 2008; AECOM 2010) [3]

Small Sites (<10 MW) and Hydro Enhancements



Current estimates of hydropower development opportunities in the Yukon are illustrated above. Note that the quality of the estimates vary substantially depending on the level of study to date. As such, these estimates should be considered general order of magnitude only and are subject to change based on project design and other considerations.

4.3 Hydropower Electricity Cost Considerations

When evaluating the electricity cost from hydropower, there are a number of key items that must be taken into consideration, including:

- Cost of electricity generated from hydropower is largely a function of project construction cost.
- Sites further from the grid become more expensive because transmission line costs need to be considered.
- There are no on-going fuel costs with hydropower or risk of fuel cost escalation & variability.
- Year-to-year variation in hydrology (amount of water available for hydroelectric generation) can be significant , and up to 60% year-to-year variability can be seen in the Yukon.
- Hydro generation of electricity must be useable to be of value:
  - Winter generation is important and generation of large quantities of electricity in summer months is of limited value.
  - Storage of water is required to generate power in winter months when flows are lowest, but energy demand is greatest. Multi-year storage is desirable to accommodate year-to-year variation in hydrology.
- Climate change effects on hydroelectric production could be positive (increased stream flow) or negative (decreased winter flows) depending on location in the Yukon.

5. Hydropower - Complimentary Applications

Hydropower is somewhat unique in that can compliment other energy options well due to hydro's flexibility. Specifically:

1. Hydropower has a quick response time relative to many other electrical generation options. Hydro can respond well to load fluctuations or generation upsets elsewhere in the system.
2. Hydropower is flexible and can "store" energy by storing water until needed. This can help deal with day-to-day fluctuations as well as inter-seasonal and even multi-year variability.
3. Excellent generation option to integrate with intermittent renewables (e.g. wind and solar) because hydro responds well to variability in generation. Typically natural gas electrical generation is used to compliment intermittent renewables in areas without hydro (Hagens 2010). As such, the Yukon is fortunate to have significant hydro assets as this can accommodate and compliment windpower without requiring natural gas electrical generation.

Haekel Hill Wind Turbines (Government of Yukon 2009)

5.1 Hydropower – Additional Applications

An additional applications for hydropower development include pumped storage. Pumped storage is a hydro-based energy storage option that pumps water to a higher elevation reservoir for storage until needed for generation.

Pumped storage can provide high capacity energy storage and could help make more of intermittent renewables' (wind/solar) energy usable.

Additional uses and benefits of hydro development can also include:

- Flood control
- Flow regulation
- Recreational opportunities
- Irrigation

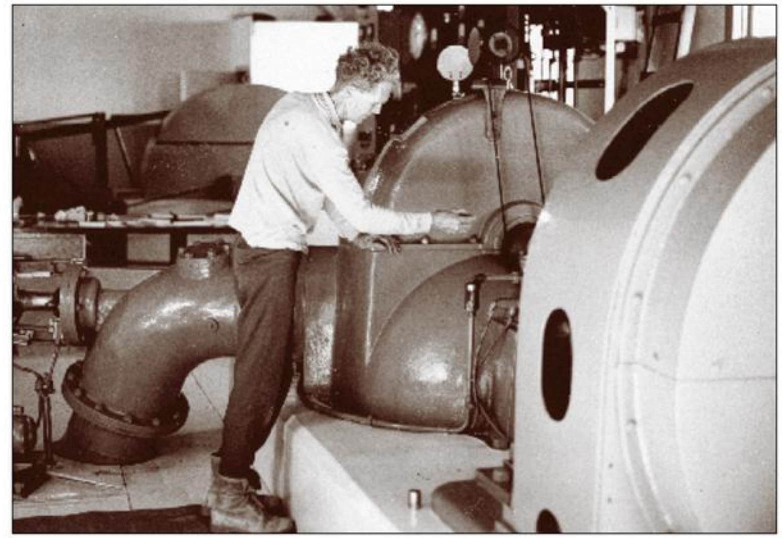
Llyn Stwlan, the upper reservoir of the Ffestiniog pumped storage scheme in north Wales. Energy stored: 1.3 GWh (MacKay, 2008)

6. Probability to Market

Hydropower is a well established, relatively simple and mature technology, making overall development risk low. The Yukon and Canada has long experience with hydro. This includes developers, contractors and operators with experience building and operating hydropower facilities.

Project costs and long-term energy generation can be estimated with good confidence given the maturity and relative simplicity of the technology. Hydropower projects are not subject to fuel cost escalation risk or fuel short-supply risk. However, as with all construction projects, hydropower developments are at risk of capital cost over-runs during construction.

Good hydrology information, including a long stream flow data record, are important to accurately estimate power generation potential. Year-to-year fluctuations in stream flow can cause energy generation to vary substantially from year-to-year.



Fish Lake Hydro #1 in 1972.   In the background is the original Pelton wheel turbine from Engineering Mine. Fish Lake hydro has been quietly generating renewable energy since 1950. (Yukon Development Corp, 2001)

7. Time to Market

Hydropower projects can have lengthy development times, ranging from 5 to more than 10 years. Larger projects generally take longer to develop, partially due to rigorous regulatory process. Depending on the size of the project, construction time can take 1 to 2 years, followed by a reservoir filling period, if required.

8. Regulatory Considerations

There is a long history of hydropower development in Yukon and Canada, and therefore there is good certainty that hydropower projects can be permitted and developed. Environmental effects are well studied and understood. However, hydropower projects are often controversial as water is a highly valued resource.

Environmental assessment and regulatory process can delay project development by several years and increase project costs. Furthermore, environmental and social mitigation can reduce the initially-estimated power benefits of a project.

9. Environmental Considerations

When considering hydropower development, there are a number of environmental considerations that should be taken into account. Some of these include:

1. New larger hydro development in the Yukon will likely require the creation of reservoirs. This causes flooding/inundation of land. Existing hydro developments in the Yukon (Whitehorse, Aishihik, Mayo and Fish Lake) have all used existing lakes for storage, resulting in limited new inundation.

2. Hydropower produces very low greenhouse gas (GHG) emissions. In the boreal environment, GHG emissions associated with hydropower are limited to the first 3 to 5 years after creating a reservoir, and after that they reduce to levels consistent with natural lakes (Temblay et al., 2004)

3. Hydropower development effects stream flow, which can impact fish and fish habitat, fish migration, etc. Project mitigation and compensation is required to address fisheries impacts.

4. Hydropower developments can effect navigation or recreational water usage. Conversely, some sites are located at reaches of rivers or streams that are not navigable (e.g. canyons, falls, rapids).

9.1 Hydropower - Sustainability

When planning for a society with low or reduced dependence on fossil fuels, hydropower is a resilient energy option for the following reasons:

- Hydropower assets are long-lived; they are investments that benefit multiple generations.
- Hydropower has the highest *Energy Return on Energy Investment* (EROI) of any primary energy source.
- Clean energy source with no local air or noise pollution and very low GHG emissions.

Energy Return on Energy Investment (EROI) for Various Energy Options

Energy Technology	EROI	Reference
Global oil production	35	Gagnon, 2009
Coal (mine mouth)	80	Cleveland 2005
Nuclear	5-15	Lenzen 2005
Hydropower	>100	Hall 2008
Wind turbines	19.8	Kubiszewski 2008
Solar Photovoltaic	6-8	Battisti 2005
Corn based ethanol	0.8-1.6	Farrel. 2005

(from Murphy and Hall, 2010)

10. Hydropower - Conclusions

Hydropower may be considered a “good-fit” for the Yukon, considering our geography, our infrastructure (e.g. isolated grid) and particular unique challenges faced in the Yukon such as a small and dispersed population. Some considerations as to why hydropower is a resilient energy option for the Yukon include:

- Yukon has a long history and experience with developing, operating and maintaining hydropower facilities.
- Hydropower requires low maintenance limited operator intervention, and is a relatively simple technology.
- Hydropower is robust.
- Hydro is a flexible energy source that can respond well to fluctuations in load, source and changing conditions.
- Hydropower is immune to fuel source variation and is a long-lived asset that provides relatively consistent energy costs for many years.

The three turbines at Whitehorse (shown above) are still in operation, surviving the fire of 1997 that burned the powerhouse to the ground above the turbines.

11. References

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Technical Notes

1. Levelized Cost of Energy (LCOE): calculated using YEC's methodology for calculation of LCOE (January 2011). Levelized cost of energy includes all capital and operating expenses over the life of the energy project. All energy estimates are at generating station and before transmission losses.

2. Weighted Average Energy Cost: Average LCOE of projects weighted based on project energy estimates.

3. Cost Estimates: Project cost estimates and energy estimated are from BC Hydro 2003a&b, KGS 2008 and AECOM 2011. Cost estimates from BC Hydro 2003 escalated by 60% to have a consistent cost basis with more recent project cost estimates.