Nottawasaga Valley Conservation Authority

Jurisdictional Review for the Administration of a Groundwater Drought Indicator

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1.0 Introduction

Ontario Low Water Response (OLWR) is a mitigation strategy, intended to reduce the socioeconomical and environmental effects of low water (Ontario Ministry of Natural Resources et al., 2010). Currently, precipitation and stream flow are the indicators to determine the low water levels for individual watersheds. To date, a groundwater indicator has not been used in the OLWR system; however, it is presently being explored. Other jurisdictions, notably several individual states in the USA, have integrated a groundwater drought indicator into their drought declaration process (Post, 2013). (In this report, drought and low water are used based on the jurisdiction's definition; however, are herein used interchangeably). Ontario is at a stage where framework for a groundwater drought indicator should be developed.

Initiated in 2002, the Provincial Groundwater Monitoring Network (PGMN) program objective is to collect ambient water level and quality data in key Ontario aquifers. The PGMN program now has in excess of 10 years of hourly groundwater data, representing a statistically agreeable time to consider the implementation of a groundwater low water indicator as part of the OLWR.

A SWOT analysis can be used as a structured planning exercise to evaluate the Strengths, Weaknesses, Opportunities, and Threats involved in the integration of a groundwater drought indicator into the OLWR program. As a method of categorization, the SWOT analysis aims to identify the key internal and external factors seen as important to achieving an objective.

Building on the work completed by Post (2013), the objective of this project is to complete a SWOT analysis from a jurisdictional review of the administration groundwater drought/low water indicator framework. This review will attempt to determine on how best to implement and integrate the groundwater indicator with other low water indicators and identify gaps, challenges and successes. These results will be summarized to develop a process map for integration of a groundwater indicator into the OLWR program.

1.1 Methodology

A survey was developed to capture information on 1) program administration 2) program technical procedures, 3) program communications, and 4) program next steps specifically dealing with the groundwater drought indicator (Appendix A). Email requests were sent to individual states that use groundwater as a drought indicator as identified by Post (2013) to solicit interest. Surveys were completed through a phone interview during the period of December 2013 to February, 2014 with staff from Maryland, Massachusetts, New Jersey, Pennsylvania, Virginia, and Rhode Island. It is noted that North Carolina provided a partial response. Using the collated survey information and the existing PGMN framework, a SWOT analysis was completed for the development of the administration of a groundwater low water indicator as part of the OLWR followed by the development of a framework for a OLWR groundwater drought indicator, using the NVCA PGMN program as a test case.

2.0 Survey Results

The survey results from Maryland, Massachusetts, New Jersey, Pennsylvania, Rhode Island, and Virginia are presented below. The responses are summarized below, subdivided into 1) program administration 2) program technical procedures, 3) program communications, and 4) program next steps.

2.1 Program Administration

	How did a groundwater drought indicator become integrated into the State drought forecasting framework?	**What agencies are involved in the drought program administration?** **How many staff are involved with the groundwater drought indicator?**
Maryland	Groundwater has always been a part of the state drought forecasting program. Note: Program was developed after 1999 drought and the first drought plan was developed for Maryland which was formally used in the 2002 drought. The drought management plan is located at: http://www.mde.state.md.us/assets/document/drought/droughtreport.pdf	In Maryland, the Department of the Environment (MDE) has primary responsibility for tracking drought conditions, and coordinating all drought responses. Several agencies are involved in drought management (http://www.mde.state.md.us/programs/Water/DroughtInformation/DroughtResponsibility/Pages/Water/Drought/responsibilities/index.aspx) The groundwater monitoring is completed by the USGS in partnership with the MDE. The USGS manages all the data for all wells. The State assists in the monitoring of the wells. The staffing contingent responsible for the groundwater aspect of the Maryland drought program consists of at least two staff for 1-5 days a month at MDE and USGS.

	How did a groundwater drought indicator become integrated into the State drought forecasting framework?	What agencies are involved in the drought program administration? How many staff are involved with the groundwater drought indicator?
Massachusetts	Groundwater has always been a part of the state drought forecasting program. The drought management plan is located at: http://www.mass.gov/eea/docs/eea/wrc/droughtplan.pdf	The Massachusetts Department of Environmental Protection (MDEP) manages the drought forecasting/management program. The Mass. Drought Management Task Force consists of the following agencies: DCR—Water Resources, Forest Fire Control, NWS– Service Hydrologist, DEP– Water Supply, Wetlands, Water Management, MA Water Works Association, MA Water Resources Authority, MA Department of Health, MA Department of Agricultural Resources, MA Department of Telecommunications and Energy, MA Department of Fish and Game, US Army Corps of Engineers, and US Geological Survey. A drought emergency results in compulsory actions required whereas watch and warning drought declarations result in voluntary actions. The Governor only has the authority to declare a drought emergency. The groundwater component is completed in partnership with a State department and the USGS. The USGS manages all the data for all wells. The State assists in the monitoring of the wells. Three people in the office operate and maintain the telemetered wells. Roughly 40% of the GW well monitoring is now done by the State for the manual monitoring wells (Cape Cod, Martha's Vineyard and Nantucket areas). Roughly 6 people deal with the GW at equivalent 10% FTE. For additional information see: http://www.mass.gov/eea/docs/eea/wrc/ma-drought-management-plan-10-11-2012.pdf.

	How did a groundwater drought indicator become integrated into the State drought forecasting framework?	What agencies are involved in the drought program administration? How many staff are involved with the groundwater drought indicator?
New Jersey	It is understood that groundwater has been a part of the state drought forecasting program since program inception. Additional state drought management information is located at: http://www.njdrought.org/	NJ Department of Environmental Protection (NJDEP) manages the drought forecasting/management program. The drought management group consisting of but not limited to USGS, forestry, agriculture agencies, etc meets biweekly during the typical dry period. During exceptionally dry periods, the drought task force is implemented with the goal of public action. The drought status (e.g. watch, warning, and emergency) is set by the NJDEP Commissioner. The drought emergency declaration is completed by the NJ Governor. NJ contracts out the USGS to monitor and analyze the groundwater. One staff at NJDEP manages the GW aspect of drought forecasting corresponding to 10% of FTE.
Pennsylvania	Groundwater has always been a drought indicator in Penn. The USGS started to collect groundwater level in the 1930's. As of 1995, the Penn. Department of Environmental Protection (PDEP) took over the data for the drought monitoring. The PDEP provides in-line collaboration with funding to the USGS for the collection of GW data. The state drought management plan is located at: http://www.elibrary.dep.state.pa.us/dsweb/Get/Document-87836/3940-BK-DEP4287%20(WAS%203920-BK-DEP4284)%20Drought%20Management%20in%20Pennsylvania.pdf	The mandate of the Penn. drought program is to protect public water supply. Drought is managed at the county level due to the state's emergency framework through PDEP. The drought emergency results in compulsory actions required whereas watch and warning drought declarations results in voluntary actions. The Governor only has the authority to declare a drought emergency. It is noted that Penn has declared a drought emergency in 2001-2002. The USGS provides PDEP with the data for the groundwater and streamflow and acts as the data keeper, while PDEP acts as the interpreter of the data. Penn. uses this data with other indicators to determine the drought level. The staffing contingent responsible for the groundwater aspect of the Penn. drought program is unknown.

	How did a groundwater drought indicator become integrated into the State drought forecasting framework?	What agencies are involved in the drought program administration? How many staff are involved with the groundwater drought indicator?
Rhode Island	Groundwater has been a drought indicator since the program inception. Additional state drought management information is located at: http://www.wrb.state.ri.us/work_programs_drought.html	The RI Drought Management Steering Committee consists of representatives from agencies that have responsibility for functions related to water resources management and/or interests likely to be affected by drought (for the membership list see: http://www.wrb.state.ri.us/meetings_committees.html#drought). The drought management process is managed by the Rhode Island Water Resources Board. A sample report can be found at: http://www.wrb.ri.gov/work_programs_drought/DSC_CWC_2012_0430.pdf and a presentation at: http://www.wrb.ri.gov/work_programs_drought/DSC_Presentation_2012_0412.pdf The Governor declares the drought phases (watch, warning, and emergency) and issues executive orders and emergency declaration. Mandatory water use restrictions are imposed under the emergency drought phase; watch and warning phases correspond to voluntary water reduction actions. The groundwater data is provided by the USGS. It is noted that the USGS uses federal standards; however, the degree and type of monitoring is dependent on the in-state collaboration funding agreement. It is unclear of the groundwater drought program staffing compliment at Rhode Island.

	How did a groundwater drought indicator become integrated into the State drought forecasting framework?	What agencies are involved in the drought program administration? How many staff are involved with the groundwater drought indicator?
Virginia	Groundwater has been part of the Virginia drought indicator suite since 2003 following several dry years (1998-2002) and the associated revamping of the drought monitoring program. The Virginia Drought Assessment and Response Plan is located at: http://www.deq.virginia.gov/Portals/0/DEQ/Water/WaterResources/vadroughtresponseplan.pdf	Statewide drought monitoring is the responsibility of several state and federal agencies done via the state-wide Drought Monitoring Task Force (DMTF). Members include staff from the Virginia Department of Agriculture and Consumer Services, Virginia Department of Emergency Management, Virginia Department of Environmental Quality, Virginia Department of Forestry, Virginia Department of Game and Inland Fisheries, Virginia Cooperative Extension Service, Farm Service Agency of the United States Department of Agriculture, National Weather Service, the University of Virginia Climatology Office and United States Geological Survey. Coordinated by the Virginia Department of Environmental Quality (VDEQ), the DMTF meets periodically throughout each year and more often (at least monthly) during dry years. The State Drought Coordinator (Secretary of Natural Resources) is responsible for making Drought Watch and Drought Warning declarations. The Governor of Virginia makes Drought Emergency declarations. A declaration of drought is not indicator specific but global. That is, when two or more of the four main drought indicators (surface water flows, groundwater levels, precipitation deficits and reservoir levels) indicate drought conditions, the DMTF will examine other available information and may recommend a drought declaration for all or part of the drought evaluation region(s) under consideration. The drought-related observation wells are operated by both the USGS and the VDEQ. The USGS conducts monitoring and maintains all of the observation well data using federal standards under a cooperative agreement with the VDEQ. Several staff members at both VDEQ and USGS spend a small part of their total allocated time conducting drought-related monitoring and data analysis activities.

2.2 Program Technical Procedures

	What percentiles do you use to determine the groundwater drought indicator? For the statistics, do you use daily, 7, 14, or 30 day/monthly average and what is the rationale for this? How do you manage the change in monthly percentile values with respect to groundwater levels with the change in months?

New Jersey	• NJ uses instantaneous groundwater data which is evaluated on a biweekly basis (Monday) using the last day GW level. Observed daily levels are compared to monthly exceedance frequency curves developed from a statistical analysis of mean monthly values against the following percentiles:
	    • moderately dry: above 30% but less than or equal to 50%,
	    • severely dry: above 10% but less than or equal to 30%, and
	    • extremely dry: below the lowest 10% of observed values for that month.
	• The groundwater percentile rationale is based on that groundwater levels do not change quickly and that the above groundwater percentiles correlate strongly with the streamflow drought declaration period.
	• All monitoring wells are shallow/unconfined wells. There are 3 monitoring wells per drought region. These wells are not affected by pumping or anthropogenic impacts. The wells typically have 50-60 years of data with no wells less than 20 years of data.
	• The groundwater drought indicator is based on the professional judgement derived from the three wells per drought region which is averaged to one value. Professional judgement is used when the percentiles change due to monthly percentile variation.

Maryland	• Maryland uses the USGS for the groundwater data and the percentile delineation for groundwater drought: <25% watch, <10% warning, <5% emergency. The well water levels are examined monthly and are compared against the corresponding historical record. The wells require a minimum of 10 year of data for drought forecasting. Maryland does not look at the record of completeness. The wells are mostly measured manually (2 wells have real time telemetry data transmission). It is unclear how Maryland manages the change in monthly percentile values with respect to groundwater levels. • Maryland is divided into 4 climatic regions and 2 special regions: the City of Baltimore and Metropolitan Washington Council of Governments (https://www.mwcog.org) which operate separately. The climatic regions are based on climate, geology, and physiography. • The distribution of wells used for drought forecasting varies throughout the state's 4 climatic regions. Where more than one well exist per the climatic region, Maryland will use a median level with input from the previous month. (e.g. where 2 wells at are normal, then the groundwater level will be normal, when the two wells are in separate percentiles, then Maryland will look at the median with professional judgment).

	What percentiles do you use to determine the groundwater drought indicator? For the statistics, do you use daily, 7, 14, or 30 day/monthly average and what is the rationale for this? How do you manage the change in monthly percentile values with respect to groundwater levels with the change in months?
Massachusetts	• The groundwater drought declaration consists of watch (4-5 consecutive months below normal), warning (6-7 consecutive months below normal), and emergency (>8 consecutive months below normal). • Mass. uses a yearly rolling average with a minimum of 5 years of monthly data per well to develop the GW percentiles. It is unclear how Mass. manages the change in monthly percentile values with respect to groundwater levels. • The wells in the Mass. climate response network are the top priority wells in the USGS GW monitoring network and require the most attention resulting in all wells having a considerably complete dataset (see http://ma.water.usgs.gov/) • Most wells are manual with monthly statistics taken on them. • The overwhelming majority of the wells are shallow to capture the linkage btw GW-SW with the average well depth of 4m feet (deepest well is 9m) and the use of these shallow wells provide a first indicator for drought low water conditions.
Pennsylvania	• The USGS maintains the real-time groundwater monitoring well network including maintenance, data analysis, and on-line data distribution for Penn. • The groundwater percentile ranges of 10 to 25, 5 to 10, and 0 to 5 representing watch, warning and emergency, respectively and are calculated on a monthly basis. The respective drought level for all wells is compiled automatically once a day. • Total network is 41 existing historical wells and 16 additional wells installed in 2003. All wells have telemetry capabilities with levels (and temperature) recorded hourly. The wells require a minimum of 20 years of data before being considered a part of the program. • Additional information is located at: http://www.portal.state.pa.us/portal/server.pt/community/drought_information/10606, http://pa.water.usgs.gov/drought/indicators/gw/, http://pa.water.usgs.gov/drought/indicators/gw/explanation.php)
Rhode Island	• Rhode Island has a network of wells that are read monthly and 5 continuous wells, monitored by the USGS. The groundwater indicator is a monthly average, though rely on the continuous wells to indicate whether conditions are improving or continuing to deteriorate. • The groundwater drought declaration consists of watch (4-5 consecutive months below normal), warning (6-7 consecutive months below normal), and emergency (>8 consecutive months below normal). It is unclear how Rhode Island manages the change in monthly percentile values with respect to groundwater levels. • Rhode Island relies on the USGS well network and their standards as well as professional judgement regarding the value of monitoring wells for assessing conditions (i.e. till v. stratified drift, # of years in operation, proximity to stream or pumping, depth, other factors such as data collection issues and/or gaps, vegetation, anomalies, etc.

	What percentiles do you use to determine the groundwater drought indicator? For the statistics, do you use daily, 7, 14, or 30 day/monthly average and what is the rationale for this? How do you manage the change in monthly percentile values with respect to groundwater levels with the change in months?

Virginia	• The groundwater drought percentiles correspond to:
	  ◦ Normal Conditions: Measured groundwater levels above the 25th percentile for all historic levels.
	  ◦ Drought Watch Condition: Measured groundwater levels between the10th and 25th percentiles for all historic levels
	  ◦ Drought Warning Conditions: Measured groundwater levels between the 5th and 10th percentile for all historic levels.
	  ◦ Drought Emergency Conditions: Measured groundwater levels below the 5th percentile for all historic levels
	• Virginia's drought-related groundwater observation wells are part of the USGS National Climate Response Network. The VA DMTF uses a 7 day rolling average to determine the monthly groundwater percentiles for the climate response network. The monthly statistics are not adjusted to account for changes in monthly percentile values between months (for example, the change between the last day of one month and the first day of the next month).
	• The wells are completed in shallow unconfined aquifers or in fractured bedrock and situated where groundwater would most rapidly be affected by drought, e.g. mountain tops instead of valley bottoms.
	• The climate response groundwater observation well network requires a minimum of 20 years of data for a well to be included. All wells are currently real-time stations, although much of the period of record for many contains periodic data only. It is noted that these wells are top priority wells and are generally visited monthly for station maintenance.

2.3 Program Communications

	Is groundwater integrated with other drought indicators? What is the approach for drought reporting?	How is the groundwater drought indicator effectively communicated out and what mechanisms are used?
Maryland	Groundwater is integrated with the other drought indicators: precipitation level, streamflow, ground water level, and reservoir storage. Declaration is done as a whole for the climate region, not based on a specific indicator. Both MDE and USGS report the drought conditions. (http://www.mde.state.md.us/programs/Water/DroughtInformation/Pages/Water/Drought/index.aspx)	Maryland issues web-based reports and press releases when drought conditions arise. Web-based program information can be found at http://www.mde.state.md.us/programs/Water/DroughtInformation/Pages/Water/drought/index.aspx. It is noted that Maryland has a state drought hot line when drought conditions arise.

	Is groundwater integrated with other drought indicators? What is the approach for drought reporting?	How is the groundwater drought indicator effectively communicated out and what mechanisms are used?
Massachusetts	A global drought is declared based on the 4 out of the 7 drought indicators being in the specific range of drought (e.g. drought warning). The seven indicators consist of: Standardized Precipitation Index, Crop Moisture Index, Keetch-Byram Drought Index, Precipitation, Groundwater Levels, Streamflows, Reservoirs Although dated, drought status reports are located at http://www.mass.gov/eea/docs/dcr/watersupply/rainfall/pr-lifting-drought-advisory-3-18-08.pdf)	Due to a global declaration of drought, there is no confusion with a 'groundwater drought'. It is unclear of the public outreach material used to communicate a groundwater drought indicator. Web based program information can be found at: http://www.mass.gov/eea/agencies/dcr/water-res-protection/water-data-tracking/drought-status.html
New Jersey	New Jersey declares a socioeconomic drought. The groundwater indicator is integrated with the other drought indicators which consist of stream flow, precipitation, reservoir levels, and groundwater. The various indicator levels are combined with professional judgement to declare a global drought. An example of New Jersey water supply reports are located at: http://www.njdrought.org/pdf/wsc-121127.pdf	Due to a global declaration of drought integrating the indicators together, there is no confusion with a 'groundwater drought'. Program information including additional drought links can be found at: http://www.njdrought.org/. Drought press releases can be found at: Program information including additional drought links can be found at: http://www.njdrought.org/
Pennsylvania	Groundwater is integrated with the other drought indicators: the USGS related indicator (streamflow and groundwater levels) is calculated every day. The soil moisture indicator- Crop Moisture Index is calculated through the NOAA, updated weekly (Thursday). Also, precipitation is used as the fourth drought indicator. Penn. DEP collectively analyzes this data along with associated trends/levels plus profession judgement to determine and declare the likelihood and chance of a global drought.	Significant public education has occurred with the Penn. drought program completed through presentations, media releases, and web site (http://www.portal.state.pa.us/portal/server.pt?open=512&objID=21263&PageID=1356623&mode=2). The public is fairly aware of this program. It is noted that it is tough for the public to comprehend dry groundwater levels in fall-winter time.
Rhode Island	Groundwater is integrated with the other drought indicators which consist of precipitation, streamflow, groundwater, and Palmer Drought Index used for Rhode Island. An example of summary of current conditions monthly reporting is located at: http://www.wrb.ri.gov/work_programs_drought/DSC_CWC_2012_0430.pdf	Due to a global declaration of drought integrating the indicators together, there is no confusion with a 'groundwater drought'. It is unclear of the public outreach material used to communicate a groundwater drought indicator. Detailed program information can be found at: http://www.wrb.ri.gov/work_programs_drought.html

	Is groundwater integrated with other drought indicators? What is the approach for drought reporting?	How is the groundwater drought indicator effectively communicated out and what mechanisms are used?
Virginia	Groundwater drought indicator is combined with other indicators and reporting is done as a whole for drought declaration for the specific climate region. An example of summary of current conditions monthly reporting is located at: http://www.deq.virginia.gov/Portals/0/DEQ/Water/WaterResources/VirginiaDroughtStatus/CurrentDroughtTaskForceReport.pdf	Through education, residents are now knowledgeable of drought monitoring and the use of drought indicators in Virginia. The web has been used to inform the public of a groundwater drought condition: http://www.deq.virginia.gov/Programs/Water/WaterSupplyWaterQuantity/Drought.aspx

2.4 Program Next Steps

	What is the perceived strength/weakness of the use of a groundwater indicator in your program?	What do you foresee as the next steps in the evolution of your drought forecasting program?	Do you exchange information with other state drought management programs?
Maryland	Strength: Decent representation of issues. Weakness: Better coverage in the western region (Garrett County lacks a monitoring well) and enhanced attention from the local authorities regarding drought.	The next steps in program evolution consists of system automation (well to web), more stream gauges, and develop more real time wells and conversely, not to lose any indicators.	The State response to drought is under the jurisdiction of the individual state. Interstate communication is completed mostly through the Susquehanna River Basin Commission (http://www.srbc.net/) and the MWCOG initiative. MWCOG has its own drought plan for the Potomac river. Also the Potomac River Board is involved with drought forecasting (http://www.potomacriver.org/) Maryland notes that Penn. is a really good example of a drought management and forecasting model.

	What is the perceived strength/weakness of the use of a groundwater indicator in your program?	What do you foresee as the next steps in the evolution of your drought forecasting program?	Do you exchange information with other state drought management programs?
Massachusetts	Strength: Extremely long data set. Weakness: Require more wells that are equipped with a telemetry system and continuous dedicated loggers to capture short term variation.	Program enhancement includes possibly more sites with telemetry in order to link with the stream flow tracking for GW-SW interactions.	Mass. works closely with Rhode Island and Conn. with drought forecasting regarding a local USGS hub and employ the same methodology and indicators for drought forecasting. Further Mass. participates in a regional climate response network that includes Mass, Rhode Island, Conn, Vermont, and New Hampshire. However, the state response is under the jurisdiction of the individual state.
New Jersey	Strength: Numerical basis and the process is transparent and publicly available with published indicator. Weakness: Use of professional judgement and not defined overall drought trigger levels.	Next steps in the program evolution includes detailed monitoring reservoir levels with real time loggers and securing additional monitoring wells that are not influenced by pumping based on geological formation, topography, etc, etc. It is noted that professional judgment has worked well in the delivery of the program.	NJ operates a separate drought management system with respect to NY and Penn (neighbouring states); however, checks stats via webpages to see where drought levels are at. It is noted that Rockland County (NY) has a fairly good drought management program completed through the local health unit and is based on reservoir levels.
Pennsylvania	Strength: Groundwater as an indicator, number of wells offers a different perspective even though tough to characterize groundwater flow paths superimposed with variability (topography, climate, geology). Weakness: The need for more monitoring wells.	The next step in the program evolution is the development of a forecasting methodology for drought period determination.	The State response to drought is under the jurisdiction of the individual state. The interstate discussion is mostly completed through the Delaware River Basin Commission (http://www.state.nj.us/drbc/) and the Susquehanna River Basin Commission (http://www.srbc.net/). However, the discussion is fairly limited outside time of dry conditions.

	What is the perceived strength/weakness of the use of a groundwater indicator in your program?	What do you foresee as the next steps in the evolution of your drought forecasting program?	Do you exchange information with other state drought management programs?
Rhode Island	Strength: Long term indicator which is especially important for assessing recovery. Weakness: Number of wells, comprehensiveness of network, factors that influence the reliability as an indicator (such as proximity to a stream or till leading to "flashiness").	Rhode Island has developed with USGS a drought decision support tool in a basin that is used for public supplies that will assist suppliers in managing withdrawals to minimize impacts. It is in publication and will be 6 months to a year before it is publically available.	The State response to drought is under the jurisdiction of the individual state. Rhode Island regularly correspond with the managers of the Massachusetts and Connecticut programs and works very closely on an on-going basis with a hydrologist from National Weather Service regional office. In addition the three states collaborated during the creation of the drought plans in the early 2000s and coordinated with the National Weather Service, the Drought Mitigation Center as well as the published federal framework for drought policy. Updates to plans are routinely shared among the states.

	What is the perceived strength/weakness of the use of a groundwater indicator in your program?	**What do you foresee as the next steps in the evolution of your drought forecasting program?**	**Do you exchange information with other state drought management programs?**
Virginia	Strengths: Long term data set. Weakness: Not enough wells resulting in spatial data gaps.	Next steps in the groundwater portion of the drought monitoring program evolution include improvement of the website regarding the logistical/administrational aspect of the program plus securing additional wells for the network. Next steps in the surface water portion of the program include probabilistic forecasting of summer low flows based on winter flows as part of a cooperative program with the USGS.	The State response to drought is under the jurisdiction of the individual state. Virginia communicates closely with with the District of Columbia, Maryland and West Virginia via the Interstate Commission on the Potomac River Basin (ICPRB) and the Metropolitan Washington Council of Governments (MWCOG) and also with North Carolina and the Tennessee Valley Authority (TVA, http://www.tva.com/) for issues related to drought. The relationship with North Carolina is based on the physiography, watershed/basins, and organizationally. It is noted that the TVA has their own drought management plan which is comprised the states within the boundaries of the TVA; however builds on the Virginia Drought Assessment and Response Plan which takes precedence within Virginia.

2.5 Summary of the Groundwater State Survey

Program administration: Groundwater has been part of the surveyed states drought forecasting model since the individual state drought program inception. The generalized state drought forecasting program is made up several federal, state and local agencies (e.g. agriculture, emergency management, environmental quality/protection, forestry, fisheries, National Weather Service, United States Geological Survey, etc).

The watch (typically the 25th percentile) and warning (typically the 10th percentile) results in voluntary actions. The drought emergency generally corresponds to the 5th percentile results in compliance-based actions. The declaration of a drought emergency is completed exclusively at the Governor level.

The declaration of drought is not indicator-specific but global, based on the composite drought indicators and professional judgement. It appears that this declaration process is based on the majority of indicators along with professional judgement only. There is no indication if a statistical multi-variate method is employed. The groundwater information is provided by the USGS in partnership with the individual state. It is noted that the USGS uses federal standards; however, the degree and type of monitoring is dependent on the in-state collaboration funding agreement and varies state to state.

Staffing for the delivery of the groundwater drought indicator including monitoring, data collection, and analysis varies per state.

Program technical procedures: The groundwater percentile thresholds vary across the different jurisdictions. In general, the 25th percentile plus is considered normal groundwater levels, the 10th -25th range is considered dry (or drought watch), and below the 10th or 5th percentile is considered a drought emergency. Broadly summarized for the individual States, the drought monitoring wells are generally completed into unconfined/water table environments. The minimum period of record used by the USGS is 10 years although Massachusetts uses a minimum of 5 years to compute the monthly statistics. Further some individual states use a combination of continuously logged wells and manually measured groundwater levels used for monthly statics to determine the percentiles for groundwater levels. The spatial distribution of the drought monitoring wells vary per individual jurisdiction: some states have a drought monitoring well in every county (e.g. Pennsylvania) whereas other states have monitoring well(s) in climate regions which are composite watersheds/counties (e.g. New Jersey and Maryland).The individual states use a variety of statistics to determine the actual percentiles (e.g. daily (New Jersey), 7 day (Virginia), 30 day (Rhode Island) rolling average used).

Program communications: Drought reporting appears to be completed on an irregular basis. No confusion has resulted in a 'groundwater drought' with the typical hydrograph lag with respect to flashy, surface water system due to the integration of groundwater indicator as a composite drought declaration process. Websites, press releases, and presentations have been typically completed by the various states as outreach to educate and raise program awareness. However, it is difficult for the public to comprehend low groundwater levels in the fall-winter time.

Program next steps: The surveyed States consistently applauded the long data set that is utilized for the groundwater drought indicator. Additionally, the transparency of the process was recognized as a strength of the groundwater drought indicator. A consistent weakness stated by the general consensus is that more wells are needed to further constrain low water conditions, preferably wells with real time telemetry data transmission.

Not surprisingly, several states envision that the next step in the evolution of their respective drought forecasting program is the addition of more monitoring wells, preferably with telemetry and automated real time well to web data delivery. Other next steps included website improvement and drought forecasting methodology.

Regarding inter-State drought program communications, drought response is the jurisdiction of the individual state. Massachusetts, Connecticut, and Rhode Island work very closely on an on-going basis with a hydrologist from the National Weather Service regional office. Outside of this, interstate drought discussion is mostly completed through the various river basin commissions (Delaware, Susquehanna, etc).

3.0 SWOT Analysis

SWOT stands for Strength, Weaknesses, Opportunities, and Threats. SWOT analysis is a planning tool used by companies or organizations to identify internal and external factors. These factors are analyzed in a simple matrix diagram that allow companies to have a wide view on how they will achieve their goal by including positive and negative elements that may have an impact on a new proposed goal (Goodrich, 2013). Internal factors include the strengths and weaknesses. Strengths are the advantages that a certain project or company has over competitors. Weaknesses are the disadvantages a company has, listing areas of needed improvement. The external factors are the opportunities and threats. Opportunities list all the advantages that could arise from the proposed goal. Threats are the negative elements that can potentially come about in the project (JRC, 2005). In order to achieve a successful SWOT analysis, internal and external factors must be listed prioritizing their importance, probability and likelihood of occurrence that may have an impact to the objective. SWOT analysis is an excellent decision-making tool as it helps companies analyze opportunities and threats that may arise from a proposed project, as well as identifying areas of improvement and weaknesses (JRC, 2005).

A SWOT analysis in relation to NVCA undertaking a drought groundwater indicator as part of the OLWR is provided below.

	Positives	Negatives
Internal Factors	**Strengths** **Number and distribution of wells**: The NVCA operates 16 PGMN monitoring wells at 10 sites within the 3300 km^2 watershed or roughly one well per 210 km^2. Hydrostratgraphically, the wells are screened into three of the four main regional aquifers. Three wells are completed into unconfined aquifer conditions (W281-1, W291-1, and W292-1) and the remainder in confined settings. **Legislative support:** the OLWR program recognized the need for a groundwater low water indicator (MNR, 2001). **Length of groundwater level record:** the majority of the PGMN network was initiated in 2003 with the majority of the wells	**Weaknesses** **Data correction process:** the logger data is required to be baro-compensated and corrected for slips, outliers, etc. Presently, the data correction process is completed twice annually which nullifies the real time use of the data for a drought indicator. **Suitable wells:** it is strongly recommended that unconfined wells be utilized for a low water/drought groundwater indicator. The NVCA has 3 unevenly distributed wells completed into the unconfined setting which covers, or 1 well per 1100km^2 of subwatershed- this may be too diffuse to generate

	Positives	Negatives
	generally having over 10 years of data which is the used by the USGS for the minimum data time series required for climate monitoring. **Well selection process:** the MOE has completed a detailed selection analysis of the provincial PGMN Wells for Ontario Low Water Response (MOE, 2013). Two NVCA sites have been recommended for long term climate monitoring by the MOE (323 well nest (Bradford) and 291-1 (Wasaga Beach). **Methodology:** there is general consensus that Level I= <25th percentile, Level II=<10th percentile, and Level III=<5th percentile. **Technology:** the MOE has purchased FTS modems and the MNR has developed the WISKI set up for real time data management and availability. **Program Delivery:** the CAs haves a long history of the PGMN program delivery and extensive local knowledge of the individual wells in addition the CAs haves an established relationship with the program partners.	meaningful results. **Capacity:** the implementation and maintenance of a groundwater drought indicator will require additional resources that will exceed the expectations listed under the current MOU for the delivery of the PGMN program. **Technology (barologgers):** it is noted that 2 NVCA sites have been selected for the FTS modems. These sites; however, presently lack a barologger for real time level corrections. **Funding**: the NVCA presently has limited funding dedicated to the PGMN program and could be vulnerable to inter-annual changes in budget.

	Positives	Negatives
External factors	**<u>Opportunities</u>** **Existing Partnership agreements:** the framework for the delivery of the PGMN program is already established through the Partnership Agreements. These agreements are recommended to be amended to include a higher level of care for the climate wells. **PGMN data utilization:** the use of the foundational data generated from the PGMN program for low water indicator further enhances the utility and the necessity of the PGMN.	**<u>Threats</u>** **Surface water-groundwater declaration overlap:** work completed by McPhie and Post (2014) for the NVCA PGMN program indicates minimal overlap between the Level I/II/III surface water declaration periods in comparison to the equivalent groundwater time. This lack of correlation suggests that groundwater by utilized as secondary drought indicator. **Communication**: guidance is required to be developed by the provincial lead in how a groundwater drought indicator is to be implemented and utilized in the OLRW framework.

4.0 A Framework for a Groundwater Drought Indicator for the OLWR

Building on the results generated through the phone interviews with the various states that use a groundwater indicator and the SWOT analysis, a framework for a groundwater drought indicator as part of the OLWR is presented below.

The PGMN program has the foundational utility and geographic concentration of wells throughout southern Ontario to allow for a hierarchical monitoring approach. One component of this hierarchical monitoring approach includes climate or drought monitoring. Monitoring wells (or well nests) completed into unconfined aquifer settings and outside the influence of anthropogenic influences (e.g. to determine baseline ambient conditions) are recommended for low water groundwater monitoring. Also, wells with at least 10 years of a complete groundwater level record should be considered as a screening tool. The well selection methodology presented by MOE (2013) should be used to further constrain the well locations for the use of a groundwater drought indicator. It is envisioned that the distribution and geographic concentration of the selected wells for the groundwater drought indicator should align to a similar distribution to the state climate/drought regions. If not, further consideration should be given here.

The low water monitoring well locations should be strategically aligned with the installation of the MOE-MNR FTS modems and assumed are. Regardless, the low water PGMN wells will require real time well to web transmission of data. For data use and confidence, the wells should be complimented with monthly manual measurements during snow free periods and bimonthly during snow periods.

The corrected water levels and the corresponding percentiles will need to be provided in a timely fashion to allow for the drought declaration decision making process. Presently, the NVCA releases the stream flow updates on a biweekly schedule during the summer months (June-early September). This data needs to be barocorrected and approved by the MOE prior to the release as per the current MOE PGMN data correction protocol. It is encouraged that for the automation of groundwater level corrections – including barometric corrections. Further, a barometer should be dedicated to each OLWR site.

The methodology for groundwater analysis will need to be developed by the Province to ensure pan-Province consistency and application. As a result, the OLWR manual (2001) will need to be updated to reflect the new groundwater low water indicator. No modification to the Level I/II/ voluntary and Level III compliance requirements are required, e.g. the administrative framework of the OLWR remains the same. Although it is recommended that the percentiles be developed using a 30 day rolling average based on the results by McPhie and Post (2014).

The groundwater low water indicator is to be evaluated globally with the existing streamflow and precipitation low water indicator with professional judgement, i.e. the groundwater low water indicator is not a standalone indicator. Groundwater and surface water low water declaration period correlation work completed by McPhie and Post (2014) strongly encourages the use of a groundwater low water indicator as a supplemental low water indicator. It is encourage that a consistent percentile be used across the province for the corresponding Level I/II/III to allow for consistent interpretation and communication of the data.

Training, operational, and outreach materials will need to be developed for the individual Water Response Teams, public agencies, and the general public as noted that it is difficult for the public to comprehend low groundwater levels in the fall-winter time. A groundwater low water indicator web presence will also need to be independently considered by the individual CAs. However, the USGS climate well web presence may be of consideration for the Ontario low water wells.

The CAs are envisioned to be the delivery agent for the groundwater low water indicator based on the long history of the PGMN program delivery and extensive local knowledge of the individual wells. It is noted that the existing MOE-NVCA MOUs for the delivery of the PGMN program be re-examined to ensure that the degree of compliance for these climate wells (e.g. manual statics, data corrections, etc).

4.1 Considerations for a NVCA Groundwater Low Water Indicator

- The NVCA operates 16 PGMN monitoring wells at 10 sites within the watershed, three of which are completed into unconfined aquifer conditions (W281-1, W291-1, and W292-1) and the remainder in confined settings. The Bradford well nest (W323-2,-3,-4) is presently equipped with a FTS modem. Well 291-1 (Wasaga Beach) is also targeted for the FTS modem based on the MOE (2013). The wells/well nests equipped with the FTS modems will be used for a groundwater low water indicator.
- The data will be analyzed using a 30 day rolling average with the 25th percentile corresponding to Level I, the 10th percentile corresponding to Level II, and the 5th percentile to Level III. A groundwater low water level will be considered following five days in a specific level.
- The groundwater low water indicator is to be used as a supplemental indicator given the results of McPhie and Post (2014).
- This groundwater low water indicator is anticipated to complement the biweekly stream flow NVCA update during the summer months (June-early September); however, the data correction process hinges on data availability. It is noted that the FTS modems are presently not equipped with barologgers for the data correction process.
- The groundwater low water indicator is based at the watershed scale and is anticipated to have limited usability at the subwatershed scale for Level III declarations.
- The low water declaration will consists globally of three indicators and will not be indicator-specific.

<u>5.0 Conclusions and Recommendations</u>

A phone survey and a SWOT analysis was completed to determine on how best to implement and integrate a groundwater indicator with other low water indicators and identify gaps, challenges and successes, and lesson learns. Telephone surveys were completed with groundwater drought indicator program staff from Maryland, Massachusetts, New Jersey, Pennsylvania, Virginia, and Rhode Island, capturing information on 1) program administration 2) program technical procedures, 3) program communications, and 4) program next steps. Summary of this information was used in a SWOT analysis for the development of an OLWR groundwater indicator with the following internal strengths and weaknesses plus external opportunities and threats identified:

Internal factors

Strengths:

- Number and distribution of wells
- Legislative support
- Length of groundwater level record
- Well Selection process
- Methodology
- Technology
- Program Delivery

Weakness:

- Data correction process
- Suitable wells
- Capacity
- Technology (Barologgers)
- Funding

External factors:

Opportunities:

- Existing Partnership agreements
- PGMN data utilization

Threats:

- Surface water-groundwater declaration overlap
- Communication

5.1 Recommendations

This jurisdictional review of a groundwater drought indicator administration provides a detailed process map for the integration of a groundwater low water indicator into the OLWR program. Given the adequate PGMN time series data, recent PGMN program technology advances with the addition of the FTS modems, and the process map generated through this study; it is recommended that the groundwater low water indicator be piloted in 2014 with a few sites that have been equipped with the FTS modems. In support of this, it is also recommended that the selected pilot sites be augmented with barologgers to ensure real time auto baro-correction. The pilot project results are encouraged to be distributed to the PGMN program partners for the broad, provincial implementation of a groundwater low water indicator in 2015.

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Appendix A- Survey

Subject: Jurisdictional Analysis of the Administration of a Groundwater Drought Indicator

Hello once again!

To date, a groundwater drought indicator has not been used in the Ontario Low Water Response system; however, it is presently being explored through the use of the percentile methodology. As Ontario further explores the utility of groundwater as a drought indicator, the NVCA in partnership with the MOE is undertaking a desktop administration jurisdictional review where groundwater is used as a drought/low water indicator. This will build on the previous study that we discussed before. This review is to determine on how best to implement and integrate groundwater indicators with other low water indicators and the associated gaps, challenges and successes, and lesson learns/recommendations resulting for the inclusion of groundwater into the drought management tool box at your respective jurisdiction. The intent is to have these results summarized to develop a process map for integration of a groundwater indicator into the Ontario Low Water Response (OLWR) Program.

In support of this, I have compiled the below questions in order to obtain an understanding of how various jurisdictions employ a groundwater indicator and to outline the strengths of the respective programs for the development of a groundwater drought indicator in Ontario; focusing on integration, communication, implementation.

If possible I would like to arrange a telephone call to go over these questions. It would be greatly appreciated if you could offer a couple dates/times over the next month that would work for this call.

Should you like to know any further details please contact me.

Your time is greatly appreciated
Sincerely
Ryan Post

Questions:
Operational procedure of the program:

- What calculation do you use to determine the groundwater level for the drought indicator; are you using the daily, 7, 14, or 30 day/monthly average? What is the rationale for this? How do you manage the change in monthly percentile values with respect to groundwater levels with the change in months?
- For the use of groundwater level data, what limit of data completeness do you employ, e.g. a 75% annual completeness record for wells with over 7 years of data?

Administration of the program:

- Regarding the program administration, besides the USGS and the State, are any other agencies involved?
- Do you have a process map outlining the administration of the groundwater drought indicator?
- How is a 'groundwater drought' defined, e.g. how long does the system have to be at or below a certain percentile before a low water/drought declared? And correspondingly, what is the definition for groundwater to exit a drought condition/percentile level?

- What are the perceived strengths/weakness of the use of a groundwater indicator in your program?
- How many staff with hydrogeological background are working with respect to the groundwater drought indicator?

Communication:

- Is groundwater integrated with other indicators and how? What is the approach and is reporting done separately or combined?
- How is a groundwater drought indicator effectively communicated out, given the lag time/out of phase between GW and surface water indicators? What mechanisms do you use to communicate drought (groundwater) out to the general public? What issues have you encountered when communicating a groundwater drought to the general public?

Program history & insights plus lessons learned:

- How did a groundwater drought indicator become integrated into your drought forecasting mechanism?
- What are the issues with using groundwater as a drought indicator at the county/state level?
- How would you change the drought program if you had a chance, specifically dealing with groundwater?
- What do you foresee as the next steps in the evolution of your drought forecasting program?
- Do you have a process map outlining the integration of groundwater drought indicator into the program (if groundwater was not always part of the equation)?
- What are you doing to strengthen the participation/interconnection with other state drought management frameworks/networks?
- Do you exchange knowledge/experience with other state drought management programs?