local groundwater flow conditions and the aquifer properties. The aquifer locations and extents are conceptualized at this stage. A computer model was then developed based on the conceptual understanding. United States Geologic Survey (*USGS*) *MODFLOW* numerical groundwater flow model was developed through previous studies (Middlesex-Elgin Groundwater Study (2004), Perth County Groundwater Study (2003), and the Phase II Groundwater Protection Study, County of Oxford (2001)). Additional refinement of the modelling has been completed on many of the systems since these investigations were completed. Any new or proposed wells within the existing systems were added to those models. The models were calibrated and *MODPATH* was used to simulate particle movement in the capture zones. These results were used to determine the extent of the travel time based *WHPA*. This estimates the horizontal travel time (within the aquifer) to the well. The model is run in reverse to determine where particles arriving at the well within the specified travel time could have originated.

The *WHPAs* in the Upper Thames River Source Protection Area are illustrated in Maps 4-1-1 to 4-1-23.

4.3.4 WHPA-E and WHPA-F

Two other *WHPAs (E* and *F)* can be delineated for wells which are under the direct influence of surface water (*Groundwater Under the Direct Influence* or *GUDI*). There are *GUDI* wells in Dorchester, London Fanshawe back up wellfield; Thamesford; Woodstock; and St. Marys. Systems were previously assessed through requirements of the Safe Drinking Water Act, 2002 (subsection 2(2) of O. Reg. 170/03) to determine if they are *GUDI*. Operators of systems that are designated as *GUDI* are required to determine if there are surface water bodies or water courses which can deliver surface water to the well, effectively short circuiting the natural protection assessed in the vulnerability assessment. Should a surface water system influence effectively bypass the aquifer's protection, a *WHPA-E* must be delineated. Rule 49(3) states that a *WHPA-E* is to be defined if the interaction between surface water and groundwater has the effect of decreasing the time of travel of water to the well when compared to the time it would take water to travel to the well if the raw water supply for the well was not under the direct influence of surface water.

Rule 50 (1), (2) and (3) require that *WHPA-F* be delineated if a *WHPA-E* is delineated, and the well is subject to *issues* (known to be partially or wholly due to anthropogenic causes), which originate from outside the other parts of the *WHPA*. *Issues* are discussed in Section 5 – Issues Evaluation.

The work on *GUDI* systems has been undertaken in the Thames-Sydenham and Region Source Protection Region. The systems outlined in Table 4-2 are included in this project. Additional work is planned for the First Nations *GUDI* system in the Lower Thames Valley SPA.

Table 4-2 Thames-Sydenham and Region GUDI wells

GUDI wells in the Upper Thames River Source Protection Area (UTRSPA)	
London and Middlesex systems	Dorchester (overburden wells 2PW-1, 3PW-1, 3PW-2B, 3PW-4A, 3PW7 and 3PW-8)
	London back up well supply Fanshawe (Fanshawe wells 1, 2, 3, 4, 5 and 6)
Oxford systems	Thamesford Wells 1 and 2 (often referred to as overburden wells or River Wells)
	Woodstock (Wells 1, 2, 3, 4, 5, 8, 11 and a planned well ‘Bond’ (Thornton and Tabor wellfields)
Town of St. Marys system	St. Marys (Wells 1 and 3)

The *WHPA-E* represents the extent of influence of a surface water feature on the affected well. According to Technical Rule 47 (5), the *WHPA-E* is delineated as an *Intake Protection Zone-2* (*IPZ-2*) as if the intake was located at the point where surface water would flow into the groundwater (i.e. the point of interaction). In the event that the point of interaction is not known, the closest point in the surface water body to the well is used.

A general description of the *WHPA-E* delineation methodology in the Upper Thames River SPA is provided below, followed by system specific information. Vulnerability scoring for *GUDI* systems is described in Section 4.3.5.

As per Rules 65 and 66, *WHPA-E* is the area within each surface water body that contributes water to the intake based on a surface water travel time of at least two hours, and a certain setback where it abuts land. The distance that *WHPA-E* extends upstream from the point of groundwater and surface water interaction depends on the time it takes for the drinking water treatment plant operators to respond to an adverse condition or emergency (such as a spill). The Technical Rule 66 requires that a minimum of two hours be used as the response time. Discussions with the *GUDI* system operators determined that a longer time was not required. As such, a 2 hour travel time was used to delineate *WHPA-E*. The travel time was estimated using stream velocity at bank full stage. It is widely accepted that bank full stage can be approximated by a 2 year return flow, but can vary dependent upon the nature of the watercourse from less than the two year flow, to as high as the five year flow.

Where the delineation abutted land, as per Rule 65 (1) for *IPZ-2* delineation, it was delineated to a setback of 120 meters (measured to the high water mark of the surface water body) or the Conservation Authority Regulatory Limit (for floodplains), or the greater of the two. Further, the *WHPA-E* was extended to include areas that contribute water to *WHPA-E* through a natural or anthropogenic pathway, as per Rules 72 and 73. Transport pathways are typically any structure, land alteration or condition resulting from naturally occurring process or human activity which would increase the probability of a contaminant reaching a drinking water source. Transport Pathways include tile drainage and other drainage works. Parcels immediately adjacent to watercourse buffers and regulated areas have been considered in the *WHPA-E* delineation, and not included in the WHPA-E unless they are believed to be connected due to transport pathways (tile drainage). These parcels have been trimmed to the subwatershed boundary outside of which water is assumed to be directed away from the intake. Also, storm sewersheds which outlet into the *WHPA-E* were included within the *WHPA-E* (within the 2 hour travel time to the intake), as per Rule 65 (2). This is due to their direct connection to a watercourse by storm sewers. The storm sewershed is the catchment area drained by the storm sewer.

The delineation and the assigning of vulnerability scores are influenced by the type of intake. Type C intakes are located in rivers and neither the direction nor the flow of water at the intake is affected by a water impoundment structure. Type D is an intake not already defined by the other Types, for example, an inland lake. In the Thames-Sydenham and Region the *GUDI* wells are considered Type C or D intakes as per the Technical Rules.

According to Rule 47 (6), the *WHPA-F* is delineated as an *Intake Protection Zone-3* (*IPZ-3*), as if the intake were located at the nearest point to the well in the surface water body. As per Rule 70, the *IPZ-3* is composed of the area within each surface water body that may contribute water to the intake, and a setback on land. This setback is 120 meters (measured to the high water mark of the surface water body) or the Conservation Authority Regulatory Limit (for floodplains), or the greater of the two. As mentioned earlier, *WHPA-F* is only delineated if the well is subject to *issues* (known to be partially or wholly due to anthropogenic causes), which originate from outside the other parts of the *WHPA*.

A description of the delineation methodology specific to each *GUDI* system in the Upper Thames River SPA is provided below. Vulnerability scoring for *GUDI* systems is described in Section 4.3.5.

Dorchester *WHPA-E*

The Dorchester system, operated by the Municipality of Thames Centre, consists of nine wells of which six are *GUDI* (wells 2PW-1, 3PW-1, 3PW-2B, 3PW-4A, 3PW7 and 3PW-8). The wells are located in Dorchester, east of Dorchester Road and south of Byron Avenue. Several surface water bodies are present in the area and include Big Swamp Drain, Tap Municipal Drain and Lawton Drain. They combine and discharge into the South Thames River via an outlet from the Dorchester Mill Pond. The Dorchester Swamp, which discharges into these drains, is a predominant feature in the wellhead protection areas.

Intake Type

The delineation of *WHPA-E*, conducted by Dillon Consulting Limited, is based on the locations of the nearest surface water body to the wells, and an intake Type C (located in a river and neither the direction nor the flow of water at the intake is affected by a water impoundment structure). Based on available information, the Dorchester wells were projected to the Big Swamp Drain. These well projections were used as the 'surrogate' intake locations for the *WHPA-E* delineation.

Extent up Surface Water Bodies

In order to delineate the area within the Big Swamp Drain and its tributaries that may contribute water to the well's closest in-stream point within a 2 hour travel time, hydrologic and hydraulic analyses as well as a field trip were conducted. There was no model available for the Big Swamp Drain to simulate hydrologic and hydraulic analyses. Therefore, for the hydrologic analysis, empirical equations combined with a field visit were used to estimate the required 2-year flow. The Moin Index Flood Method (IFM) and the Primary Multiple Regression Method (PMRM) were used to calculate bankfull 2 year flow in the Big Swamp Drain and its tributaries (Lawton Drain, Tributary 'A' and Tap Drain). The more conservative flow (i.e. the larger flow) between IFM and PMRM methods was used for velocity, and eventually travel time analysis. For the hydraulic analysis, instream velocities were estimated by using Manning's Equation combined with the GIS data and field observations. Further, a field survey of the Big Swamp Drain and its tributaries was conducted in March 2011 by the consultant. For each cross-section of interest, the physical condition was noted and the bank and channel geometry was estimated, where possible.

Setbacks on Land, Storm Sewersheds and Transport Pathways

Where the delineation abutted land, it was truncated to the greater of either the setback of 120 meters (measured to the high water mark of the Big Swamp Drain) or the Conservation Authority Regulatory Limit. Further, the tile drainages, channels and ditches were examined for transport pathways. Tile drains and roadside ditches that can contribute water to *WHPA-E* within a 2 hour travel time were examined and included into the *WHPA-E* delineation where applicable. The available tile drain GIS layer did not include the outlets of the tiles, therefore an assumption was made that the tiles drain in the same direction as the general slope of the land. Tiles that touch the 120 m buffer or the Regulation Limits and located within 2 hour travel time from the intake were included in the *WHPA-E* delineation. A stormwatershed east of Oakwood Dr. is located very close to the Big Swamp Drain. However, based on the Dorchester stormwatershed map its outfall is downstream of the well projection, i.e. flows away from the 'surrogate' intake. Based on available information, no stormwatersheds were included in the delineation as transport pathways.

Final WHPA-E Delineation

The final delineation considers the local watershed boundaries, such that only areas that can contribute overland flow to the well are included in the delineation. The Dorchester *WHPA-E* is shown in **Map 4-1-2a**. Vulnerability Scoring is described in Section 4.3.5.

WHPA-F

As mentioned earlier, *WHPA-F* is only delineated if the well is subject to *issues* (known to be partially or wholly due to anthropogenic causes), which originate from outside *WHPA-A to E*. No *issues* were identified for the Dorchester well supply system. Therefore a *WHPA-F* was not required to be delineated.

Fanshawe *WHPA-E*

The Fanshawe wells are part of the City of London's back up wells. There are six wells that draw water from an unconfined sand aquifer. All six wells are classified as *GUDI*. Five of these wells are located within the boundaries of the Fanshawe Golf Course and one pumping well is located just west of Clarke Road. No drains or creeks flow through the wellfield capture zone. However, several ponds and small ditches are present within the previously delineated *WHPA*. These ponds appear to have a limited catchment area, and are essentially surface exposures of the water table.

Intake Type

The delineation of *WHPA-E*, conducted by Dillon Consulting Limited, is based on the locations of the nearest surface water body to the wells, and an intake Type D (inland lakes). Based on available information, the Fanshawe wells were projected to nearby water bodies. These well projections were used as the 'surrogate' intake locations for the *WHPA-E* delineation.

Extent up Surface Water Bodies

During a field survey, several additional ponds and wetland areas, beyond those identified in the MNR watercourse mapping, were observed around the well houses. In particular, small ponds were observed west of Well 5 and Well 6. All of these features are considered to be points of interaction or transport pathways between surface water and the well. There are no streams which contribute to the ponds and therefore no travel time analysis is required. The well operator indicated that from time to time pumps must be turned on to eliminate standing water around the pump houses.

Setbacks on Land, Storm Sewersheds and Transport Pathways

The Fanshawe *WHPA-E* delineation includes a setback of 120 m along the abutted land measured from the high mark of the Fanshawe ponds and the area that contributes water to *WHPA-E* through transport pathways. A 120 m setback from the surface water features located in *WHPA-A* and *WHPA-B* (which are considered the zone of interaction) constitute the final *WHPA-E*. It should be noted that local watershed boundaries (quarry limits on west and east side) take priority over the extent of 120 m buffer, and therefore, *WHPA-E* was clipped on the west and east side.

Transport pathways which were observed in the zone of interaction were also included into *WHPA-E*. These are the wetland areas within the study area. Based on available information, no other transport pathways such as drainages, channels and ditches, or stormwatersheds were included in the delineation.

Final WHPA-E Delineation

The final delineation considers the local watershed boundaries, such that only areas that can contribute overland flow to the well are included in the delineation. The Fanshawe *WHPA-E* is shown in **Map 4-1-4a**. Vulnerability Scoring is described in Section 4.3.5.

WHPA-F

As mentioned earlier, *WHPA-F* is only delineated if the well is subject to *issues* (known to be partially or wholly due to anthropogenic causes), which originate from outside *WHPA-A* to *E*.

Based on the issues evaluation conducted (see Section 5), organic nitrogen was identified as a water quality *issue*, which may be due to anthropogenic causes, at the Fanshawe wells. However, organic nitrogen likely originates from the area immediately attached to the well field (i.e. within *WHPA-A* through *E*). Therefore no *WHPA-F* delineation is required.

St. Marys *WHPA-E*

The Town of St. Marys wells consist of three pumping wells, two of which (Well 1 and Well 3) are identified as *GUDI*. Several surface water features including Skinner, Sheldon, Rolston and Waghorn Drains, Trout Creek, Otter Creek and the Thames River cross the St. Marys *WHPAs*.

Intake Type

The intake type is based on the location of the nearest surface water body to the wells. Well 1 is adjacent to Trout Creek and Well 3 is adjacent to the North Thames River. As such an intake Type C (located in a river and neither the direction nor the flow of water at the intake is affected by a water impoundment structure) was used to determine the appropriate rules to apply to the delineation of *WHPA-E* for both wells.

The delineation of that portion of the *WHPA-E* related to the St. Marys Well 1 was completed by the Upper Thames River Conservation Authority (with input from Schlumberger Water Services (SWS)), while the delineation of that portion of the *WHPA-E* related to Well 3 was completed by Dillon Consulting Limited in a separate study. Both studies included work on the *WHPA-E* extent up surface water bodies, setbacks on land, transport pathways and storm sewersheds. The final delineation of *WHPA-E* for the St. Marys *GUDI* wells incorporates the delineations from both studies.

St. Marys Well 3 was projected to the nearest water body, the North Thames River. This point was used as the surrogate for an intake and the *WHPA-E* was delineated from this point. Well 1 was the subject of previous investigations to determine the location of surface water interaction. In the past, the river reach within the general vicinity of the well was the subject of investigation and exploration to locate a point of interaction without success. These well projections which were used to determine the surrogate intake location would have been in the area where the past investigation did not identify a pathway or other interaction point. As such additional work was undertaken by SWS to idenitify the area within which it is likely that the interaction could occur. This area of potential interaction was used to delineate the *WHPA-E*.

Extent up Surface Water Bodies

The area within the surface water bodies and their tributaries that may contribute water to the surrogate intake was based on a 2 hour time of travel.

a) Delineation of the WHPA-E extent up Trout Creek and its tributaries

The interaction of the surface and groundwater in the St. Marys Well 1 has been the subject of much investigation in the past. This previous exploration focused on trying to locate a potential transport pathway in or near the watercourse in the vicinity of the well. The cause of this interaction or the location at which the interaction occurs could not be determined.

According to the Technical Rules, in the event that the point of interaction is not known, the closest point in the water body to the well is to be used. This would establish the point within the area of the previous investigation. In 2007, Schlumberger Water Services (SWS) conducted a study to determine the area within which it is likely for the point of interaction to occur. This area was called the zone of potential groundwater/surface water interaction. It was determined by comparing surface water elevation levels and groundwater hydraulic heads. If the water elevation in the stream was higher than the hydraulic head in the groundwater at the interface, then it was concluded that water moved from the stream into the groundwater. Stream elevation and bedrock groundwater equipotential maps were examined. Based on review of the available data, a reach along Trout Creek was identified to likely contribute surface water to the groundwater system, and then subsequently to Well 1. Therefore the zone of interaction included Trout Creek and overbank areas a few kilometers upstream of Well 1, and a few hundred meters downstream of this well. In other words, the upper end of the zone of interaction occurs approximately where 14 Line crosses Trout Creek, and the lower end occurs approximately where Church Street North crosses Trout Creek. The SWS study showed that the interaction could be significantly more removed from the well than the nearest point to the well in the water body. As a result it was determined that the *WHPA-E* should be delineated upstream from the zone of potential groundwater/surface water interaction and include the zone of potential interaction. This provided a conservative, but reasonable start for the travel time determination.

The UTRCA conducted the remaining work to delineate the Well 1 *WHPA-E* portion. A 2 hour time of travel up Trout Creek was estimated using Wildwood Dam discharge and stream guage data, as well as HEC-RAS model output. The Wildwood Dam discharges to Trout Creek upstream of the upper end of the zone of interaction (near 14 Line), and upstream of the St. Marys Well 1. There is a stream gauge on Trout Creek at the upper end of the zone of potential interaction near 14 Line, and another stream guage downstream of the confluence of Trout Creek and the North Thames River (but upstream of the Well 3). By examining flows at these two guage stations after Wildwood Dam operations, it was concluded that discharges from the dam occur well within the 2 hour time of travel from the zone of interaction. While this analysis was not performed for bankfull conditions, the discharge volumes are high enough that it is reasonable to arrive at the same conclusion if 2 year flow bankfull conditions were considered. Similarly, by examining the velocities produced by the HEC-RAS model of Trout Creek between Wildwood Dam and the confluence with the North Thames River, it was found that the 2 hour travel time for a 2 year flow from the outlet of the dam is well into the zone of potential interaction. The residence time of Wildwood reservoir is much greater than 2 hours, being in the order of days. Thus any potential contamination occurring upstream of the dam could not make it to the zone of interaction within the prescribed 2 hour limit. It was therefore concluded that the entire length of Trout Creek downstream of Wildwood Dam be included in the *WHPA-E* of St. Marys Well 1.

A 2 hour time of travel up the smaller tributaries that feed Trout Creek was estimated using Manning's equation. This equation was used to calculate velocities and therefore travel times based on the lengths of the tributaries. Cross sections and channel slope are taken from Ontario Base Mapping, and the depth of water in the channel is assumed to be equal to the bank elevation of the most upstream cross section for bankfull flow, based on observed local conditions. Cross sections are assumed to be trapezoidal, with stream widths estimated from aerial photography. Stretches of Birches Creek and Ralston Drain, as well as stretches up tributaries to Birches Creek were included in the delineation. The stretches of Birch Creek tributaries beyond the 2 hour travel time were excluded. The travel time of an unnamed tributary which enters the Trout Creek from the north to the zone of potential interaction was estimated to be approximately half an hour. As the hydrology is quite similar in other areas of this subwatershed below Wildwood Dam, and because the travel distances for other tributaries to the zone of potential interaction are shorter, it was concluded that all additional tributaries, aside from the previously discussed Birches Creek and Ralston Drain, are within the 2 hour time of travel.

b) Delineation of the WHPA-E extent up North Thames River and its tributaries

In order to delineate the area within the surface water bodies and their tributaries that may contribute water to the respective well's closest in-stream point within the 2 hour time of travel, hydrologic and hydraulic analyses as well as a field trip were conducted. The hydrologic analysis helps to estimate a 2 year flow or, as it commonly referred to, bank full discharge. The 2 year flow in the North Thames River and flow change locations along the North Thames River were gathered from the HEC-RAS model calibrated and used by the Upper Thames River Conservation Authority (UTRCA) for flood plain mapping of the area. For small tributaries and for reaches where the existing model did not provide coverage, these empirical equations were used: Moin Index Flood Method (IFM) and the Primary Multiple Regression Method (PMRM) to determine the 2 year flow. The more conservative flow (i.e. the larger flow) between IFM and PMRM methods was used for velocity, and eventually travel time analysis. For the hydraulic analysis of the North Thames River, the HEC-RAS model was used to estimate flow velocities. For the hydraulic analysis of the smaller tributaries, instream velocities were estimated by using Manning's Equation combined with the GIS data and field observations. A tributary field survey was conducted in March 2011 by the consultant. For each cross-section of interest, the physical condition was noted and the bank and channel geometry was estimated, where possible. The 2 year flow velocities were calculated for Otter Creek, Flat Creek, Tributary A, Avon River and Tributary B.

Setbacks on Land, Storm Sewersheds and Transport Pathways

Similar methodologies were used in both studies to determine setbacks on land and extensions to include transport pathways and storm sewersheds. Where the delineation abutted land, it was truncated to the greater of either the setback of 120 meters (measured to the high water mark of the North Thames River, Trout Creek and their tributaries) or the Conservation Authority Regulatory Limit. A number of stormwater outfalls are located in close proximity to the St. Marys wells, and several outlet to Trout Creek within the zone of potential interaction for Well 1. Travel velocities within urbanized areas with sewersheds can be relatively high due to surface grading and storm sewer conveyance. Based on the analysis of available data, all St. Marys stormwatersheds with outfalls upstream of the Well 3, and both upstream and downstream of Well 1 on Trout Creek were included in *WHPA-E*. This results in an overlap of areas around the confluence of the North Thames River and Trout Creek.

Further, tile drainage, channels and ditches were examined for transport pathways. Tile drains and roadside ditches that can contribute water to *WHPA-E* within a 2 hour travel time were examined and included into the *WHPA-E* delineation where applicable. The available tile drain GIS layer did not include the outlets of the tiles, therefore an assumption was made that the tiles drain in the same direction as the general slope of the land. Tiles that touch the 120 m buffer or the Regulation Limits and located within 2 hour travel time from the intake were included in the *WHPA-E* delineation.

While valley slopes and flood plain areas drain directly to the watercourses, wetlands should be screened to determine if they are connected either by natural or anthropogenic transport pathways. There are 2 such wetland areas within the study area. One is at the headwaters of both a watercourse which drains south to Trout creek, and a second watercourse which drains to Wildwood Reservoir. The area draining to Wildwood Reservoir is beyond the area which could flow to the zone of interaction within the 2 hour operator response time. Therefore the part of this wetland area draining to Wildwood Reservoir has been trimmed from the area to be included in *WHPA-E* using catchment areas available with the watercourse information. The other area is between Birches Creek and a tributary north of Birches Creek. Review of the tile drainage information indicates that part of this area is tile drained. The entire area is included in the *WHPA-E*.

Final WHPA-E Delineation

The final delineation considers the local watershed boundaries, such that only areas that can contribute overland flow to the well are included in the delineation. The St. Marys *WHPA-E* is shown in **Map 4-1-21a**. Vulnerability Scoring is described in Section 4.3.5.

WHPA-F

As mentioned earlier, *WHPA-F* is only delineated if the well is subject to *issues* (known to be partially or wholly due to anthropogenic causes), which originate from outside *WHPA-A to E*. No *issues* were identified for the St. Marys well supply system. Therefore a *WHPA-F* was not required to be delineated.

Thamesford *WHPA-E*

The Thamesford well supply system is comprised of 3 wells located near County Road No. 19, north and south of the Canadian Pacific Railway alignment. Two of the wells, Well 1 and Well 2 are classified as *GUDI* wells. Both wells pump water from an alluvial sand and gravel unconfined aquifer. Below the alluvial aquifer are silty tills, which overlay the bedrock limestone aquifer. Both wells are located near the Middle Thames River, with Well 1 and 2 being 20 m and 40 m south of the river, respectively. In addition to the river, there is a small tributary that flows into the Middle Thames River, and is within 70 m of the wells. Based on the close proximity of these wells to the river and their *GUDI* status, a *WHPA-E* is required.

Intake Type

The delineation of *WHPA-E*, conducted by Dillon Consulting Limited, is based on the locations of the nearest surface water body to the wells, and an intake Type C (located in a river and neither the direction nor the flow of water at the intake is affected by a water impoundment structure). Based on available information, the Thamesford wells 1 and 2 were projected to the nearest shore of the Middle Thames River. These well projections were used as the ‘surrogate’ intake locations for the *WHPA-E* delineation. In addition, the small tributary located around 70 m away from the wells was also considered as potentially having a hydraulic connection to the wells based on its close proximity.

Extent up Surface Water Bodies

In order to delineate the area within the Middle Thames River and its tributaries that may contribute water to the well’s closest in-stream point within a 2 hour travel time (based on a 2 year bankfull flow), hydrologic and hydraulic analyses as well as a field trip were conducted.The travel time analysis for the Middle Thames River was completed using the HEC-RAS model (hydraulic analysis). For small tributaries and for reaches of the Middle Thames River not covered through HEC-RAS modeling, the travel time analysis (2-year flow) for was conducted using empirical equations (hydrologic analysis) combined with a field visit. The Moin Index Flood Method (IFM) and the Primary Multiple Regression Method (PMRM) were used to calculate bankfull 2 year flow in the Middle Thames River tributaries of Daymun Drain, George Roberts Drain, Arthur Vanatter Drain, 12th Concession Drain, Mcdonald Drain, Nissouri Creek and the watercourse just southwest of Wells 1 and 2. The more conservative flow (i.e. the larger flow) between IFM and PMRM methods was used for velocity, and eventually travel time analysis. For the hydraulic analysis, instream velocities were estimated by using Manning's Equation combined with the GIS data and field observations. Further, a field survey of the Middle Thames River and its tributaries was conducted in March 2011 by the consultant. For each cross-section of interest, the physical condition was noted and the bank and channel geometry was estimated, where possible.

Setbacks on Land, Storm Sewersheds and Transport Pathways

Where the delineation abutted land, it was truncated to the greater of either the setback of 120 meters (measured to the high water mark of the Middle Thames River) or the Conservation Authority Regulatory Limit. Further, the tile drainages, channels and ditches were examined for transport pathways. Tile drains and roadside ditches that can contribute water to *WHPA-E* within a 2 hour travel time were examined and included into the *WHPA-E* delineation where applicable. The available tile drain GIS layer did not include the outlets of the tiles, therefore an assumption was made that the tiles drain in the same direction as the general slope of the land. Tiles that touch the 120 m buffer or the Regulation Limits and located within 2 hour travel time from the intake were included in the *WHPA-E* delineation. Based on available information, no stormwatersheds were included in the delineation as transport pathways.

Final WHPA-E Delineation

The final delineation considers the local watershed boundaries, such that only areas that can contribute overland flow to the well are included in the delineation. The Thamesford *WHPA-E* is shown in **Map 4-1-16a**. Vulnerability Scoring is described in Section 4.3.5.

WHPA-F

As mentioned earlier, *WHPA-F* is only delineated if the well is subject to *issues* (known to be partially or wholly due to anthropogenic causes), which originate from outside *WHPA-A to E*. The only *issue* identified for the Thamesford well supply system (manganese) is naturally occurring (see Section 5). No other *issues* were identified for this system. Therefore a *WHPA-F* was not required to be delineated.

Woodstock *WHPA-E*

The water supply for Woodstock is predominantly supplied by the Thornton and Tabor rural wellfields, which are located east and southeast of the community of Sweaburg. Wells 1, 3, 5 and 8 of the Thornton wellfield and Wells 2 and 4 of the Tabor wellfield have been designated as *GUDI* wells. Nitrate has been identified as an anthropogenic raw water quality issue for both the Thornton and Tabor systems.

The Thornton Wells 1, 3, 5 and 8 draw water from a sand and gravel unconfined aquifer. The pumping test conducted during the *GUDI* study identified a strong hydraulic connection between the aquifer and the local wetland. During periods of pumping, the water table fell below the ground surface resulting in a predominant downward movement of groundwater flow. When the pumping of the well field was stopped, springs and localized ponding occurred, as the groundwater levels rose above the ground surface in some areas.

The Tabor Wells 2 and 4 also draw water from a sand and gravel unconfined aquifer. Water level data suggests a predominant downward movement of groundwater flow.

Intake Type

The delineation of *WHPA-E*, conducted by Dillon Consulting Limited, is based on the locations of the nearest surface water body to the wells, and the intake type. For the purpose of the *WHPA-E* delineation, the Thornton and Tabor *GUDI* wells are classified as a Type D (inland lakes) surface water intake. A Type D designation is deemed appropriate as both wellfields are near the Sweaburg Wetland.

Extent up Surface Water Bodies

The *WHPA-E* delineations are completed separately for the two wellfields of Thornton and Tabor.

The Thornton Wells 1, 3, 5 and 8 are located within 25 to 100 m of a wetland and other surface water bearing features such as creeks, ditches and ponds. Two waterbodies were identified as potential areas of groundwater-surface water interactions: a Cedar Creek tributary and the Sweaburg wetland. Through field investigations, previous reports and communications with various technical staff, a creek running between Wells 1 and 5, a ditch near Well 1, and a pond close to Well 3 were identified and included in the *WHPA-E* delineation. During the field visit, it was confirmed that there is no surface water flow from the adjacent wetlands (which is down slope of the wellfield) to the wells. Rather, surface water flow is away from the wells, towards the wetland. Based on this information, the Sweaburg wetland is not expected to decrease the time of travel for surface water to migrate to the well, and it was not included in the delineation.

For the Tabor Wells 2 and 4, two waterbodies were identified as potential areas of groundwater-surface water interactions: a ditch along Cedar Line that is part of a tributary fed by two ponds (located 0.5 to 1 km south of the wellfield), and a small creek near Well 2 that seems to be spring-fed. During a field survey conducted to investigate these waterbodies, the ditch (along the west of Cedar Line), ponds (south of Wells 2 and 4) and a small creek (near Well 2 that discharges to a ditch along River Road) were identified and included in the *WHPA-E* delineation.

Setbacks on Land, Storm Sewersheds and Transport Pathways

Where the delineation abutted land, the Thornton *WHPA-E* was truncated to a setback of 120 meters, measured to the high water mark of the creek, ditch and pond located near Thornton Well 3. The west side of Sweaburg Road is downstream of the wells and therefore *WHPA-E* was clipped to the east side of the road. This assumption is supported by observed direction of flow in the creek during the field visit.

Based on available information, no tile drained areas or stormwatersheds were included in the Thornton *WHPA-E* delineation as transport pathways.

Where the delineation abutted land, the Tabor *WHPA-E* was truncated to a setback of 120 meters, measured to the high water mark of the tributary, two ponds and the small creek. Cedar Line is a local watershed boundary, and therefore *WHPA-E* was clipped to the road on the west side. This assumption is supported by observed direction of flow in a culvert across Cedar Line, during the field visit.

Based on available information, no tile drained areas or stormwatersheds were included in the Tabor *WHPA-E* delineation as transport pathways.

Final WHPA-E Delineation

The final delineation considers the local watershed boundaries, such that only areas that can contribute overland flow to the well are included in the delineation. The Thornton and Tabor *WHPA-Es* are shown in **Map 4-1-17a**. Vulnerability Scoring is described in Section 4.3.5.

WHPA-F

As mentioned earlier, *WHPA-F* is only delineated if the well is subject to *issues* (known to be partially or wholly due to anthropogenic causes), which originate from outside *WHPA-A to E*. Elevated nitrate levels are identified as an *issue* for the Woodstock-rural well supply system (see Section 5). Information from the University of Waterloo suggests that the nitrate may have originated from surface runoff of adjacent farm fields, and infiltrated into the aquifer. Since the nitrate originates from areas within the *WHPA-A* to *E*, a *WHPA-F* was not required to be delineated.

4.3.5 Vulnerability Assessment of the WHPA

Within the *WHPA* zones, the vulnerability must be assessed using one of the four methods described in Rule 37 of the *Technical Rules: Assessment Report*:

- *Intrinsic susceptibility index* (*ISI*).
- Aquifer vulnerability index (*AVI*).
- Surface to aquifer advection time (*SAAT*).
- *Surface to well advection time* (*SWAT*).

The results of the vulnerability assessment for the *WHPA* in the Upper Thames River Source Protection Area are shown in the vulnerability maps in Appendix 1 (Maps 4-1-1 to 4-1-23). Vulnerability scores for the UTRSPA are summarized below in Table 4-4.

Table 4-4 List of Groundwater Wells and Vulnerability Scores for WHPA-A, B, C, D

Groundwater Intake	Vulnerability Score				Vulnerability Comments
	WHPA-A	WHPA-B	WHPA-C	WHPA-D	H= high, M= moderate, L= Low
London Middlesex Study					
Birr	10	6	4	2	Vulnerability is low
Dorchester Overburden & Bedrock	10	10, 6	8, 4	6, 2	Vulnerability is high in overburden and low in bedrock
London Back Up Wells Fanshawe & Hyde Park	10	10, 8, 6	8, 6, 4	doesn't exist for Fanshawe 6, 4, 2	High for Fanshawe, reaches steady state at WHPA-C
Melrose	10	10	8,6	6,4,2	H for WHPA-B, H and M for WHPA-C; H, M and L for WHPA-D
Thorndale	10	6	4	2	Vulnerability is Low in WHPA
Oxford Study					
Beachville (larger and smaller)	10	8, 6	8, 4	6,4,2	High for WHPA-B & C; High, Medium & Low for WHPA-D, (Smaller WHPA) Medium for part of WHPA-B & low for WHPA-C & D
Embro	10	6	4	2	L for all WHPA-D
Hickson	10	8	4	2	M for part of WHPA-B but all included as moderate, L for WHPA-C & D
Ingersoll	10	10, 8, 6	6, 2 (H & L SWAT)	6 (due to overlap of WHPA), 4, 2	Ingersoll was completed with SWAT Table 2b. WHPA values different. H, M, & L for WHPA-B; M & L for WHPA-C & D
Innerkip	10	8	8, 6	4, 2	WHPA-B: M, WHPA-C: H & M; WHPA-D: M & L
Lakeside	10	6	4	2	WHPA-B-D all low vulnerability
Mount Elgin	10	6	4	2	WHPA-B-D all low vulnerability
Tavistock	10	6	4	2	WHPA-B-D all low vulnerability

Table 4-4 List of Groundwater Wells and Vulnerability Scores for WHPA-A, B, C, D

Groundwater Intake	**Vulnerability Score**				**Vulnerability Comments**
	WHPA-A	WHPA-B	WHPA-C	WHPA-D	H= high, M= moderate, L= Low
Thamesford (bedrock & overburden WHPA)	10	10, 8 (due to overlap of WHPA), 6	10 (due to overlap of WHPA), 8, 4	8 (due to overlap of WHPA), 4, 2 No D for overburden	WHPA-B-D bedrock well are all low vulnerability; WHPA-B-D are all high for overburden wells
Woodstock	10	10, 8, 6	8,6, 2	4, 2 & (10, 8, 6, due to overlap of WHPA)	Woodstock was completed with SWAT. WHPA values table 2b.WHPA-B: H, M, & L; WHPA-C: M & L; & WHPA-D: M, L (H, M & L in overlap wells)
Perth Study					
Mitchell	10	6	4	2	WHPA-A-D vulnerability is low
Sebringville	10	10	4	2	WHPA-A-D are all in low vulnerability areas. WHPA-B appears to be beneath WHPA-A
Shakespeare	10	6	4	2	WHPA-A-D are all in low vulnerability areas.
St. Pauls	10	6	4	2	WHPA-A-D are all in low vulnerability areas.
St. Marys	10	10, 8, 6,	6, 4	6, 4, 2	WHPA B and D- high, medium and low vulnerability, WHPA-C has medium and low vulnerability areas
Stratford	10	6	4	2	WHPA-A-D vulnerability is low

Vulnerability Scoring within WHPA-E

The vulnerability score of a *WHPA-E* is calculated as per the Technical Rules on vulnerability scores for *Intake Protection Zone-2* (*IPZ-2*). A higher score signifies a greater vulnerability to contamination. The vulnerability score must be calculated based on the vulnerability of the source and the area in the *WHPA-E,* which in turn are based on a number of factors described below. The vulnerability score is a product of the area vulnerability factor and the source vulnerability factor. **Table 4-5** summarizes the vulnerability scores of the *GUDI* well systems in the UTRSPA.

Table 4-5 List of GUDI Wells and Vulnerability Scores for WHPA-E

GUDI Well System	Intake Type	*WHPA-E* Area Vulnerability Factor	*WHPA-E* Source Vulnerability Factor	*WHPA-E* Vulnerability Score
Dorchester	C	7.0	0.9	6.3
London Back Up Wells - Fanshawe	D	7.0	1.0	7.0
St. Marys	C	8.0	0.9	7.2
Thamesford	C	7.0	0.9	6.3
Woodstock – rural - Thornton	D	7.0	1.0	7.0
Woodstock – rural - Tabor	D	7.0	1.0	7.0

Area Vulnerability factor: According to the *Technical Rules*, the area vulnerability factor for a *WHPA-E* is assigned in the same manner of assigning a factor to a surface water intake *IPZ-2*. Therefore the area vulnerability factor for a *WHPA-E* ranges between 7 and 9. A higher number corresponds to a higher vulnerability. The area vulnerability factor is dependent on the percentage of area that is land in the *WHPA-E*, land cover, soil type and permeability of the land, slope of any setbacks, and the hydrological and hydrogeological conditions in the area that contribute water to the area through *transport pathways*. The above mentioned criteria have been given equal weight based on professional judgement.

Source Vulnerability factor: According to the Technical Rules, the area vulnerability factor for a *WHPA-E* is assigned based on the type of intake. The source vulnerability factor for a Type C intake can be 0.9 or 1.0 and is based on certain criteria: depth of the intake from the top of the water surface, distance of the intake from land, and number of recorded drinking water issues related to the intake. The source vulnerability factor for a Type D intake can be 0.8 to 1.0 and is based on the same criteria.

The consideration of the above criteria in assigning area and source vulnerability factors to each *GUDI* system's *WHPA-E* is described below.

Dorchester WHPA-E Area and Source Vulnerability Factors

The Dorchester *WHPA-E* consists primary of the Dorchester swamp, wetlands and agricultural lands. Soils are predominantly organic and fine sand loam with high runoff potential. A number of agricultural tile drainages cross the *WHPA-E*. The surficial geology consists of mainly glacial outwash sand deposits. Modern alluvium, consisting mainly of silty sand, occurs within the floodplains of the Big Swamp Drain and its tributaries. *WHPA-E* is relatively flat with 73% of its area having overland slopes less than 1%. From a range between 7 and 9, an area vulnerability factor of 7 (low value) was assigned to the Dorchester *WHPA-E*. The decision was mainly based on flat topography, low soil permeability and low percentage of urban area.

The Dorchester *GUDI* wells pump water from a shallow overburden unconfined aquifer consisting of glaciofluvial sand and gravel. The overburden thickness is in the order of 24 m at the well fields. In the general vicinity of the well field, the aquifer varies in thickness from 4 m to 17 m. A relatively homogenous till underlies the sand and gravel aquifer. The wells are located about 100 to 200 m from the Big Swamp Drain. Considering that the wells are not located in the immediate vicinity of the Big Swamp Drain and no historical drinking water issues were recorded, a source vulnerability factor of 0.9 was assigned to *WHPA-E*. The factor, which is at the low end of the recommended range for a Type C intake, reflects the condition that the well does not pump directly from surface water, has no water quality issues and is located relatively far from the potential surface sources of contamination.

Fanshawe WHPA-E Area and Source Vulnerability Factors

The *WHPA-E* is mostly cultivated grass (golf course) and roads, with forests and some waterbodies. The soils are mainly sandy loams. The soils are moderately to well permeable. Overland slopes are mild, mainly less than 5%. A number of kettle ponds are located around the well field. These kettles generally contain less than 1 m of standing water and are disconnected and do not have outlets. These ponds are vertically hydraulically connected to the water supply. The pumped aquifer consists of a 15 m to 20 m thick deposit of unconfined sand and gravel. The water table is fairly shallow, being approximately 1 m to 5 m below surface. From a range of 7 to 9, an area vulnerability factor of 7 (low value) was assigned to the Fanshawe *WHPA-E*. The decision was mainly based on low percentages of paved areas, high permeability of soils, and mild slopes.

Considering that the aquifer is very shallow (1 to 5 m), the Fanshawe wells are located in the immediate vicinity of kettle ponds, the identified drinking water *issue* (organic nitrogen) and Type D intake, a high source vulnerability factor of 1.0 was assigned. This high factor considers that the wells pump groundwater that is susceptible to water quality impacts from surface water contamination.

St. Marys WHPA-E Area and Source Vulnerability Factors

The St. Marys *WHPA-E* primarily consists of the urban land uses of St. Marys and agricultural land upstream of St. Marys. Soils are predominantly clay loam and silty loam with relatively poor permeability. A number of agricultural tile drainages cross the *WHPA-E*. The *WHPA-E* has generally mild slopes, mainly less than 5%; however in areas close to the river channel slopes may be steep. From a range between 7 and 9, an area vulnerability factor of 8 (middle value) was assigned to the St. Marys *WHPA-E*. The decision was mainly based on percentage of urban area and concentration of transport pathways (St. Marys stormwatersheds and tile drainages), low permeability of soils and relatively steep slopes.

The wells pump water from the bedrock which is relatively deep around the wells. The zone of interaction with the surface water is located several hundreds metres away from the well projections. The major source of water to the well is attributed to groundwater, however, a small, and unknown portion of water may potentially originate from a surface water source. No drinking water issues were recorded in the St. Marys wells. Considering that the wells are located in deep bedrock, and the zone of interaction is several hundreds meters away from the wells and no historical drinking water issues were recorded, a source vulnerability factor of 0.9 was assigned to *WHPA-E*. The factor is at the low end of the recommended range for a Type C intake.

Thamesford WHPA-E Area and Source Vulnerability Factors

The *WHPA-E* is mostly agricultural, with some wetlands and forests. The overburden in the area is part of the Oxford Till Plain, which consists of sandy-silt to clayey silt soils. Alluvial and glaciofluvial sand and gravel are observed in the drainage channels and valleys. The topography is relatively flat. A large number of agricultural tile drainages and some road ditches exist in *WHPA-E*. From a range between 7 and 9, an area vulnerability factor of 7 (low value) was assigned to the Thamesford *WHPA-E*. The decision was mainly based on flat topography, low percentage of water in the area and low to moderate soil permeability.

Both Thamesford wells are installed in alluvial sands and gravels in an unconfined aquifer. Well 1 is 14.5 m deep and Well 2 is 9.4 m deep. The two wells are located close to the Middle Thames River, with Well 1 and Well 2 being approximately 20 m and 40 m away from the river, respectively. In addition, there is a tributary approximately 70 m south of the wells. Raw water in the wells may be vulnerable to contamination from these surface water features; however, no existing drinking water issues were recorded. Considering that no drinking water issues were recorded and wells are relatively deep, a source vulnerability factor of 0.9 was assigned to *WHPA-E*. The factor, which is at the low end of the recommended range for a Type C intake, reflects the condition that the potential vulnerability of the well to surface water impacts may be low.

Woodstock WHPA-E Area and Source Vulnerability Factors

Both the Thornton and Tabor wellfield *WHPA-Es* encompass a high percentage of rural land. The land cover is predominantly forest for Thornton wellfield, and agriculture for Tabor wellfield. Soils are very permeable, being predominantly sandy loam for Thornton wellfield and loam for Tabor wellfield. No tile drainages within *WHPA-E* were mapped or observed for either wellfield. The topography is moderately flat for both systems, with 98% of their areas having overland slopes less than 5%. Considering these criteria, an area vulnerability factor of 7 (lowest value) was assigned to the Thornton and Tabor wellfields *WHPA-Es*. The decision was based on the percentages of land, relatively high permeability of soils, flat slopes and absence of transport pathways (i.e. tile drainages).

The depth of the Thornton wells ranges from 11 to 32 m below ground surface. The Tabor wells are approximately 14 to 24 m deep. The Thornton and Tabor wells are located very close to the surface water features. Nitrate was identified as a drinking water issue for both wells. Considering these criteria and the intake type (D), a source vulnerability factor of 1.0 (highest value) was assigned for both wellfields.