Delineation of Significant Groundwater Recharge Areas: Supplemental Technical Guide

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All of the information contained in this Supplemental Technical Guide is based on information taken from the Clean Water Act Assessment Reports and supporting Water Budget and Risk Assessment Reports unless otherwise noted and identified. See the complete list of references.

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1.0 INTRODUCTION

In 2007, the *Clean Water Act,* (Bill 43; Ministry of Environment, 2006) came into effect to protect existing and future sources of drinking water as part of an overall commitment to safeguard human health and the environment.

Under the Clean Water Act, Source Protection Committees (SPCs) must prepare a Terms of Reference (i.e. workplan), an Assessment Report (i.e. compiled technical studies) and a Source Protection Plan (i.e. policies) for each Source Protection Area (SPA) that they represent. Technical Teams within each SPA are required to conduct the Assessment Report's technical studies which identify existing and potential water quality and quantity threats to municipal drinking water in accordance with the regulations, Technical Rules: Assessment Report (Technical Rules), and Terms of Reference for their Area. Through the development of community-based Source Water Protection Plans, actions will be implemented to reduce or eliminate significant threats to the quality or the quantity of municipal drinking water supplies.

As part of the Assessment Report, SPCs must identify four types of vulnerable areas within each SPA. These include wellhead protection areas, intake protection zones, highly vulnerable aquifers, and Significant Groundwater Recharge Areas (SGRAs).

Essentially, SGRAs are those areas within a SPA which generate higher than average groundwater recharge and are hydraulically connected to a drinking water system. SGRAs are delineated through the development of Water Budget and Risk Assessment studies (Water Budget Reports) as per the Technical Rules listed below:

> *44. Subject to rule 45, an area is a significant groundwater recharge area if,*
> *(1) the area annually recharges water to the underlying aquifer at a rate that is greater than the rate of recharge across the whole of the related groundwater recharge area by a factor of 1.15 or more; or*
>
> *(2) the area annually recharges a volume of water to the underlying aquifer that is 55% or more of the volume determined by subtracting the annual evapotranspiration for the whole of the related groundwater recharge area from the annual precipitation for the whole of the related groundwater recharge area.*
>
> *45. Despite rule 44, an area shall not be delineated as a significant groundwater recharge area unless the area has a hydrological connection to a surface water body or aquifer that is a source of drinking water for a drinking water system.*
>
> *46. The areas described in rule 44 shall be delineated using the models developed for the purposes of Part III of these rules and with consideration of the topography, surficial geology, and how land cover affects groundwater and surface water.*

This supplemental technical guide reviews the experiences and approaches of SPAs, summarizing the methodologies they used to delineate SGRAs across the Province. In preparing this supplemental technical guide, all available Clean Water Act Water Budget Reports and Assessment Reports have been reviewed along with relevant documents provided by the Province. Methodologies for generating groundwater recharge estimates will not be summarized within this document. Rather, this review and summary will focus primarily on the three main tasks associated with the delineation of SGRAs which follows the generation of groundwater recharge estimates. The three general tasks for delineating SGRAs are as follows:

1. Determine Threshold For High Recharge Areas

   Areas with groundwater recharge estimates greater than a prescribed threshold are deemed to be SGRAs, provided other requirements are met (Task#2 below). The Technical Rules provides two methodologies for determining the high recharge threshold. These methodologies are as follows: 1) Greater than 115% of the average groundwater recharge; or 2) Greater than 55% of net precipitation (precipitation minus evapotranspiration). Technical Teams are free to select the methodology that they think is most appropriate for their SPAs.

2. Determine Linkage to Drinking Water Systems

   To be considered an SGRA, a hydraulic link must be established between the high recharge areas identified in Task 1 and a drinking water system. A "drinking water system" includes municipal water systems, as well as private domestic wells.

3. Apply Professional Judgement

   The final step in generating SGRAs allows the Technical Teams to exercise professional judgement in modifying the delineated SGRAs where appropriate. The purpose of this task is to allow the Technical Teams to modify the results of the SGRA exercise to reflect local knowledge or to facilitate policy development. Examples may include: excluding SGRAs within known groundwater discharge areas; or excluding small isolated areas that are identified as SGRA.

Additionally, this supplemental technical guide will consider any secondary analysis used to confirm SGRA thresholds, specific considerations in the delineation of SGRAs, as well as approaches used for refining SGRAs based on Tier 2 and Tier 3 water budget study refinement.

2.0 SIGNIFICANT GROUNDWATER RECHARGE AREA IDENTIFICATION

Following the review of Water Budget Reports from all SPAs, four main decision points were identified as being common to all SGRA delineation exercises.

- ***Select High Recharge Threshold*** – Which Provincial threshold is most appropriate for identifying high groundwater recharge areas (115% of average recharge versus 55% of net precipitation)
- ***Spatial Scale for Averaging*** – Rule 44(1) states that 115% of average groundwater recharge for the "*whole of the related groundwater recharge area*" is used to identify high recharge areas. There is currently no guidance on what geographic extent makes up the "whole of the related groundwater recharge area", therefore Technical Teams must select the appropriate spatial scale to calculate the average groundwater recharge rate over.
- ***Linkages Between High Recharge Areas and Drinking Water Systems*** – Once high recharge areas are identified, a hydrological linkage to a drinking water system must be shown to classify that area as an SGRA, as per Rule 45.

- ***Professional Judgement*** – Determine whether delineated SGRAs may be modified to better represent actual conditions, as per Rule 46.

The following section describes each of these decision points and identifies trends among the approaches employed by the various SPAs.

2.1 Significant Groundwater Recharge Area Thresholds

As defined by the Technical Rules, the two methods available to Technical Teams for delineating SGRAs are listed below.

> *44(1) the area annually recharges water to the underlying aquifer at a rate that is greater than the rate of recharge across the whole of the related groundwater recharge area by a factor of 1.15 or more; or*
>
> *44(2) the area annually recharges a volume of water to the underlying aquifer that is 55% or more of the volume determined by subtracting the annual evapotranspiration for the whole of the related groundwater recharge area from the annual precipitation for the whole of the related groundwater recharge area.*

The first rule, 44 (1), was developed for areas where the recharge rates within the SPAs are similar. This method can assist in distinguishing between high versus low recharge even when narrow ranges in recharge rates exist across an area. The method is highly dependent on the scale of the area selected for calculating the average recharge (which is discussed in the following section). Considerable differences can occur in the delineation of SGRAs depending on the scale (e.g. subwatershed/watershed/SPA/Region) at which this method is applied. If the method is applied at smaller spatial scales (e.g each subwatershed within a SPA) it may lead to a wide range of SGRA thresholds for the various subwatersheds within the SPA, resulting in a higher likelihood of boundary issues occurring between the different subwatersheds (MNR & MOE, 2009).

The second rule, 44 (2), was developed for areas with a greater range of recharge rates throughout the SPA. This method is dependent on net precipitation for an individual land segment, therefore neither calculating the average recharge nor determining which spatial scale from which to calculate average recharge for is required.

The approach selected for use by each of the SPAs is summarized in Appendix A. A significant majority (70%) of SPAs selected method 44 (1) over 44 (2).

It is interesting to note that there seems to be a geographic bias with regards to the SGRA threshold selected for use. While there are exceptions, SPAs located in the East of the Province generally selected Rule 44 (2), while SPAs located around Toronto and South-western Ontario generally selected Rule 44 (1). SPAs in the North were split between the two thresholds. It is not known if this bias was introduced due to differences in hydrology or if it was caused by shared consultants and Peer Review Committees among adjacent SPAs.

Of the 38 SPAs, seven included a comparison of the SGRAs identified by the application of Rules 44(1) and 44(2) in the final Water Budget Reports. In some cases (e.g. Raisin Region and South Nation SPAs), one methodology was selected over the other through the determination of which approach was more conservative (i.e. identified more land area). Other SPAs (e.g. Credit Valley, Toronto and Region, Central Lake Ontario SPAs) thought that Rule 44 (1) most accurately identified areas that produce high estimates of groundwater recharge.

While all SPAs did not include a comparison of the two methodologies in the final Water Budget Reports, it is MNR's experience that most SPAs considered results generated from both methodologies at some point during the Water Budget Process. Typically, this comparison was an interim result that was presented to the Peer Review Committee, with only the selected methodology included in the final Water Budget Report.

In SPAs that were overwhelmingly dominated by clay soils with low average recharge rates (e.g. Essex Region or Niagara Peninsula SPA), it was found that use of Rule 44 (1) resulted in SGRA thresholds that were too low, and large portions of clay dominated soils were identified as SGRAs. To avoid clay soils with low average recharge rates being identified as SGRAs, these SPAs selected Rule 44 (2), which worked well at only identifying pervious materials.

From review of the Water Budget Reports, it is apparent that allowing individual SPAs the flexibility to select the most appropriate methodology was required to produce defendable and realistic SGRA maps. While 44 (1) was seen by many SPAs as being the most appropriate methodology for their Area, the remaining SPAs found 44 (2) to produce better results. These differences are a primarily a result of the geological composition of the SPA, specifically the proportion of low permeability soils to high permeability soils. There were no SPAs that elected to use Technical Rule 15.1 to propose an alternate methodology for setting the SGRA threshold.

2.1.1 Recommendation

It was evident that the flexibility built into the Technical Rules, which allowed Technical Teams to select among two methodologies, was critical and allowed teams to identify SGRAs in their Areas. Physiographic composition and hydrologic response varies across the SPAs, necessitating this flexibility. To ensure that SGRAs are properly identified, it is recommended that this flexibility be retained for future refinements. In addition, it is recommended that SPAs should be required to evaluate both methodologies before selecting a threshold. From the review, it is evident that those SPAs which evaluated both methodologies, were better positioned to select the most appropriate threshold methodology.

2.2 Spatial Scale for Averaging

For the application of Rule 44 (1), Technical Teams must calculate the average groundwater recharge rate for the "*whole of the related groundwater recharge area*". Due to the variability in groundwater recharge estimates between differing land use and soil types, the spatial extent that is chosen for calculating the average recharge value is critical. Selecting an area that is dominated by highly pervious materials will yield a high average groundwater recharge estimate, and subsequently produce a high threshold. As the Technical Rules do not specify what the "related groundwater recharge area" may be, Technical Teams have the latitude to calculate an average recharge rate for the entire SPA (and have a single threshold) or sub-divide their Areas into sub-areas, each with differing average groundwater recharge values and subsequently different SGRA thresholds.

Generally speaking, Technical Teams considered three different spatial scales when calculating the average recharge rate. These three scales are as follows: 1) The entire SPA; 2) Subwatersheds that comprise the SPA; or 3) Physiographic regions that comprise the SPA. In the case of subwatersheds and physiographic regions, the SPA would have multiple average recharge rates and thresholds. Figure 1 shows a histogram of the number of SPAs that applied each of the three spatial scales when calculating their average recharge. The breakdown for each SPA is included in Appendix A. An overwhelming majority (i.e. 24 of 38) of SPAs choose to calculate a single average recharge value for their entire Area.

Calculating average recharge values for different physiographic regions was used by two SPAs, while only two SPAs calculated average recharge values on a subwatershed basis. Ten SPAs selected Rule 44(2) to identify SGRAs, and were therefore not required to calculate the average recharge value for an area.

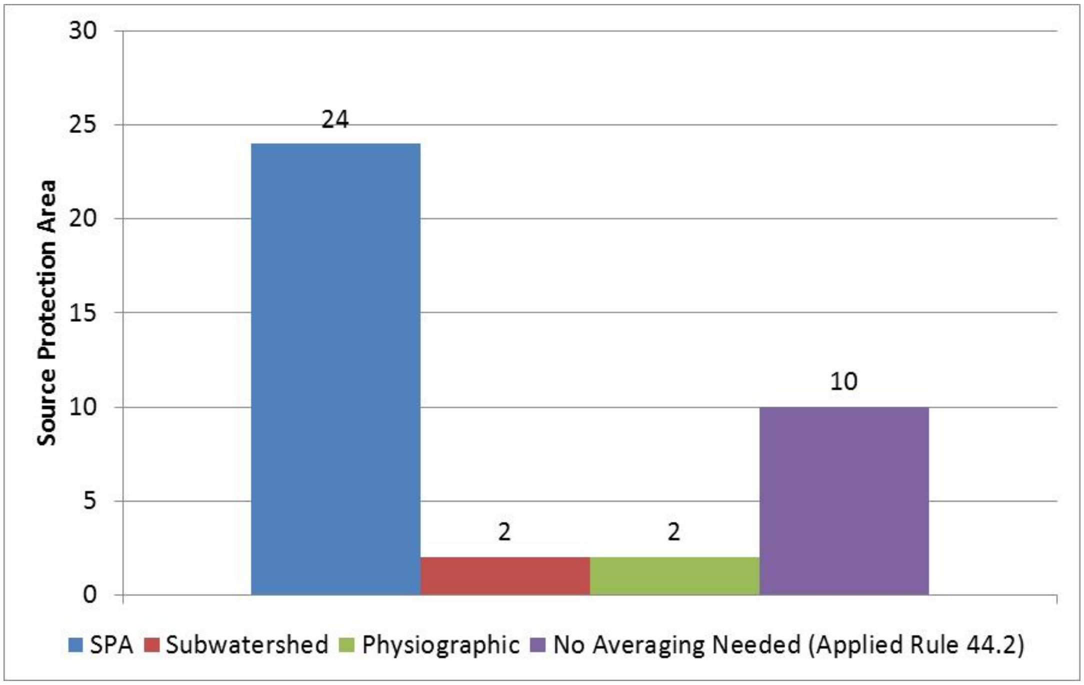

Figure 1 Spatial Scale use to Estimate Average Recharge

The primary reason given for using the entire SPA in the calculation of the average recharge rate is consistency in the threshold used in SGRA identification. By dividing the SPA into sub-groups, and having differing thresholds for each sub-group, it is possible for adjacent land areas with similar recharge estimates to be classified as an SGRA in one sub-group and not be classified in the other. Such inconsistencies could cause difficulties during policy development and public communications and, as a result, many SPAs chose to generate a single threshold for their entire Area.

However, calculating the average recharge value for a SPA may result in a threshold that fails to identify certain areas that, while lower than the Area-wide threshold, may be locally significant recharge features. This can occur within SPAs that are highly heterogeneous in terms of soil permeability (e.g. watersheds that have a high proportion of sands/gravels, as well as clay dominated soils). In such cases, the average recharge value calculated for the entire area is skewed higher by the pervious materials. This higher threshold will exclude specific areas within the lower permeability area from being identified that while having less recharge than the threshold, may still be locally significant.

To better identify these locally significant recharge features, some SPAs divided their Areas into physiographic regions with one value of average groundwater recharge being calculated for each physiographic region (e.g. clay plains, till plains, moraine). By splitting the SPA along physiographic lines, a more representative average can be calculated for each area. This can help ensure that areas within lower permeability physiographic zones, that provide locally significant recharge, can be identified as SGRAs (provided other SGRA conditions are met).

Another methodology used by some SPAs was to divide their Areas into subwatersheds and calculate the average recharge for each subwatershed. Subwatershed delineation was typically at a much finer scale than the physiographic delineation and therefore resulted in a wider range of SGRA thresholds for the SPA. Subsequently, this approach generated more inconsistencies in SGRA delineation across subwatershed boundaries.

2.2.1 Recommendation

As with the threshold methodology, the flexibility offered by the Technical Rules in selecting the spatial area for calculating the average recharge was essential to accurately identifying SGRAs. It is recommended that this flexibility remain available to Technical Teams. However, Teams should be discouraged from selecting a large number of small sub-areas to calculate average thresholds. This results in a large amount of inconsistencies across sub-area boundaries. In the future, Technical Teams should be encouraged to avoid dividing their SPAs into sub-areas that are smaller than the physiographic regions. Rationales should be required for further dividing an SPA into finer subwatersheds.

2.3 Linking High Recharge Areas to a Drinking Water System

Under the Clean Water Act, Rule 45 is an exception rule. Rule 45 states that an areas identified by Rule 44 (high recharge area) cannot be delineated as an SGRA unless there is a hydrological connection to a surface water body or aquifer that is a source of drinking water for a drinking water system. Drinking water system is defined under the Safe Drinking Water Act. This definition of a drinking water system includes all municipal water supply systems and private rural wells for domestic purposes.

Determining specific hydrological linkages between a high recharge area and a drinking water system requires the use of complex groundwater modelling tools for each area that is identified as a high recharge area. Due to the large number of drinking water systems found throughout the Province, completing complex groundwater modelling was not a feasible approach. To complete this task in an efficient manner, all SPAs simplified this process.

To illustrate linkages between the high recharge areas and drinking water systems, an almost universal approach employed by the SPAs was to include both domestic water wells and the identified high recharge areas on a single map. For most SPAs, the high density of domestic water wells ensured that all identified high recharge areas had some hydrological linkage to a drinking water system. While this is a conservative approach, the high density and uniform distribution of water wells throughout the landscape validates this broad-based assumption.

Several SPAs excluded high recharge areas from becoming SGRAs, based on additional information. In some cases (e.g. North Bay, Mattagami, Sudbury), the SPAs were located in Northern or Central Ontario, where large portions of their Areas do not have drinking water systems. These areas, based on their lack of drinking water systems as per the MOE Water Well Information System, were excluded from being identified as SGRAs.

Additionally, SPAs in urbanized watersheds, whose source of municipal water is the Great Lakes (e.g. Toronto Region), excluded high recharge areas that were located within the serviced area of the municipal water distribution system. In these cases, it was assumed that any domestic water wells within the serviced area would not be actively providing drinking water, as the population would be connected to the municipal system. As a result, there are no SGRAs located within the serviced areas of the City of Toronto.

Appendix A presents the methodology used by each SPA for this exercise. Of the 38 SPAs, 30 assumed that the density of domestic water wells was sufficient to prove connection between all high recharge areas and drinking water systems. The remaining eight SPAs excluded some portions of the high recharge areas, based on either the areas being found within municipally serviced areas or no drinking water systems found in proximity to the high recharge areas.

2.3.1 Recommendation

It is recommended that Technical Teams overlay SGRA mapping with water well records to identify a linkage to a drinking water system. In areas with no water wells, the identified lands should be removed from the SGRA mapping. For urbanized communities that are dependent on the Great Lakes for their water supply, the lack of active water supply wells within the municipally serviced area, should be the basis for removing any SGRAs within that serviced area.

2.4 SGRAs and Professional Judgement

Technical Rule 46 states that analysis products developed for the Tier 1, 2 and 3 Water Budgets, will be used to determine groundwater recharge rates and subsequently the SGRAs. However, Rule 46 further states that these products will be used along "*with consideration of the topography, surficial geology and how land cover affects groundwater and surface water*". The Province's interpretation of this rule provides Technical Teams with the flexibility to apply professional and engineering judgement to refine SGRAs delineated under Rules 44 and 45.

The Province expects the Technical Teams and peer reviewers to use professional judgement in the assessment, delineation, and review of SGRAs. For example, in applying professional judgement, consideration should be given to the appropriate scale and accuracy of datasets used to generate the recharge mapping, and whether the final SGRA mapping needs to be modified to reflect the appropriate scale. Other areas where professional judgement may be applied include removing SGRAs within known areas of groundwater discharge or including areas with recharge values below the SGRA threshold but which are thought to provide a critical recharge function to a municipal well or intake.

The review of the Assessment and Water Budget reports revealed that there were five general areas in which professional judgement was applied. These areas were as follows:

- Used smoothing/infilling techniques
- Used significant geologic features to include/exclude areas
- Considered water table elevation or excluded groundwater discharge areas
- Considered capture zones, time of travel studies

Each of these components are discussed in the following sections. The application of each of these areas is summarized in

Table 1.

Table 1 - Professional Judgement

Application of Professional Judgement	# of SPAs who Applied
Smoothing/Infilling	24
Used significant Geologic Formations to Include/Exclude Areas	9
Considered water table elevation or excluded groundwater discharge zones	6
Considered Capture Zones, Time of Travel	2

2.4.1 Smoothing/Infilling

Groundwater recharge rates that are used for SGRA delineation are generated using detailed soil/quaternary geology and land cover mapping that have a high level of precision. This high level of precision typically does not reflect the certainty of the methodology used to generate the groundwater recharge estimates or the certainty of the soil/quaternary geology and land cover mapping. To better reflect the uncertainty associated with the groundwater recharge rates and the mapping products the rates are generated from, a strong majority of SPAs applied a smoothing or infilling procedure to the final SGRA mapping product. In addition to better reflecting the uncertainty in the identified SGRAs, this procedure was also applied to facilitate the application of policy. Applying policy to extremely small, isolated SGRAs would have been impractical.

The applied smoothing/infilling procedure identified those isolated areas that were less than a specific threshold area and removed them from the SGRA coverage. In addition, where there were areas of unidentified lands, less than a specified threshold area but surrounded by areas identified as SGRAs, they were reclassified as being an SGRA. The end result of these procedures was a relative contiguous SGRA coverage with fewer smaller isolated pockets of SGRA lands. An example of the effect the infilling/smoothing had on SGRA mapping is shown in Figure's 2 and 3.

The thresholds applied in the infilling/smoothing procedures varied between SPAs from 1 ha to 100 ha. Thresholds were selected based on what the Technical Teams and the Peer Review Committees felt were appropriate given the uncertainty in the groundwater recharge estimates and the spatial accuracy of the input datasets.

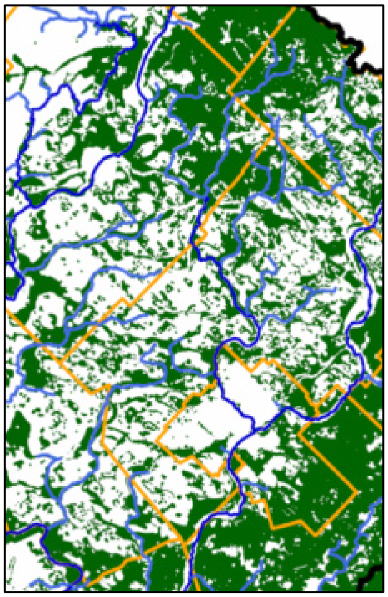

Figure 2 - SGRA Mapping Before Infilling/Smoothing

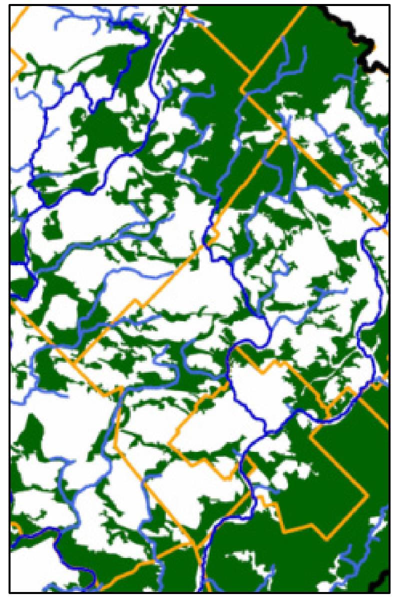

Figure 3 - SGRA Mapping After Infilling/Smoothing

2.4.2 Modifying SGRA Mapping Based on Geologic Features

While the geology of an SPA is one of the primary considerations when generating spatially distributed estimates of groundwater recharge, there were occasions where the final recharge estimates did not identify certain geologic features that were locally known to be significant recharge areas. To ensure critical areas received the appropriate level of protection, some Technical Teams added specific geologic features to the SGRA coverage under Rule 46.

An example of this was the consideration of the karst sinkholes present in Ausable Bayfield SPA. Throughout the SPA there is documented evidence of large scale drainage features, in the form of karst sinkholes at ground surface. These sinkholes collect both natural and agricultural drainage and represent a major process that provides direct recharge to the bedrock aquifers in the area. As the methodology used to generate the groundwater recharge rates never considered this recharge process, the sinkholes and the contributing area to the sinkholes were never identified. To ensure this major process was identified as an SGRA, the Technical Team and the peer review committee added these areas to the SGRA mapping.

Technical Teams also removed some geologic areas from SGRA mapping. Typically, the areas removed were comprised of modern-alluvium and are representative of current floodplain extents. These areas were removed as they are likely discharge areas, and would not support significant amounts of groundwater recharge to be generated. Additionally, any generated groundwater recharge within these areas, this water would likely discharge to adjacent watercourses in short order, replicating an interflow process.

While methodologies used to generate groundwater recharge rates for SGRA delineation do consider the hydrologic nature of the geologic features present in the SPA, not all methodologies could capture the complexity of the hydrologic processes that are associated with all geologic features (e.g. karst sinkholes). As a result, the Technical Teams required the flexibility of Rule 46 to modify the SGRA mapping, where appropriate, to incorporate these complex geologic features.

2.4.3 Discharge Areas

Groundwater recharge is the portion of infiltrated water that reaches the surface of the water table. In areas with shallow water tables, or in areas where groundwater is discharging to ground surface, this movement of water into the subsurface is typically limited by the shallow water table. The majority of methodologies used to estimate groundwater recharge rates do not consider depth to water table when quantifying groundwater recharge. As a result, high groundwater recharge estimates, and subsequently SGRAs, can be identified within a known groundwater discharge area.

To ensure that the contradictory result of an SGRA being identified within a groundwater discharge area was not carried forward to Assessment Report mapping, many SPAs removed any SGRAs from groundwater discharge areas. This was typically done through one of two methods.

The most common methodology used was to consider depth-to-water-table mapping. Where the water table was within a specified threshold (most often two metres), any SGRAs were removed from the SGRA mapping. This ensured that those lands in which groundwater discharge may occur were not classified as an SGRA.

Other methodologies for excluding potential groundwater discharge areas included comparison of SGRA mapping to ecologic data (e.g. cold-water watercourses or brook trout spawning habitat). Cold-water watercourses and brook trout spawning habitat are strong indicators of groundwater discharge.

2.4.4 Consideration of Wellhead Capture Zones

While Rule 45 of the Technical Rules requires an SGRA to be hydraulically linked to a drinking water system, there is no specific requirement for recharge areas (which fall below the SGRA threshold) within a Wellhead Protection Area (WHPA) to be included as an SGRA. In the case of Mattagami and Lakehead SPAs, the initial SGRA mapping exercise identified minimal, if any, SGRAs within the 25 year WHPAs. This was due to areas outside the WHPA having much higher groundwater recharge estimates than areas within the WHPA, and resulted in a high SGRA threshold and minimal SGRAs being identified within the WHPA.

To ensure that the groundwater recharge function within the WHPAs is protected, these Technical Teams expanded the SGRAs to include all lands within a 25 year time-of-travel of a municipal well. This approach is highly conservative, as it assumes that all groundwater recharge generated by land area within the 25 year time-of-travel is significant and requires protection. Undoubtedly, a portion of these lands generate low volumes of groundwater recharge, and as such, do not require protection. It should also be noted that falling within a 25 year time-of-travel already affords these lands some level of protection under Source Water Protection.

3.0 SECONDARY ANALYSIS TO CONFIRM SGRA THRESHOLDS

After establishing a threshold for SGRA delineation, several SPAs documented secondary confirmation to confirm or refine the thresholds. Using the analysis performed on the Long Point SPA, the following section provides some additional insight on how one may confirm SGRA thresholds. The Grand River, Kettle Creek, Catfish Creek and Niagara Peninsula SPAs followed a similar approach.

3.1 Long Point

The Long Point SPA is characterized by three main geologic areas: 1) Haldimand Clay Plain (eastern portion); 2) Norfolk Sand Plain (central); and 3) Port Stanley Till Plain (west). The Norfolk Sand Plain and its associated high groundwater recharge rates dominate the Long Point SPA. The lower permeability clay plain to the east and till plain to the west both generate low values of groundwater recharge.

Upon viewing the initial SGRA mapping products, the Technical Team and peer reviewers questioned the validity of the SGRA threshold (115%), specifically, if minor variations in the threshold could result in a significantly different SGRA map.

To evaluate the reasonableness of these threshold recharge values, the distribution of recharge within the SPA was analysed using exceedance curves, calculated as follows:

- % Volume Exceeding Recharge Rate = sum of recharge volume for all rates equal to or above a threshold value, divided by the total recharge volume;
- % Area Exceeding Recharge Rate = sum of area associated with all rates equal to or above a threshold value, divided by the total area;

Figure 5 was generated using these exceedance curves, the SGRA threshold value, and the individual volumes of recharge that are generated at each specific rate of groundwater recharge. Figure 5 allows one to determine the relationship between total land area and total groundwater recharge volume, expressed as a percentage of the total. This figure shows that there are two main geologic areas that are generating groundwater recharge: 1) those areas that generate 175 mm/yr or less; and 2) those areas that generate 300 mm/yr or more. These values represent inflection points in both the total groundwater recharge and total land area exceedance curves. Inflections in these curves illustrate natural divisions within the distribution and reflect the variation in surficial geologic and land use within the Long Point SPA. The plateau in both the recharge and area exceedance curves, between 175-300 mm/yr, indicates that relatively little land area produces groundwater recharge between these values.

As the computed threshold value, shown on Figure 4, lies within a plateau of the percent volume and percent area curves, it can be stated that the total land area identified as SGRA would not be sensitive to uncertainties associated with the threshold itself. From Figure 4, it can be seen that the threshold could be reduced to 200 mm/yr (from approximately 260 mm/yr), and the total area identified as an SGRA would only be increased from ~50% to ~ 51%. Likewise, if the threshold was increased to 300 mm/yr, the total area of SGRAs would be reduced from ~50% to ~49%.

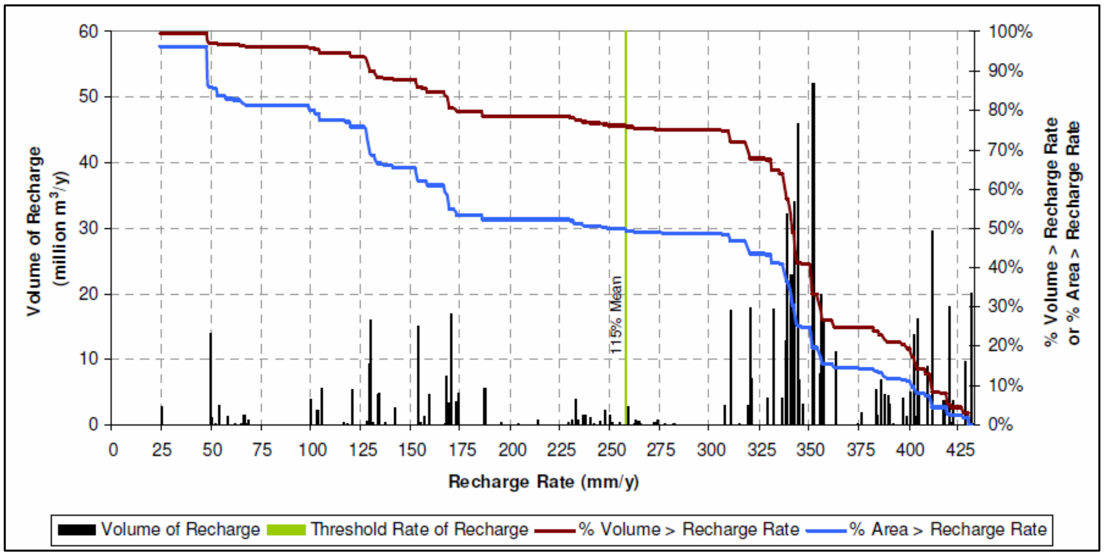

Figure 4 - Long Point SPA Exceedance Graph Example (Source: Long Point SPA Assessment Report)

Analysing the distribution of groundwater recharge rates, the associated areas of the recharge generating lands and variations in the SGRA thresholds, can be an excellent methodology to test the sensitivity of SGRA delineation to the threshold value utilized.

4.0 REFINEMENT OF SGRAS

The Technical Rules also require that SGRA mapping be updated as an SPA moves from Tier 1 to Tier 2 and ultimately to the Tier 3 Local Area Risk Assessment. As many Tier 3 studies were still underway when this report was generated, there were few examples illustrating how one may refine SGRAs at each Tier in the Water Quantity Framework.

Typically, as one moves from Tier 1 to Tier 2 there is an increase in the level of confidence associated with groundwater recharge estimates. This increase in confidence is brought about by using calibrated numerical models, rather than GIS analysis, to estimate groundwater recharge. However, Tier 2 investigations may not include the entire SPA, but rather a smaller spatial area than the original Tier 1 investigation. This results in refined information for one portion of the SPA, and generalized information for the remaining portion. In cases such as this, it is recommended that the threshold calculated for the Tier 1 SGRA delineation is applied to the Tier 2 refined recharge estimates. This results in a refined SGRA delineation within the Tier 2 study area, which can then be placed onto the SPA SGRA mapping product, overriding the Tier 1 SGRA mapping product. It should be noted that this is likely to introduce boundary issues, with differing recharge values on either side of the Tier 2 study domain.

Where a Tier 2 investigation produced a numerical model, and therefore updated recharge rates for the entire SPA, Technical Teams should regenerate the entire SGRA map, including recalculating SGRA thresholds.

Updating Tier 2 SGRA mapping information with Tier 3 mapping information is similar as going from Tier 1 to Tier 2. Tier 3 studies are more localized than Tier 2 investigations, and may only consider a small portion of an SPA. Where the most up-to-date study only considers a small portion of the previous study's domain, SGRA thresholds from the previous study and the updated groundwater recharge rates should be used to refine the SGRA mapping for the current study domain.

In the case that groundwater recharge rates are not updated as part of a new phase of work in the Water Quantity Framework, there is no need to update SGRAs. This may be the case where a Tier 3 study relies upon recharge estimates generated in a Tier 2 study.

5.0 OTHER SGRA CONSIDERATIONS

Delineation of SGRAs is limited by the processes used by the hydrologic model to estimate recharge, the mapping used to create hydrologic response units, and the climate data available. A hydrologic model is a simplification of natural processes. Recharge is based on water that infiltrates through two soil layers and is not lost to runoff or evapotranspiration. This recharge may include interflow as well as true recharge to the aquifer system. The water budget mapping used to create recharge estimates has data limitations.

The following section outlines a number of considerations identified by SPAs for delineating SGRAs.

5.1 Under Threshold, but Within Margin of Error

While numeric models allow precise estimates of groundwater recharge to be calculated, it should be noted that this level of precision is beyond the accuracy of models. While the calibration process addresses the confidence of the hydrologic and hydrogeological simulation within a subwatershed, the water budget parameters for a specific soil/land use combination are not calibrated and the results should only be considered as a relative measure of hydrologic processes. As such, there can be a wide margin of uncertainty associated with a groundwater recharge estimate for a specific soil/land cover combination.

This range of uncertainty should be considered when applying the SGRA threshold to recharge estimates. For example, it may be appropriate to round the threshold and recharge estimate to the nearest 10 mm, ensuring that a soil/land cover combination that is 1 mm less than the threshold is still captured as a SGRA. The level of uncertainty associated with recharge values should be made by the professionals who generated the recharge estimate, and should consider the rigor of the hydrologic processes represented, the availability and quality of input data, the amount of observation data used during calibration, and the ability of the model to replicate observed conditions.

5.2 Data Scale and Accuracy

The calculations used to delineate SGRAs may be carried out at a regional scale using climate, hydrologic, geologic, and land cover data sets that contain significant uncertainty. Therefore, SGRA delineations should be used with caution as they are not accurate at a local scale without proper field verification and/or improved data used to refine SGRAs.

Additionally, the selection of SGRA methods can have an impact on accuracy at different scales. The 55% method is considered to have less variability when applied at various scales and should be a factor in deciding the best approach. Many SPAs that completed their SGRA analysis at a watershed-subwatershed scale did identify scale as a limitation of the data, indicating SGRA results could not be considered reliable at a finer scale. In most cases, these SPAs selected Rule 44 (1) as their approach.

5.3 Watershed Boundaries

It is important to note that in most cases, analyses are restricted to subwatershed or watershed boundaries. Important contributing areas may exist beyond SPA boundaries, providing critical recharge that sustain lateral groundwater inflows to the watershed and supply groundwater for both drinking water and ecologic uses.

In addition, changes in pumping rates could conceivably extend contributing areas beyond existing contributing areas, into adjacent watersheds.

5.4 Complex Geology

Understanding recharge in fractured rock aquifers is a challenge, since recharge is isolated to open fractures that must be connected to the surface or the overlying soil. The open fractures provide a conduit for recharge, but also for surface contamination. Confirmation of complex flow characteristics can generally only be done through further investigation and ground-truthing over time. To further understand recharge in complex geologic environments, localized, site-specific investigations may be required.

6.0 CONCLUSIONS & RECOMMENDATIONS

When delineating SGRAs, all Technical Teams are strongly encouraged to consider the following steps:

1. **Compare Mapping Products using both Rule 44 (1) and 44 (2)**. Depending on the geologic composition of the SPA, the application of one methodology may better reflect high recharge areas than another. Prior to proceeding beyond Rule 44, Technical Teams are recommended to apply both Rule 44(1) and 44(2) to the available groundwater recharge mapping and select the most appropriate methodology.

2. **When Calculating Average Recharge, use the Source Protection Area, or Broad-Physiographic Areas as the Spatial Unit**. Application of Rule 44(1) requires the use of a specific spatial unit to calculate the average recharge. Technical Teams are strongly recommended to either use the SPA, or broad-based physiographic regions, to calculate average recharge rates. Using spatial units smaller than these (i.e. subwatersheds), can result in a large number of highly differing SGRA thresholds, which will cause edge matching issues between subwatersheds, and may cause difficulty for policy development.

3. **Use Secondary Analysis to Confirm SGRA Thresholds**. Where there is concern about the validity of the selected SGRA threshold, Technical Teams should consider completing the analysis completed by the Long Point SPA. By illustrating that neither the volume of recharge generated by the SGRA lands, or the total area of the SGRA lands, would be significantly affected by variance in the SGRA threshold, uncertainty associated with the SGRA mapping process can be reduced.

4. **Use Water Well Mapping to Show Linkage to Water Systems**. To show a linkage between a SGRA identified under Rule 44(1) or Rule 44(2), it is sufficient to include mapping of both the identified SGRAs and point information showing water wells. In areas without water wells, the SGRAs should be removed. In South/Central/Eastern Ontario, this likely only occurs within

urbanized areas that are serviced from the Great Lakes. Areas that are immediately adjacent to the Great Lakes, and have no water wells, may also be removed.

5. **Remove Discharge Areas from SGRA Mapping.** Prior to publishing SGRA mapping, Technical Teams should remove any SGRAs that are found to be located within a known, or expected, groundwater discharge zone. This may include removing SGRAs that are in areas with shallow water tables, immediately adjacent to known coldwater fisheries, or within floodplains.

6. **Smooth/Infill SGRA Mapping.** Prior to publishing SGRA mapping, Technical Teams should consider using a GIS procedure to remove small SGRA polygons, or infill small gaps in the SGRA coverage. This will result in a more contiguous SGRA coverage, and may ease the policy development process.

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APPENDIX A

INDIVIDUAL SOURCE PROTECTION AREA RESULTS

Source Protection Area	SGRA Methodology 44(1)	44(2)	Tested Both	Averaging Scale	Filter Applied	Linkage To Water Systems	Other Professional Judgment
Ausable Bayfield SPA	Yes			SPA		Assumed based on density of water wells	Included drainage area to karst features
Cataraqui SPA	Yes		Compared both, 115% resulted in more area	SPA		Assumed based on density of water wells	
Catfish Creek SPA	Yes			SPA	< 100 ha	Assumed based on density of water wells	Cumulative distribution plots to confirm thresholds
Central Lake Ontario SPA	Yes		Yes, 115% was deemed more accurate	SPA		Assumed based on density of water wells	Removed deposits of modern alluvium, and other areas of likely groundwater discharge
Credit Valley SPA	Yes		Yes, 115% was deemed more accurate	SPA	< 1 ha	Assumed based on density of water wells	
Crowe Valley SPA		Yes			< 1 ha	Assumed based on density of water wells	Areas with water table less than 2 m removed
Essex Region SPA	Yes		Compared both, 55% resulted in no SGRAs	SPA	< 100 ha	Assumed based on density of water wells	
Ganaraska Region SPA		Yes			<1 ha	Assumed based on density of water wells	Areas with water table less than 2 m removed
Grand River SPA	Yes			SPA	< 100 ha	Assumed based on density of water wells	Cumulative distribution plots to confirm thresholds
Greater Sudbury SPA		Yes				Assumed based on density of water wells	
Grey Sauble SPA	Yes			SPA		Assumed based on density of water wells	
Halton Region SPA	Yes			Physiographic	<3 ha	Assumed based on density of water wells	Areas serviced by Great Lakes removed
Hamilton Region SPA	Yes			Physiographic	<3 ha	Assumed based on density of water wells	Areas serviced by Great Lakes removed
Kawartha-Haliburton SPA		Yes			<1 ha	Assumed based on density of water wells	Areas with water table less than 2 m removed
Kettle Creek SPA	Yes			SPA	< 100 ha	Assumed based on density of water wells	Cumulative distribution plots to confirm thresholds
Lake Simcoe and Couchiching-Black River SPA	Yes			SPA	< 10 ha	Assumed based on density of water wells	
Lakehead SPA	Yes			SPA		Removed areas with minimal water well density	Added areas within the 25-year time of travel to the Rosslyn supply well
Long Point Region SPA	Yes			SPA	< 100 ha	Assumed based on density of water wells	Cumulative distribution plots to confirm thresholds
Lower Thames Valley SPA	Yes			Subwatersheds	< 25ha	Assumed based on density of water wells	
Lower Trent SPA		Yes			<1 ha	Assumed based on density of water wells	Areas with water table less than 2 m removed
Maitland Valley SPA	Yes			SPA		Assumed based on density of water wells	Included drainage area to karst features
Mattagami SPA		Yes				Drinking water well overlay, required one well intersecting the recharge area	Added areas within the 30-year time of travel for municipal wells

Source Protection Area	SGRA Methodology			Averaging Scale	Filter Applied	Linkage To Water Systems	Other Professional Judgment
	44(1)	44(2)	Tested Both				
Mississippi Valley SPA		Yes			< 25 ha	Assumed based on density of water wells	Added eskers and outcrop of main bedrock aquifer
Niagara Peninsula SPA	Yes			SPA	< 2ha	Assumed based on density of water wells, removed areas adjacent to Great Lakes shorelines	Cumulative distribution plots to confirm thresholds
North Bay-Mattawa SPA	Yes			SPA	< 10 ha	Water well overlay and MPAC parcel fabric was used to determine linkage to either SW or GW water system	
Northern Bruce Peninsula SPA	Yes			SPA	<1ha	Assumed based on density of water wells	
Nottawasaga Valley SPA	Yes			SPA		Assumed based on density of water wells	
Otonabee-Peterborough SPA		Yes			<1 ha	Assumed based on density of water wells	Areas with water table less than 2 m removed
Quinte Region SPA		Yes			<100 ha	Assumed based on density of water wells	Removal of alluvial deposits, cold water streams, and areas with shallow water tables
Raisin Region SPA	Yes		Compared both, 115% resulted in more area	SPA		Assumed based on density of water wells	
Rideau Valley SPA		Yes			<25 ha	Assumed based on density of water wells	Added eskers and outcrop of main bedrock aquifer
Saugeen Valley SPA	Yes			SPA		Assumed based on density of water wells	
Sault Ste Marie SPA	Yes			SPA		Removed areas with minimal water well density	
Severn Sound SPA	Yes			SPA	< 10 ha	Assumed based on density of water wells	
South Nation SPA	Yes		Compared both, 115% resulted in more area	SPA		Assumed based on density of water wells	
St. Clair Region SPA	Yes			Subwatersheds	< 25 ha	Assumed based on density of water wells	
Toronto and Region SPA	Yes		Yes, 115% was deemed more accurate	SPA		Drinking water well overlay	Removed modern alluvium deposits, removed areas serviced by Great Lakes
Upper Thames River SPA	Yes			SPA	< 25 ha	Assumed based on density of water wells	Removed modern alluvium deposits