Literature Review
Surface Water & Shallow Hydrogeology

Integrated Assessment of Water Resources for Unconventional Oil and Gas Plays, West-Central Alberta

July 7, 2013

Prepared by:
Foundry Spatial Ltd.
Victoria, BC

This page intentionally left blank

DISCLAIMER

The information presented in this document and associated materials was compiled and interpreted as part of the Integrated Assessment of Water Resources for Unconventional Oil and Gas Plays, West-Central Alberta project ("The Project"). The purpose of the project is to compile existing data and research results, interpret key factors controlling water availability, and integrate the results from surface to deep subsurface zones. Foundry Spatial has provided the material strictly for the purpose noted above.

Foundry Spatial has exercised reasonable skill, care, and diligence to assess the information acquired during the execution of this project, but makes no guarantees or warranties as to the accuracy or completeness of this information. The information contained in these materials is based upon, and limited by, information available at the time of its preparation. The information provided by others is believed to be accurate but cannot be guaranteed. Access to original information provided by others should be through the original source which is noted in various locations in the materials.

Foundry Spatial does not accept any responsibility for the use of this material for any purpose other than that stated above and does not accept responsibility to any third party for the use in whole or in part of this material. Any alternative use, including that by a third party, or any reliance on, or decisions based on these materials, is the responsibility of the user or third party.

Any questions concerning the information or its interpretation should be directed to Ben Kerr.

Ben Kerr

President
Foundry Spatial Ltd.
1055 San Marino Cres.
Victoria, BC
V8X 3B3

phone: 250-858-8593
email: ben@foundryspatial.com
web: www.foundryspatial.com

EXECUTIVE SUMMARY

The Integrated Assessment of Water Resources for Unconventional Oil and Gas Plays, West-Central Alberta, is a multi-stakeholder project that is building a regional understanding of surface water, groundwater and deep saline water resources and disposal zones in a large portion of west-central Alberta.

The project is compiling existing data and research results, interpreting key factors controlling water availability, and integrating the results from surface to deep subsurface zones.

An initial phase of the project involved a survey of existing knowledge in the form of publically available research products. This report summarizes the results of this survey, in the form of an annotated bibliography for selected references and additional listed references for follow up on specific items of interest.

In parallel to the literature review, compilation was undertaken for spatial data related to aspects of both surface water and groundwater systems. Information on the provenance of these data sources is available under separate cover in companion with the data itself. There exists some overlap, however, particularly in cases where journal articles or government publications relating to the development of specific data products are included.

CONTENTS

Annotated Bibliography

Other references of interest:

(1) *Alberta Environment. 2007. Current and Future Water Use in Alberta. Prepared by AMEC Earth & Environmental for Alberta Environment, Edmonton, Alberta. pp. 724.*

Comments:

- Study looking at current water allocations, use and use forecasts for 12 major river basins in Alberta.

- Major sectors considered include municipal, agriculture, commercial, petroleum, and industrial.

- Relevant to the study area are: Red Deer, North Saskatchewan, Battle, Athabasca, and Peace/Slave.

- Distinguishes between licensed and actual water use.

(2) *Alberta Environment. 2008. Handbook for State of the Watershed Reporting: A Guide for Developing State of the Watershed Reports in Alberta. accessed: http://environment.gov.ab.ca/info/library/8044.pdf April 29, 2013.*

Comments:

"Characterizing the current state of one's watershed, its problems, and the pressures upon it can provide the basis for developing effective management strategies to meet watershed goals. This, along with the desired Water for Life outcome that "Albertans have the knowledge, tools, and motivation to implement actions that will maintain or improve the province's water resources," was the impetus behind drafting the document"

- basic process for any scale or any landscape, for gathering and evaluating information to develop an understanding of past and current watershed conditions and their influencing factors.

- objectives are to assess environmental conditions and setting and achieving environmental outcomes within watershed

- analysis of how landscape and hydrologic systems interact and function within the watershed. examining history of the watershed

- scientific interpretation of watershed information and data, leading to conclusions about watershed condition
- objective tool that uses available data and information to assess conditions and concerns within a watershed, as well as identify information gaps
- a report on the analysis and findings of the watershed assessment that by identifying factors potentially contributing to concerns within the watershed, can be used to develop appropriate actions; and
- component of a watershed management package that leads to planning, implementation and evaluation

- not a plan or endpoint

- understanding how natural features and processes influence watershed conditions

- insight into linkages between watershed health and land and water uses

a) purpose
    - provide background for future planning
    - identify sensitive or at-risk areas
    - identify information and knowledge gaps
b) scale
c) format
    (1) Plan the watershed assessment - purpose, focus, plan

(2) characterizing watershed - data and gaps
(3) analyzing and presenting data - context is key
(4) integrate information - interactions and relationships between themes
(5) drafting report
(6) using information for decision making

(3) *Alberta Environment. 2008. Water Supply Assessment for Alberta. Prepared by Golder Associates for Alberta Environment, Edmonton, Alberta. accessed: http://www.environment.gov.ab.ca/info/posting.asp?assetid=8393&searchtype=asset&txtsearch=water%20supply%20assessment April 29, 2013.*

Comments:

Intro:

- Objective: Gain understanding of the current water supply or water yield from basins in Alberta through an analysis of existing records of stream flow data and other information.
- Surface water and ground water
- Secondary objective, path forward to assess potential effects of climate change on future water yield
- Hydrologic regionalization of Alberta, accounting for non-contributing areas that are relevant in some manly east-central and southern watersheds
- Compilation and analysis of flow data based on hydrologic regions
- Regions based on topography, climate, hydrology, drainage, geology, and soils.
- Groundwater: elementary estimates of recharge, discharge and sustainable yield
    - Baseflow separation
    - Aquifer vulnerability index map for agricultural areas of Alberta, ERCB/AGS map Natural suitability of geological setting for waste management, Alberta Canada.
- Sustainable yield as 15% of difference between total open-water baseflow and the total (8 mo) ecological portion of open-water baseflow equivalent to the 20th percentile of the average of the winter monthly mean flows.
    - Winter baseflow 4.8 billion m^3
    - Assuming winter baseflow = minimum recharge, annualized recharge = 14.6 billion m^3
    - Accounting for increases in open-water baseflow, baseflow = 25 billion m^3
    - Different approaches would put baseflow range between 15 and 30 billion m^3
    - Surficial geology interpretation estimate 27.1 billiion m^3
    - Using above method, sustainable groundwater yield would be 1.9 billion m^3
- Identified North Saskatchewan River and Battle River as basins showing supply-demand constraints during part of the year
- Identify larger natural variability of water supply than recorded since European settlement -> increased adaptation capacity required

Body:

- Average annual ppt < et for most of the southern part of the province.
- Groundwater allocations only 3% of licenses. But primary source for substantial portion of rural Alberta.
- Saline water source push coming from oil sands

- Reliable, quality water supplies to include:
    - Dependability
    - Sustainability, for now and future generations and growth of the province
    - Suitability for all practical uses
    - Maintenance of the health of aquatic ecosystems and environmental sustainability
    - Water supply that is well understood, wisely managed, protected from quantity and quality impacts, and can be passed on with suitable quantity and quality to downstream stakeholders.
- Supply and demand in balance form basic tenet of reliability, and assurance that sufficient water supplies are available under most, if not all conceivable conditions.
- Can demand growth be mitigated through efficiency and productivity alone, or are new more elaborate (expensive) measures such as reservoirs and storage needed.
- Hydrologic response a function of drainage area, slope, precipitation, temperature, evapotranspiration and infiltration.
- Looked at relationship between drainage area and mean annual runoff, 2 yr and 10 yr flood, mean Feb flows
- Prairie hydrology makes a distinction between effective drainage area which is area that contributes runoff during 2 year flood, and gross drainage area which contributes runoff only during very wet conditions and is topography based.
- Groundwater recharge locally concentrated in low lying areas collecting more snow and runoff or from streams, ponds, lakes that fill above water table in parts of the year. For majority of year, groundwater flows by gravity from high to low elevations, typically discharging into surface water bodies. Groundwater provides base flow to streams and rivers and may be the only source of flow during dry or winter months.
- Estimate 22mm of recharge below phreatic surface to deeper groundwater stores (still in communication with SW but year to decade or longer transit time)
- Connection between groundwater and surface water makes it only one resource – with different replenishment times. Conjunctive management of the resource might allow groundwater to be pumped at greater rates when surface supplies are reduced, and then aquifers allowed to recharge when surface water is more abundant.
- Sustainable groundwater yield of 4-9mm per year, average 5.2mm.
- Climate change study suggested reduction of flows of -13% to -4%.

Included in the paper are additional presentations from a workshop:

- Kevin Shook
    - Prairie hydrological processes:
        - Transport of water in liquid, vapour and frozen – runoff, percolation, evapotranspiration, sublimation, blowing snow
        - Phase changes in snow and snows – snowmelt, infiltration in frozen soils, soil freeze thaw
        - Snow and rain interception

        - Episodic flow between soil, groundwater, ponds and streams
        - Variable storage, drainage and contributing areas
        - Land use changes
- DH Burn presentation
    - Issues with water supply include non-stationarity, trending series
    - Use LOESS
    - T-test, Mann-Kendall test for trend
- Sauchyn pres
    - Carbon dynamics don't support direct link between growth and drought – see drought evapotranspiration studies.
- Use 15% of MAF as reasonable allocation limit

Additional references from within publication:

Alberta Environment. 2005. Alberta Climate Model (ACM) to provide climate estimates (1961-1990) for any location in Alberta from its geographic coordinates. Publ. No. T/749. Alberta Environment 35pp.

Sauchyn, D., S. Kulshreshtha. 2008. Prairies; in From Impacts to Adaptation: Canada in a Changing Climate 2007, edited by DH Lemmen, FJ Warren, J Lacroix and E. Bush; Government of Canda, Ottawa ON, p.275-328.

Sauchyn, D., E. Barrow, S. Lapp. 2008. Explorations of Climate Variability in Alberta: Past, Present and Future. Prepared for Alberta Environment as part of the Alberta Biophysical Vulnerability Assessment Project. March 2008.

Sophocleous, M.A. 1997. Managing water resources systems: Why safe yield is not sustainable. Ground Water 35 (4), 561.

(4) *AQUALITY Environmental Consulting. 2005. State of the North Saskatchewan Watershed Report 2005. Prepared for North Saskatchewan Watershed Alliance, Edmonton, Alberta. accessed: http://www.nswa.ab.ca/content/state-north-saskatchewan-river-watershed-report-0 April 29, 2013.*

Comments:

Metrics on:

- Land Use
  - Riparian health
  - Linear development
  - Land use inventory
  - Livestock density
  - Wetland inventory
- Water quality
  - Surface water quality index (AENV)
  - E. coli
  - Phosphorous
  - Pesticides
- Water quantity
  - water allocations by sector
  - groundwater extraction
- biological indicator
  - aquatic macrophytes
  - fish (population estimates)
  - vegetation types (alberta vegetation inventory)
  - benthic invertebrates

- focus on land use and water quality impacts

- some info on natural regions - foothills, fescue, etc.

- limited commentary on indicator impact on hydrology

Additional references from within publication:

Alberta Environmental Protection. 1996. 1996 Alberta State of the Environment Report: Aquatic Ecosystems. Alberta Environmental Protection, Edmonton, Alberta. 153 p.

Alberta Environment. 1999. Surface water quality guidelines for use in Alberta. Environmental Sciences Division, Alberta Environment. Edmonton, Alberta. 20 p.

Alberta Environment. 2001. Framework for Water Management Planning. Queen's Printer.

Allan, J.H. 1984. An Overview of the Fish and Fisheries of the North Saskatchewan River Basin. Pisces Environmental Consulting Services, Red Deer, Alberta. Prepared for Alberta Environment, Edmonton, Alberta. 203 p.

CCME—Canadian Council of Ministers of the Environment. 2001. Canadian Water Quality Guidelines for the Protection of Aquatic Life: CCME Water Quality Index 1.0, User's Manual. In: Canadian environmental quality guidelines, 1999, Canadian Council of Ministers of the Environment, Winnipeg.189

Stewart, R.E. and H.A. Kantrud. 1971. Classification of Natural Ponds and Lakes in the Glaciated Prairie Region. Resource Publication 92, Bureau of Sport Fisheries and Wildlife, U.S. Fish and Wildlife Service, U.S. Department of the Interior. 57 pp.

(5) *AQUALITY Environmental Consulting. 2009. Red Deer River State of the Watershed Report. Prepared for Red Deer River Watershed Alliance, Red Deer, Alberta. accessed: http://www.rdrwa.ca/node/59 April 29, 2013.*

Comments:

- Red Deer River joins S. Saskatchewan 8km into Saskatchewan.

6 indicators:

- Wetland loss - condition
- Riparian health - condition
- livestock manure production - risk
- urban, rural and recreational development - risk
- linear developments - condition indicator
- oil and gas activities - risk indicator

Additional references from within publication:

Alberta Environment. 1999. Surface Water Quality Guidelines for use in Alberta. Environmental Sciences Division, Alberta Environment, Edmonton, Alberta. 20 p.

Alberta Environment. 2000. Red Deer River Corridor Integrated Management Plan. Alberta Environment, Edmonton, Alberta. 94 p. + Technical Background Document.

Alberta Environment. 2007. Current and Future Water Use in Alberta. Alberta Environment, Edmonton, Alberta. 724 p.

Alberta Environment. 2007. Information Synthesis and Initial Assessment of the Status and Health of Aquatic Ecosystems in Alberta: Surface Water Quality, Sediment Quality and Non-Fish Biota. Report prepared by North/South Consultants Inc., Calgary, Alberta, for Alberta Environment, Edmonton, Alberta. 522 p.

Hayashia, M., G. van der Kamp, and R. Schmidt. 2003. Focused infiltration of snowmelt water in partially frozen soil under small depressions. Journal of Hydrology 270: 214-229.

RDRWA (Red Deer River Watershed Alliance). 2008. What is Watershed Management? Red Deer River Watershed Alliance, Red Deer, Alberta. accessed: http://www.rdrwa.ca May 1, 2013.

Rood, S.B., G.M. Samuelson, J.K. Weber and K.A. Wywrot. 2005. Twentieth-century decline in streamflows from the hydrographic apex of North America. Journal of Hydrology 306: 215-233.

Rood, S.B., J. Pan, K.M. Gill, C.G. Franks, G.M. Samuelson and A. Shepherd. 2008. Declining summer flows of Rocky Mountain rivers: Changing seasonal hydrology and probable impacts on floodplain forests. Journal of Hydrology 349: 397-410.

Schick, C.D. 1972. A Documentation and Analysis of Wetland Drainage in the Alberta Parkland. Canadian Wildlife Service, Environment Canada, Edmonton, Alberta. 15 p.

Stewart, R.E. and H.A. Kantrud. 1971. Classification of Natural Ponds and Lakes in the Glaciated Prairie Region. Resource Publication 92, Bureau of Sport Fisheries and Wildlife, U.S. Fish and Wildlife Service, U.S. Department of the Interior, Washington, D.C. 57 p.

Strong, W.L., B.K. Calverley, A.J. Richard and G.R. Stewart. 1993. Characterization of Wetlands in the Settled Areas of Alberta. Alberta Environmental Protection, Edmonton, Alberta. 143 p.

United States Environmental Protection Agency. 2002. Index of Watershed Indicators: An Overview. United States Environmental Protection Agency, Office of Wetlands, Oceans, and Watersheds, Washington, D.C. 37 p.
van der Kamp, G. and M. Hayashi. 1998. The groundwater recharge function of small wetlands in the semi-arid northern prairies. Great Plains Research 8: 39-56.

(6) *Fiera (Fiera Biological Consulting Ltd.). 2012. Athabasca State of the Watershed Report: Phase 2. Report prepared for the Athabasca Watershed Council. Fiera Biological Consulting Report #1142. Pp 100.*

Additional references from within publication:

Allen, J.D., D. L. Erickson and J. Fay. 1997. The influence of catchment land use on stream integrity across multiple spatial scales. Freshwater Biology 37: 149–161.

AWRI (Alberta Water Research Institute). 2011. Groundwater in Alberta: an assessment of source, use and change. Worley Parsons, Edmonton, Alberta. accessed: http://www.albertawater.com/index.php?option=com_content&view=article&id=629&Itemid=83 May 1, 2013.

Bell, B.J. 1994. Annual unit runoff on the Canadian Prairies, Hydrology Report # 135. Agriculture and Agri-Food Canada, Prairie Farm Rehabilitation Administration, Engineering and Sustainability Service, Hydrology Division. Regina, Saskatchewan.

Brabec, E., S. Schulte, and P.L. Richards. 2002. Impervious surfaces and water quality: A review of current literature and its implications for watershed planning. Journal of Planning Literature 16:499-514.

Dube, M., B. Johnson, G. Dunn, J. Culp, K. Cash, K. Munkittrick, I. Wong, K. Hedley, W. Booty, D. Lam, O. Resler, and A. Storey. 2006. Development of a new approach to cumulative effects assessment: a northern river ecosystem example. Environmental Monitoring and Assessment 113:87-115.

Moilanen, A., J. Leathwick, and J. Elith. 2009. A method for spatial freshwater conservation prioritization. Freshwater Biology 53:577-592.

Seneka, M. 2006. Alberta River Flow Quantity Index (Final Draft). Alberta Environment, Environmental Monitoring & Evaluation Branch. Edmonton, Alberta.

Strahler, A. N. 1964. Quantitative geomorphology of drainage basins and channel networks in Handbook of Applied Hydrology, Ven Te Chow (Editor). McGraw Hill, New York. pp 4-39 - 4-76.

Worley Parsons. 2009. North Saskatchewan River basin: overview of groundwater conditions, issues, and challenges. Report prepared for North Saskatchewan Watershed Alliance. Edmonton, Ab.

(7) *Sauchyn, D., J. Vanstone, C. Perez-Valdivia. 2011. Modes and forcing of hydroclimatic variability in the upper north Saskatchewan river basin since 1063. Canadian Water resources journal 36(3), 205-217.*

Comments:

- Prolonged droughts outside of gauged record.
- Assumption of stationarity in hydrometric data is undermined by observations preceeding and future projections.
- May 1796, no water in the river at Edmonton to export furs - Sauchyn 2003.
- Tree ring reconstruction linked to past hydro-climate
- Future extreme fluctuations partly represent natural variability that exceeds the range measured over the instrumental period.
- Evidence for extended droughts not in gauged record.

Additional references from within publication:

Sauchyn, D.J., J. Stroich, A. Beriault. 2003. A paleoclimatic context for the drought of 1999-2001 in the northern great plains. The geographical journal 169, 158-167.

(8) *Smakhin, V.U. 2001. Low flow hydrology: a review. Journal of Hydrology 240, 147-186.*

Comments:

- Catchment a series of interlinked reservoirs, each of which has components of recharge, storage and discharge. Recharge dependent on precipitation, storage and discharge complex functions of catchment physiographic characteristics. Processes usually operate in the vicinity of the river channel zones as opposed to the full range of hydrological processes that operate over larger parts of catchments during periods of higher discharge.
- For low flows to be sustainable, the draining aquifer must be recharged seasonally with adequate amounts of moisture, the water table must be shallow enough to be intersected by the stream and the aquifers size and hydraulic properties must be sufficient to maintain flows throughout the dry season.
- Low flows may be sustained by drainage of a saturated top soil zone throughflow rather than by deeper groundwater (Anderson 1980)
- Near channel storage, alluvial or channel bank storage may or may not be in contact with phreatic surface and is not technically groundwater.
- Effects of groundwater pumping near the head of a perennial river may result in gw table depletion through interception of recharge water and induced recharge of the aquifer from the river itself. Results in substantial environmental degradation of the river habitats etc.
- Use log-normal for FDC
- Monthly window acceptable for FDC – Mngodo 1997
- 7Q10 and 7Q2 most widely used in USA
- Reviews of baseflow separation techniques
- Most significant parameters with regard to low flows – drainage density, ratio of length of tributaries to length of main channel, percent of drainage area w/ ne aspect, average weighted slope.

Additional references from within publication:

Anderson, M., & Burt, T. (1980). Interpretation of Recession Flow. *J. Hydrol. 46*, 89-101.

Barnes, C. (1986). *Methods for estimating low-flow statistics for ungaged streams in the lower Hudson River basin, NY.* USGS Water Resources Investigations Report 85-4070.

Cervione Jr., M., Melvin, R., & Cyr, K. (1982). *A method for estimating the 7-day, 10-year low flow of streams in Connecticut.* Connecticut Water Resources Bulletin No.34.

Cumming Cockburn Ltd. (1990). *Low flow characteristics in Ontario.* Ontario Ministry of the Environment.

Hamilton, D. (1985). *Preliminary data compilation for selected drainage basins in Nova Scotia for a low flow regional analysis study.* Dartmouth, N.S.: Environment Canada, Inland Waters Directorate, Atlantic Region, Water Planning and Management Branch.

LeBoutillier, D., & Waylen, P. (1993). Stochastic model of flow duration curves. *Water Resources Research 29(10)*, 3535-3541.

Mngodo, R. (1997). Flow duration characteristics of Southern African rivers. *Acta Hydrotechnica 15/18 - Proceedings of oral presentations, FRIEND'97*, (pp. 49-63).

Morrisey, D., Randall, A., & Williams, J. (1988). Upland runoff as a major source of recharge to stratified drift in the glaciated northeast. *AWRA Symposium on Monitoring, Modeling and Mediating Water Quality. AWRA Monograph Series No.11*, (pp. 17-36).

Pelletier, P.M., Bilozor, W., Glennie, R.A. 1986. Low flow characteristics of selected streams in southern Manitoba. Proceedings of the 16th Canadian Hydrology Symposium: Drought - the Impending Crisi? Regina, Saskatchewan, p 159-174

Pilon, P.J., Condie, R. 1986. Median drought flows at ungauged sites in southern Ontario. proceedings of the 16th Canadian Hydrology Symposium: Drought - the impending Crisis? Regina, Saskatchewan, p.189-196.

Pol, R.A. 1985. Flow duration and low flow frequency analyses for selected watersheds in the Atlantic provinces. Environment Canada, Inland Waters Directorate, Atlantic Region, Water Resources Branch, vols 85-80, 20pp.

Ries III, K.G. 1994. Development and application of generalized least squares regression models to estimate low-flow. USGS Water Resources Investigations Report 94-4155, 33pp.

Risle, J.C. 1994. Estimating the magnitude and frequency of low flows of streams in Massachusetts. USGS Water Resources Investigations Report 94-4100, 34pp.

Skop, E., Loaiciga, H.A. 1998. Investigating catchment hydrology and low-flow characteristics using GIS. Nordic Hydrol. 29(2), 105-128.

Smakhtin V.Y., Watkins, D.A. 1997. Low-flow estimation in South Africa. Water Research Commission Report No. 494/1/97, Pretoria, South Africa.

Vogel, R.M., Fennessey, N.M. 1995. Flow duration curves. II. a review of applications in water resource planning. Water Resource Bulletin 31(6), 1029-1039.

(9) *Wang, Q.J., T.C. Pagano, S.L. Zhou, H.A.P. Hapuarachchi, L. Zhang, D.E. Robertson. 2011. Monthly versus daily water balance models in simulating monthly runoff. Journal of Hydrology 404, 166-175.*

Comments:

- Wapaba model based on Budyko framework.
- Uses consumption curves to partition water
- No disadvantage to not considering within month variability.
- Supports use of monthly water balance models for applications where one is primarily interested in monthy, seasonal and annual streamflow volumes
- Monthly model to translate catchment characteristics (rainfall, PET) into simulation and prediction of streamflow
- Parsimonious models are those with as few parameters as necessary, central to the "top-down" approach
- Processes only added to the model when they lead to meaningful increases in the explanatory power of the model and largely determined by the availability of data.
- Shuffled complex evolution for calibration (Duan 1994)

Additional references from within publication:

Duan, Q., S. Sorooshian, V.K. Gupta. 1994. Optimal use of the SCE-UA global optimization method for calibrating watershed models. J. Hydrol. 158 (3-4), 265-284.

Mouelhi, S., C. Michel, C. Perrin, V. Andreassian. 2006. Stepwise development of a two-parameter monthly water balance model. J. Hydrol. 318 (1-4), 200-214.

Thornthwaite, C.W. 1948. An approach toward a rational classification of climate. Geogr. Rve. 38, 55-94.

Xiong, L., S. Guo. 1999. A two-parameter monthly water balance model and its application. J. Hydrol. 216 (1-2), 111-123.

Xu, C-Y., V.P. Singh. 1998. A review on monthly water balance models for water resources investigations. Water Resou. Manage. 12 (1), 20-50.

Zhang, L., N. Potter, K. Hickel, Y. Ahang, Q. Shao. 2008. Water balance modeling over variable time scales based on the Budyko framework – model development and testing. J. Hydrol. 360 (1-4), 117-131.

(10) *Watrecon Consulting. 2012. The Peace Watershed, Current and Future water use and issues. accessed: http://www.mightypeacewatershedalliance.org/reports/ April 29, 2013.*

Comments:

- Water quality generally good in upper reaches, declines due to increased suspended solids, nutrients and metals, turbidity.
- Highest groundwater yields found in Grimshaw and other buried valley aquifers
- many surficial aquifers vulnerable to contamination from underlying saline waters
- Canada-Alberta Environmentally sustainable agriculture agreement (CAESA) groundwater studies?
- Wapiti River provides groundwater source twp 66 to 76, west to BC.
- Some "other" water allocations are based on evapotranspirative loss from waterbody. Some older ones over estimate the increase in evapotranspiration due to the works (lake stabilization, etc) and license volume is based on the evapotranspiration for the whole waterbody.
- Fox Ck stabilization project at Iosegun Lk., Ducks Unlimited at Gift Lake.

Additional references from within publication:

Hatch. 2010. Update on Alberta's hydroelectric energy resources. Final report for Alberta Utilities Commission, Calgary, Alberta. accessed: http://www.energy.alberta.ca/Electricity/pdfs/AUCHydroelectricStudy.pdf May 1, 2013.

(11) *Walsh, H. (ed). 2008. State of the Athabasca Watershed, 2008. Contributed to Keepers of the Athabasca by Canadian Parks and Wilderness Society Northern Alberta. accessed: http://www.keepersofthewater.ca/files/state2008.pdf April 29, 2013.*

Additional references from within publication:

Alberta Environment (1996). Northern River Basins Study Final Report. accessed: http://environment.gov.ab.ca/info/library/8701.pdf May 1, 2013.

MRB (Mackenzie River Basin) (2003). State of the Aquatic Ecosystem Report: Athabasca Sub-basin.

UARIS (2005). The Upper Athabasca River Information System: Overview of Basin Characteristics and Data Completeness. Alberta Environment. Prepared by: North/South Consultants Inc.

Other references of interest:

Climate

Alberta Environment. 2005. Alberta Climate Model (ACM) to provide climate estimates (1961-1990) for any location in Alberta from its geographic coordinates. Publ. No. T/749. Alberta Environment 35pp.

Abbaspour, K.C. 1991. A Comparison of Different Methods of Estimating Energy-Limited Evapotranspiration in the Peace River Region of British Columbia. Atmosphere-Ocean. 29(4): 686-698.

Allen, R.G., L.S. Pereira, D. Raes, M. Smith. 1998. Crop evapotranspiration - guidelines for computing crop water requirements. FAO Irrigation and Drainage Paper 56. Rome: FAO (Food and Agriculture Organization of the United Nations).

Ameriflux, 2013. accessed: http://public.ornl.gov/ameriflux/ May 1, 2013

Amiro, B.D., E. E. Wuschke. 1987. Evapotranspiration from a boreal forest drainage basin using an energy balance / eddy covariance technique. Boundary Layer Meteorology. 38: 125-139.

Arain, M.A., T.A. Black, A.G. Barr, T.J. Griffis, K. Morgenstern, Z. Nesic. 2003. Year-round Observations of the Energy and Water Vapour Fluxes Above a Boreal Black Spruce Forest. Hydrological Processes. 17: 3581-3600.

Baldocchi, D., F.M. Kelliher, T.A. Black, P. Jarvis. 2000. Climate and Vegetation Controls of Boreal Zone Energy Exchange. Global Change Biology. 6(Suppl. 1): 69-83.

Baldocchi, D.D., C.A. Vogel, B. Hall. 1997. Seasonal Variation of Energy and Water Vapor Exchange Rates Above and Below a Boreal Jack Pine Forest Canopy. Journal of Geophysical Research. 102(D24): 28939-28951.

Barnett, T.P., J.C. Adam, D.P. Lettenmaier. 2005. Potential impacts of a warming climate on water availability in snow-dominated regions. Nature. 438(17): 303-309 doi:10.1038/nature04141.

Berry, W.M., W. Stichling. 1954. Evaporation from lakes and reservoirs in the northern plains region of North America. Int. Union Geod. Geophys., General Assembly, Rome. Tome 3: 121-134.

Black, T.A., G. den Hartog, H. Neumann. 1996. Annual cycles of CO^2 and water vapor fluxes above and within a boreal aspen stand. Global Change Biology. 2: 219-230.

Blanken, P. D., W. R. Rouse, A. D. Culf, C. Spence, L. D. Boudreau, J. N. Jasper, B. Kochtubajda, W. M. Schertzer, P. Marsh, and D. Verseghy. 2000. Eddy covariance measurements of evaporation from Great Slave Lake, Northwest Territories, Canada. Water Resour. Res., 36(4): 1069–1077, doi:10.1029/1999WR900338

Blanken, P.D., T.A. Black, H.H. Neumann, G. den Hartog, P.C. Yang, Z. Nesic, X. Lee. 2001. The Seasonal Water and Energy Exchange Above and Within a Boreal Aspen Forest. Journal of Hydrology. 245: 118-136.

Budyko, M.I. 1974. Climate and Life. Academic Press, New York.

Burn, D.H., N.M. Hesch. 2007. Trends in evaporation for the Canadian Prairies. Journal of Hydrology. 336: 61-73.

Chen, B., J.M. Chen, G. Mo, C.W. Yuen, H. Margolis, K. Higuchi, D. Chan. 2007. Modeling and scaling coupled energy, water, and carbon fluxes based on remote sensing: An application to Canada's Landmass. Journal of Hydrometeorology, Vol. 8: 123-143.

Demuth, M.N. and A. Pietroniro. 2003. The Impact of Climate Change on the glaciers of the Canadian rocky mountain eastern slopes and implications for water resource-related adaptation in the Canadian prairies, "Phase 1" – Headwaters of the North Saskatchewan River Basin. Report to the climate change action fund – prairie adaptation research collaborative, PARC. Project p55. GSC open file 4322.

Donohue, R.J., M.L. Roderick, T.R. McVicar. 2007. On the importance of including vegetation dynamics in Budyko's hydrological model. Hydrology and Earth System Sciences. 11: 983-995.

El Maayar, M., J.M. Chen. 2006. Spatial scaling of evapotranspiration as affected by heterogeneities in vegetation, topography, and soil texture. Remote Sensing of Environment, 102: 33-51.

Ferguson, H.L., A.D.J. O'Neill, H.F. Cork. 1970. Mean Evaporation over Canada. Water Resources Research, 6(6): 1618-1633.

Gibson, J.J., R. Reid. 2010. Stable isotope fingerprint of open-water evaporation losses and effective drainage area fluctuations in a subarctic shield watershed. Journal of Hydrology 381, p.142-150.

Glenn, E.P., A.R. Huete, P.L. Nagler, K.K. Hirschboeck, P. Brown. 2007. Integrating remote sensing and ground methods to estimate evapotranspiration. Critical Reviews in Plant Sciences, 26:3: 139-168.

Grelle, A., A. Lundberg, A. Lindroth, A.S. Moren, E. Cienciala. 1997. Evaporation components of a boreal forest: variations during the growing season. Journal of Hydrology. 197: 70-87.

Hall, F.G., D.E. Knapp, K.F. Huemmrich. 1997. Physically Based Classification And Satellite Mapping Of Biophysical Characteristics In The Southern Boreal Forest. Journal of Geophysical Research. 102(D24): 29567-29580.

Hijmans, R.J., S.E. Cameron, J.L. Parra, P.G. Jones, A. Jarvis. 2005. Very High Resolution Interpolated Climate Surfaces for Global Land Areas. International Journal of Climatology. 25: 1965-1978.

Hogg, R., S. Jassal, K. Morgenstern. 2006. Impact of changing soil moisture distribution on net ecosystem productivity of a boreal aspen forest during and following drough. Agriculture and Forest Meteorology. 139:208-223.

Jarvis, P.G., J.M. Massheder, S.E. Hale, J.B. Moncrieff, M. Rayment, S.L. Scott. 1997. Seasonal Variation of Carbon Dioxide, Water Vapor, and Energy Exchanges of a Boreal Black Spruce Forest. Journal of Geophysical Research. 102(D24): 28953-28966.

Kljun, N., T.A. Black, T.J. Griffis, A.G. Barr, D. Gaumont-Guay, K. Morgenstern, J.H. McCaughey, Z. Nesic. 2006. Response of Net Ecosystem Productivity of Three Boreal Forest Stands to Drought. Ecosystems. 9: 1128-1144.

Krishnan, P., T.A. Black, N.J. Grant, A.G. Barr, E.H. Hogg, R.S. Jassal, K. Morgenstern. 2006. Impact of Changing Soil Moisture Distribution on Net Ecosystem Productivity of a Boreal Aspen Forest During and Following Drought. Agricultural and Forest Meteorology. 139: 208-223.

Kriticos, D.J., Webber, B.L., Leriche, A., Ota, N., Macadam, I., Bathols, J. & Scott, J.K. (2012) CliMond: global high resolution historical and future scenario climate surfaces for bioclimatic modelling. Methods in Ecology and Evolution 3: 53-64. DOI: 10.1111/j.2041-210X.2011.00134.x

Kucharik, C.J., J.A. Foley, C. Delire, V.A. Fisher, M.T. Coe, J.D. Lenters, C. Young-Molling, N. Ramankutty, J.M. Norman, S.T. Gower. 2000. Testing the performance of a Dynamic Global Ecosystem Model: Water Balance, Carbon Balance and Vegetation Structure. Global Biogeochemical Cycles. 14(3): 795-825.

Kustas, W.P., J.M. Norman. Use of remote sensing for evapotranspiration monitoring over land surfaces. Hydrological Sciences Journal, 41(4): 495-516.

Liu, J., J.M. Chen, J. Cihlar. 2003. Mapping Evapotranspiration Based on Remote Sensing: An Application to Canada's Landmass. Water Resources Research. 39(7), 1189, doi:10.1029/2002WR001680.

Mbogga, M. S., Hansen, C., Wang, T. and Hamann, A. 2010. A comprehensive set of interpolated climate data for Alberta. Government of Alberta, Publication Number: Ref. T/235.

McCaughey, J.H., Lafleur, P.M., Joiner, D.W., Bartlett, P.A., Costello, A.M., Jelinski, D.E., Ryan, M.G. 1997. Magnitudes and Seasonal Patterns of Energy, Water, and Carbon Exchanges at a Boreal Young Jack Pine Forest in the BOREAS Northern Study Area. Journal of Geophysical Research. 102(D24):28997-29007.

Morton, F.I. 1983. Operational Estimates of Lake Evaporation. Journal of Hydrology, 66: 77-100.

New, M., D. Lister, M. Hulme, I. Makin. 2002. A high-resolution data set of surface climate over global land areas. Climate Research, 21: 1-25.

Palmer, W.C. 1965. Meteorologic drought. Res. Pap. U.S. Weather Bur., 45, 58 pp.

Petrone, R.M., U. Silins, K.J. Devito. 2007. Dynamics of evapotranspiration from a riparian pond complex in the Western Boreal Forest, Alberta, Canada. Hydrological Processes, 21: 1391-1401.

Sauchyn, D., E. Barrow, S. Lapp. 2008. Explorations of Climate Variability in Alberta: Past, Present and Future. Prepared for Alberta Environment as part of the Alberta Biophysical Vulnerability Assessment Project. March 2008.

Sauchyn, D., J. Vanstone, C. Perez-Valdivia. 2011. Modes and forcing of Hydroclimatic Variability in the Upper North Saskatchewan River Basin Since 1063. Canadian Water Resources Journal 36(3): 205-218.

Sauchyn, D., S. Kulshreshtha. 2008. Prairies; in From Impacts to Adaptation: Canada in a Changing Climate 2007, edited by DH Lemmen, FJ Warren, J Lacroix and E. Bush; Government of Canda, Ottawa ON, p.275-328.

Sauchyn, D.J., J. Stroich, A. Beriault. 2003. A paleoclimatic context for the drought of 1999-2001 in the northern great plains. The geographical journal 169, 158-167.

Spittlehouse, D. L. 1989. Estimating evapotranspiration from land surfaces in British Columbia. Proceedings of Estimation of Areal Evapotranspiration Workshop, Vancouver, 1987. IAHS Publication No. 177, 1989.

Stewart, R.E., H.G. Leighton, P. Marsh, G.W.K. Moore, H. Ritchie, W.R. Rouse, E.D. Soulis, G.S. Strong, R.W. Crawford, B. Kochtubajda. 1998. The Mackenzie GEWEX Study: The Water and Energy

Cycles of a Major North American River Basin. Bulletin of the American Meteorological Society. 79(12): 2665-2683.

Thornthwaite, C.W. 1948. An approach toward a rational classification of climate. Geogr. Rve. 38, 55-94.

Trabucco, A., R.J. Zomer. 2010. Global Soil Water Balance Geospatial Database. CGIAR Consortium for Spatial Information. accessed: http://www.cgiar-csi.org/data/global-high-resolution-soil-water-balance, May 8, 2013.

Wang, T., Hamann, A., Spittlehouse, D.L., Murdock, T.Q. 2012. ClimateWNA - High Resolution Spatial Climate Data for Western North America. Journal of Applied Meteorology and Climatology. DOI: 10.1175 / JAMC-D-11-043.1.

Zhang, L., K. Hickel, W.R. Dawes, F.H.S. Chiew, A.W. Western, P.R. Briggs. 2004. A Rational Function Approach for Estimating Mean Annual Evapotranspiration. Water Resources Research. 40, W02502, doi:10.1029/2003WR002710.

Groundwater

Barnes, R. 1977. Hydrogeology of the Mount Robson - Wapiti Area, Alberta. Research Council of Alberta Report 76-5. Alberta Research Council, Edmonton, Alberta.

Barnes, R.G. 1978. Hydrogeology of the Brazeau-Canoe River Area, Alberta. Research Council of Alberta Report 71-1. Alberta Research Council, Edmonton, Alberta.

Borneuf, D. 1980. Hydrogeology of the Winagami Area, Alberta. Research Council of Alberta Report 79-3. Alberta Research Council, Edmonton, Alberta.

Burns, E.R., L.R. Bentley, M. Hayashi, S.E. Grasby, A.P. Hamblin, D.G. Smith, P.R.J. Wozniak. 2010. Hydrogeological implications of paleofluvial architecture for the Paskapoo Formation, SW Alberta, Canada: a stochastic analysis. Hydrogeology Journal 18:6. pp 1375-1390.

Chen, Z., S.E. Grasby, P.R.J. Wozniak. Paskapoo groundwater study. Part VI: Aquifer transmissivity estimation and a preliminary data analysis of the Paskapoo Formation, Alberta. Geological Survey of Canada Open File 5444, pp. 32.

Chen, Z., S.E. Grasby, T. Hamblin, S. Xiu. 2007. Paskapoo groundwater study. Part II: Sandstone thickness and porosity estimations using well log data for the aquifer system in the Tertiary Paskapoo Formation, Alberta. Geological Survey of Canada Open File 5445, 1 CD-ROM.

Cummings, D.I., H.A.J. Russell, D.R. Sharpe. 2012. Buried valleys and till in the Canadian Prairies: geology, hydrogeology, and origin. Geological Survey of Canada Current Research 2012-4, pp. 22.

Demchuk, T.D., L.V. Hills. 1991. A Re-examination of the Paskapoo Formation in the Central Alberta Plains: The Designation of Three New Members. Bulletin of Canadian Petroleum Geology, 39(3): 270-282.

Farvolden, R.N. 1961. Groundwater Resources Pembina Area, Alberta. Research Council aof Alberta, Edmonton, Alberta. ESR 1961-04.

Fenton, M.M., E.J. Waters, S.M. Pawley, N. Atkinson, D.J. Utting, K. Mckay. 2013. Surficial Geology of Alberta. Alberta Geological Survey Map 601. Energy Resources Conservation Board / Alberta Geological Survey, Edmonton Alberta.

Grasby, S., W. Tan, Z. Chen, A.P. Hamblin. 2007. Paskapoo groundwater study. Part I: Hydrogeological properties of the Paskapoo Formation determined from six continuous cores. Geological Survey of Canada, Open File 5392, pp. 6.

Grasby, S.E., Z. Chen, A.P. Hamblin, P.R.J. Wozniak, A.R. Sweet. 2008. Regional characterization of the Paskapoo bedrock aquifer system, southern Alberta. Canadian Journal of Earth Sciences, Vol. 45: 1501-1516

Hackbarth, D. 1977. Hydrogeology of the Grande Prairie Area, Alberta. Research Council of Alberta Report 76-4. Alberta Research Council, Edmonton, Alberta.

Hamblin, A.P. 2004. Paskapoo-Porcupine Hills formations in western Alberta: Synthesis of regional geology and resource potential. Geological Survey of Canada Open File 4679, pp. 31.

Hamblin, A.P. 2007. Paskapoo groundwater study. Part III: Detailed core measured sections of the Paskapoo Formation in central Alberta. Geological Survey of Canada Open File 5537, pp. 13.

Hamblin, A.P. 2007. Paskapoo groundwater study. Part IV: Detailed outcrop measured sections of the Paskapoo Formation in the Red Deer region, Alberta. Geological Survey of Canada Open File 5535, pp. 20.

Hamblin, A.P. 2007. Paskapoo groundwater study. Part V: Detailed outcrop measured sections of the Scollard, Porcupine Hills and Paskapoo Formations in the Calgary region, Alberta. Geological Survey of Canada Open File 5536, pp.16.

Hamblin, AP (2004) Paskapoo-Porcupine Hills Formations in western Alberta: synthesis of regional geology and resource potential. Open file report 4679, Geological Survey of Canada, Ottawa, 31 pp.

Huff, G.F., L. Woods, H. Moktan, G. Jean. 2012. Geochemistry of groundwater and spring water in the Paskapoo Formation and overlying glacial drift, south-central Alberta. Energy Resources Conservation Board, ERCB/AGS Open File Report 2012-05, pp. 58.

Hydrogeological consultants ltd. (hcl), 1999. County of Barrhead No. 11, Parts of the Pembina and Athabasca River Basins, Parts of Tp 056 to 063, R 01 to 08, W5M, Groundwater Potential Evaluation. Prepared for County of Barrhead No.11 in conjunction with AAFC and PFRA. hcl File No. 97-103.

Hydrogeological consultants ltd. (hcl), 1999. Lac Ste. Anne County, Parts of the North Saskatchewan and Athabasca River Basins; Parts of Tp 053 to 059, R 01 to 09, W5M Regional Groundwater Assessment July 1998 (revised November 1999). Prepared for Lac Ste. Anne County in conjunction with AAFC and PFRA. hcl File No. 97-112.

Hydrogeological consultants ltd. (hcl), 1999. Leduc County, Part of the North Saskatchewan River Basin, Parts of Tp 047 to 051, R 21 to 28, W4M and R01 to 04, W5M Regional Groundwater Assessment February 1999 (revised December 1999). Prepared for Leduc County in conjunction with AAFC and PFRA. hcl File No. 98-130.

Hydrogeological consultants ltd. (hcl), 1999. M.D. of Brazeau No. 77, Part of the North Saskatchewan and Athabasca River Basins; Parts of Township 045 to 050, Range 03 to 11, W5M; Revised Regional Groundwater Assessment 1999. Prepared for M.D. of Brazeau No.77 in conjunction with AAFC and PFRA. hcl File No. 97-232.

Hydrogeological consultants ltd. (hcl), 1999. Parkland County, Part of the North Saskatchewan and Athabasca River Basins, Parts of Tp 050 to 054, R 25, W4M to R 08, W5M Regional

Groundwater Assessment January 1998 (Revised November 1999). Prepared for Parkland County in conjunction with AAFC and PFRA. hcl File No. 97-202.

Hydrogeological consultants ltd. (hcl), 2001. Lacombe County, Part of the Red Deer River Basin, Tp 038 to 041, R 21 to 28, W4M & Tp 038 to 041, R 01 to 04, W5M Regional Groundwater Assessment January 2001. Prepared for Lacombe County in conjunction with AAFC and PFRA. hcl File No. 00-174.

Hydrogeological consultants ltd. (hcl), 2004. AAMD&C Northern Zone, Part of the Peace River Basin, Tp 065 to 107, R 05 to 27, W5M and Tp 069 to 087, R 01 to 13, W6M Regional Groundwater Assessment May 2004. Prepared for AAMD&C in conjunction with AAFC and PFRA. hcl File No. 02-239.

Hydrogeological consultants ltd. (hcl), 2004. Clearwater County, Part of the North Saskatchewan and South Saskatchewan River Basins, Tp 031 to 047, R 04 to 11, W5M Regional Groundwater Assessment, February 2004 EASTERN HALF. Prepared for Clearwater County in conjunction with AAFC and PFRA. hcl File No. 02-221.

Hydrogeological consultants ltd. (hcl), 2004. Ponoka County, Part of the North Saskatchewan and South Saskatchewan River Basins, Tp 041 to 044, R 22 to 28, W4M & Tp 041 to 045, R 01 to 05, W5M Regional 044, R 22 to 28, W4M & Tp 041 to 045, R 01 to 05, W5M Regional Groundwater Assessment, May 2004. Prepared for Ponoka County in conjunction with AAFC and PFRA. hcl File No. 02-191.

Hydrogeological consultants ltd. (hcl), 2004. Yellowhead County, Part of the Athabasca River Basin, Tp 050 to 057, R 07 to 26, W5M, Regional Groundwater Assessment. Prepared for Yellowhead County in conjunction with AAFC and PFRA. hcl File No. 02-227.

Hydrogeological consultants ltd. (hcl), 2008. County of Wetaskiwin Regional Groundwater Assessment, Part of the North Saskatchewan River Basin, Parts of Tp 044 to 048, R 22 to 28, W4M & Tp 045 to 047, R 01 to 07, W5M, March 2008. Prepared for County of Wetaskiwin in conjunction with AAFC and PFRA. hcl File No. 07-771.03.

Lemay, T.G., S. Guha. 2009. Compilation of Alberta Groundwater Information from Existing Maps and Data Sources. Energy Resources Conservation Board, ERCB/AGS Open File Report 2009-02, pp. 43.

Le Breton, E.G. 1971. Hydrogeology of the Red Deer Area, Alberta. Research Council of Alberta Report 71-1. Alberta Research Council, Edmonton, Alberta.

Lyster, S., L. Andriashek. 2010. Insights into the Internal Architecture of the Paskapoo Formation. Extended Abstract, GeoCanada 2010 conference.

Lyster, S., L.D. Andriashek. 2012. Geostatistical rendering of the architecture of hydrostratigraphic units within the Paskapoo Formation, central Alberta. ERCB/AGS Bulletin 066, pp. 103.

Matthews, V.A. 2011. Stochastic Modeling of the Paskapoo Formation. Unpublished thesis, Geoscience Dept., University of Calgary, Calgary, Alberta. Accessed: http://dspace.ucalgary.ca/jspui/bitstream/1880/48383/1/2011_Matthews_MSc.pdf, April 30, 2013.

Ozoray, G.F. 1972. Hydrogeology of the Wabamun Lake Area, Alberta. Research Council of Alberta Report 79-7. Alberta Research Council, Edmonton, Alberta.

Parks, K., L. Andriashek. 2009. Preliminary investigations of potential, natural hydraulic pathways between the Scollard and Paskapoo Formations in Alberta: Implications for coalbed methane production. Energy Resources Conservation Board, ERCB/AGS Open File Report 2009-16, pp. 66.

Schmidt, A., J.J. Gibson, I.R. Santos, M. Schubert, K. Tattrie, H. Weiss. 2010. The contribution of groundwater discharge to the overall water budget of two typical Boreal lakes in Alberta/Canada estimated from a radon mass balance. Hydrology and Earth Systems Science, 14: 70-89.

Sophocleous, M.A. 1997. Managing water resources systems: Why safe yield is not sustainable. Ground Water 35 (4), 561.

Steenhuis, T.S., W.H. Van Der Molen. 1986. The Thornthwaite-Mather procedure as a simple engineering method to predict recharge. Journal of Hydrology (84:3-4) p.221-229

Tokarsky, D. 1977. Hydrogeology of the Whitecourt Area, Alberta. Research Council of Alberta Report 76-3. Alberta Research Council, Edmonton, Alberta.

Tokarsky, O. 1971. Hydrogeology of the Rocky Mountain House Area, Alberta. Research Council of Alberta Report 71-3. Research Council of Alberta, Edmonton, Alberta.

Tokarsky, O. 1977. Hydrogeology of the Iosegun Lake Area, Alberta. Research Council of Alberta Report 76-2. Alberta Research Council, Edmonton, Alberta.

Vogwill, R.I.J. 1983. Hydrogeology of the Edson Area, Alberta. Research Council of Alberta Report 79-7. Alberta Research Council, Edmonton, Alberta.

Wozniak, P.R.J. Paskapoo groundwater study. Part VII: Alberta groundwater wells data dictionary - a view to groundwater data modeling. Geological Survey of Canada Open File 5574, pp. 106.

Hydrology

Agriculture and Agri-Food Canada (AAFC). 2013. National Annual Unit Runoff Study. Anna Cole, p. comm.

Alberta river water quality index. accessed: http://environment.alberta.ca/01275.html May 1, 2013.

Anderson, M., & Burt, T. (1980). Interpretation of Recession Flow. J. Hydrol. 46, 89-101.

Bell, B.J. 1994. Annual unit runoff on the Canadian Prairies, Hydrology Report #135. Agriculture and Agri-Food Canada, PFRA, Engineering and Sustainability Service, Hydrology Division. Regina, Saskatchewan.

Birks, J., J.P. Jones, J. Gibson. 2012. Surface Water - Groundwater Interactions in the Lower Athabasca Region. Cumulative Environmental Management Association, Fort McMurray, Alberta.

Chen, W-P. and C.H. Lee. 2003. Estimating groundwater recharge from streamflow records. Environmental Geology, 44: 257-265, doi 10.1007;s00254-002-0753-2.

Comeau, L.E.L., A. Pietroniro, M.N. Demuth. 2009. Glacier Contribution to the North and South Saskatchewan Rivers. Hydrological Processes, 23: 2640-2653.

Cumming Cockburn Ltd. (1990). Low flow characteristics in Ontario. Ontario Ministry of the Environment.

Devito, K.J., A.R. Hill, N. Roulet. 1996. Groundwater – surface water interactions in forested headwater wetland of the Canadian Shield. Journal of Hydrology, 181: 127-147.

Devito, K.J., J.M. Waddington, B.A. Branfireun. 1997. Flow reversals in peatlands influenced by local groundwater systems. Hydrological Processes, 11(1): 103-110.

Ferone, J.M., K.J. Devito. 2004. Shallow groundwater-surface water interactions in pond-peatland complexes along a boreal plains topographic gradient. Journal of Hydrology, 292: 75-95.

Golder Associates. 2006. Hydrologic Regions of Alberta. Submitted to Alberta Environment, Edmonton, Alberta.

Hamilton, D. (1985). Preliminary data compilation for selected drainage basins in Nova Scotia for a low flow regional analysis study. Dartmouth, N.S.: Environment Canada, Inland Waters Directorate, Atlantic Region, Water Planning and Management Branch.

Hatch. 2010. Update on Alberta's hydroelectric energy resources. Final report for Alberta utilities commission, Calgary, Alberta. accessed: http://www.energy.alberta.ca/Electricity/pdfs/AUCHydroelectricStudy.pdf May 1, 2013

Hornberger, G.M., J.P. Raffensperger, P.L. Wiberg, K.N. Eshleman. 1998. Elements of physical hydrology. Baltimore, MA: The John Hopkins University Press.

Ivkovic, K.V. 2009. A top-down approach to characterize aquifer-river interaction processes. Journal of Hydrology, 365: 145-155, doi:10.1016/j/jydrol.2008.11.021.

Kite, G.W., A. Pietroniro. 1996. Remote sensing applications in hydrological modeling. Hydrological Sciences Journal, 41(4): 563-591.

Lane, P.N.J., A.E. Best, K. Hickel, L. Zhang. 2005. The response of flow duration curves to afforestation. Journal of Hydrology, 310: 253-265.

LeBoutillier, D., & Waylen, P. (1993). Stochastic model of flow duration curves. Water Resources Research 29(10), 3535-3541.

Meyboom, P. 1961. Estimating groundwater recharge from stream hydrographs. Journal of Geophysical Research, 66(4), 1203-1214.

Nathan, R.J., T.A. McMahan. 1990. Evaluation of automated techniques for baseflow and recession analysis. Water Resource Research, 26(7), 1465-73

Nemeth, M.W., S.W. Kienzle, J.M. Byrne. 2012. Multi-variable verification of hydrological processes in the upper North Saskatchewan River basin, Alberta, Canada. Hydrological Sciences Journal, 57(1): 84-102.

Pelletier, P.M., Bilozor, W., Glennie, R.A. 1986. Low flow characteristics of selected streams in southern Manitoba. Proceedings of the 16th Canadian Hydrology Symposium: Drought - the Impending Crisi? Regina, Saskatchewan, p 159-174

Pilon, P.J., Condie, R. 1986. Median drought flows at ungauged sites in southern Ontario. proceedings of the 16th Canadian Hydrology Symposium: Drought - the impending Crisis? Regina, Saskatchewan, p.189-196.

Pol, R.A. 1985. Flow duration and low flow frequency analyses for selected watersheds in the Atlantic provinces. Environment Canada, Inland Waters Directorate, Atlantic Region, Water Resources Branch, vols 85-80, 20pp.

Riemersma, S., S. Andrews. 2007. Overview of riparian health assessments and other riparian evaluations completed in Alberta, excluding those completed by Cows and Fish. Report Prepared for Alberta Riparian Habitat Management Society - Cows and Fish.

Seneka, M. 2006. Alberta River Flow Quantity Index (Final Draft). Alberta Environment, Environmental Monitoring and Evaluation Branch. Edmonton, Alberta.
Skop, E., Loaiciga, H.A. 1998. Investigating catchment hydrology and low-flow characteristics using GIS. Nordic Hydrol. 29(2), 105-128.
Smakhtin V.U., Watkins, D.A. 1997. Low-flow estimation in South Africa. Water Research Commission Report No. 494/1/97, Pretoria, South Africa.
Thomas, H.A. 1981. Improved methods for national water assessment. Report, Contract WR15249270, US Water Resource Council, Washington, D.C.
Thompson, S.E., C.J. Harman, A.G. Konings, M. Sivapalan, A. Neal, P.A. Troch. 2011. Comparative hydrology across AmeriFlux sites: The variable roles of climate, vegetation, and groundwater. Water Resources Research, 47, W00J07, doi:10.1029/2010WR009797
Toyra, J., A. Pietroniro. 2005. Towards operational monitoring of a northern-wetland using geomatics-based techniques. Remote Sensing of Environment, 97: 174-191.
Vogel, R.M., Fennessey, N.M. 1995. Flow duration curves. II. a review of applications in water resource planning. Water Resource Bulletin 31(6), 1029-1039.
Winter, T.C., D.O. Rosenberry. 1995. The interaction of groundwater with prairie pothole wetlands in the Cottonwood Lake area, east-central North Dakota, 1979-1990. Wetlands, 15(3): 193-211.

Landuse

ABMI (Alberta Biodiversity Monitoring Institute) 2009. ABMI_RSG Brief Report, 2007 Human Footprint Characterization and Preliminary Statistics, Version 2008-01-23. ABMI, Alberta Canada. accessed: http://www.abmi.ca May 1, 2013.
Lowry, C.S., S.P. Loheide II. 2010. Groundwater-dependent vegetation: Quantifying the groundwater subsidy. Water Resources Research, 46: W06202, doi:10.1029/2009WR008874.
Natural Regions Committee 2006. Natural Regions and Subregions of Alberta. Compiled by D.J. Downing and W.W. Pettapiece. Government of Alberta. Pub. No. T/852.

Modeling

Alley, W.M. 1984. On the treatment of evapotranspiration, soil moisture accounting and aquifer recharge in monthly water balance models. Water Resour. Res., 20(8), 1137-1149.
Baldwin, C.K., D.G. Tarboton, M. McKee. 2002. Estimation of Long-Term Mean Monthly Runoff for Water Balance Calculations. Technical Studies for the WRIA 1 Watershed Management Project.
Barnes, C. (1986). Methods for estimating low-flow statistics for ungaged streams in the lower Hudson River basin, NY. USGS Water Resources Investigations Report 85-4070.
Cervione Jr., M., Melvin, R., & Cyr, K. (1982). A method for estimating the 7-day, 10-year low flow of streams in Connecticut. Connecticut Water Resources Bulletin No.34.
Cleveland, W.S., S.J. Devlin. 1988. Locally weighted regression: an approach to regression analysis by local fitting, J. Am. Stat. Assoc., 83, 596-610.
Devito, K., C. Mendoza, C. Qualizza. 2012. Conceptualizing water movement in the Boreal Plains. Implications for watershed reconstruction. Synthesis report prepared for the Canadian Oil

Sands Network for Research and Development, Environmental and Reclamation Research Group. 164 pp.
Duan, Q., S. Sorooshian, V.K. Gupta. 1994. Optimal use of the SCE-UA global optimization method for calibrating watershed models. J. Hydrol. 158 (3-4), 265-284.
Mallows, C.L. 1973. Some comments on Cp, Technometrics, 15, 661-675.
McCabe, G.J., D.M. Wolock. 2011. Independent effects of temperature and precipitation on modeled runoff in the conterminous United States. Water Resources Research, 47, W11522, doi:10.1029/2011WR010630.
Mngodo, R. (1997). Flow duration characteristics of Southern African rivers. Acta Hydrotechnica 15/18 - Proceedings of oral presentations, FRIEND'97, (pp. 49-63).
Moore, R.D. 1993. Application of a conceptual streamflow model in a glacierized drainage basin. Journal of Hydrology. 150: 151-168.
Moore, R.D., J.W. Trubilowicz, J.M. Buttle. In press. Prediction of Streamflow Regime and Annual Runoff For Ungauged Basins Using a Distributed Monthly Water Balance Model. Journal of the American Water Resources Association. DOI: 10.1111 / j.1752-1688.2011.00595.x.
Morrisey, D., Randall, A., & Williams, J. (1988). Upland runoff as a major source of recharge to stratified drift in the glaciated northeast. AWRA Symposium on Monitoring, Modeling and Mediating Water Quality. AWRA Monograph Series No.11, (pp. 17-36).
Mouelhi, S., C. Michel, C. Perrin, V. Andreassian. 2006. Stepwise development of a two-parameter monthly water balance model. J. Hydrol. 318 (1-4), 200-214.
Ries III, K.G. 1994. Development and application of generalized least squares regression models to estimate low-flow. USGS Water Resources Investigations Report 94-4155, 33pp.
Risle, J.C. 1994. Estimating the magnitude and frequency of low flows of streams in Massachusetts. USGS Water Resources Investigations Report 94-4100, 34pp.
Solomon, S.I., J.P. Denouvilliez, E.J. Chart, J.A. Woolley, C. Cadou. 1968. The Use of a Square Grid System for Computer Estimation of Precipitation, Temperature, and Runoff. Water Resources Research. 4(5): 919-929.
Thornthwaite, C.W., J.R. Mather. 1955. The water balance. Climatol. Lab. Climatol. Drexel Inst. Technol., 8(1), 1-104.
Vandewiele, G.L., C.Y. Xu, Ni-Lar-Win. 1992. Methodology and comparative study of mothly water balance models in Belgium, China and Burma. Journal of Hydrology, 134: 315-347.
Xiong, L., S. Guo. 1999. A two-parameter monthly water balance model and its application. J. Hydrol. 216 (1-2), 111-123.
Xu, C-Y., V.P. Singh. 1998. A review on monthly water balance models for water resources investigations. Water Resou. Manage. 12 (1), 20-50.
Zhang, L., N. Potter, K. Hickel, Y. Ahang, Q. Shao. 2008. Water balance modeling over variable time scales based on the Budyko framework – model development and testing. J. Hydrol. 360 (1-4), 117-131.