Thornhill Area Road Reconstruction
City of Vaughan

Stormwater Management
Final Report

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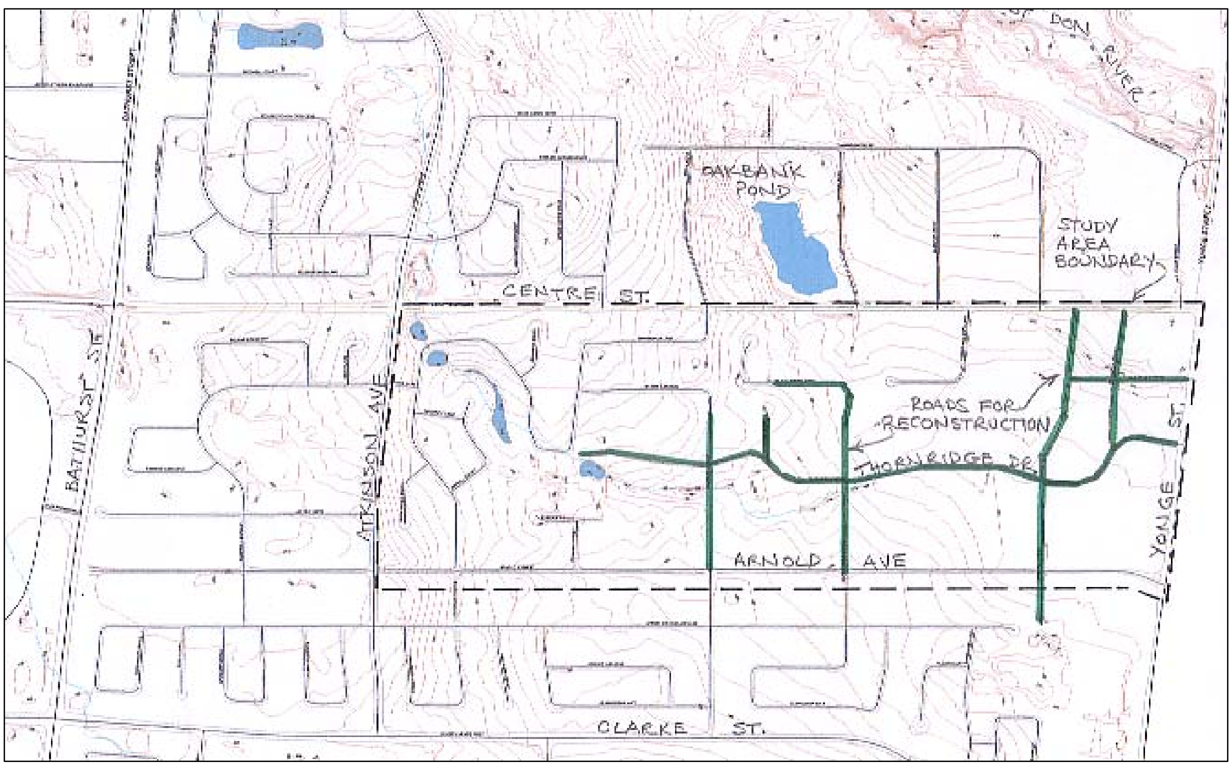
1 Introduction

1.1 General

The Thornhill Road Reconstruction Study area is located in the City of Vaughan bounded by Arnold Street on the south, Centre Street on the north Yonge Street in the east and Bathurst Street in the west (see Figure 1). The site is in the Don River watershed under the jurisdiction of Toronto Region Conservation Authority (TRCA).

SNC-Lavalin Inc. (SLI) is carrying out the engineering design for the reconstruction of a number of the roads in the study area (see Figure 1). As part of the road work, drainage system improvements are also to be carried out to address the recurrent flooding problems in the area. This Stormwater Management Report presents the hydrologic and hydraulic analyses of the drainage systems and the calculations supporting the SLI design for drainage improvements associated with the road design works. The drainage design work builds on the recommendations of the Thornhill Storm Drainage Improvement Study completed by Genivar Ltd. in February 2008.



Location Plan

Figure 1

1.2 Study Scope

The stormwater management study is a component of the Thornhill Road Reconstruction Project. The purpose is to support the road design and to prepare the detail design for the drainage improvements to be constructed with the road works to alleviate some of the flooding problems in the study area. The study is intended to assess the drainage systems in the overall study area. However, the design of specific improvements is confined to the locations where road improvement will be carried out.

Most of the hydrologic and hydraulic analysis results from the Thornhill Drainage Improvement Study have been reviewed as part of this design project. However, the peak design flow to the Brooke Street trunk sewer from the proposed SWM pond in Gallanough Park has been taken from the Genivar report. The analysis of the Gallanough Park SWM pond is outside of the scope of this study. The pond will be evaluated in subsequent Class EA and design projects.

For the purpose of this study, it is assumed that the pond will be constructed as proposed in the Genivar report as part of the overall flood relief scheme.

2 Background

2.1 History

The study area is located in the headwaters of the East Don River. Over the years, the older residential development in the old Town of Thornhill (now within the City of Vaughan) has been replaced by more intense development characterized by large residences. Drainage planning for the area dates from the early 1980's when stormwater management (SWM) was just being introduced into the area. At that time, the drainage system between Bathurst Street and Yonge Street consisted of several small Tributaries of the East Don River flowing through backyards and along the road ditches within the existing development. As new development occurred upstream of the area, a number of flow diversions and SWM ponds were constructed to control peak flows in the watercourses east of Bathurst Street to prevent flooding on these existing Tributaries (see Figure 2).

Despite these measures, periodic local flooding has been experienced in the study area over the years. This flooding can be attributed to various causes including infilling and relocation of the watercourses on private property, damage and deterioration of the existing culverts, the increase in development density with larger houses and increased pavement areas and some extreme rainfall events (i.e. August 2005).

2.2 Land Use

The land use in the study area is predominantly single family residential with a few institutional properties (churches, schools and heritage sites). The existing lots are generally very large in the older areas along Thornridge Drive and in the Oakbank Pond area. In the newer subdivisions, the housing and lot sizes are typical of subdivision development since 1980.

The area is generally built out and only a few small areas of potential future infilling are present. Some of the large older lots have been severed into smaller land parcels but many of them have been redeveloped with very large homes including circular driveways, tennis courts, swimming pools, etc.

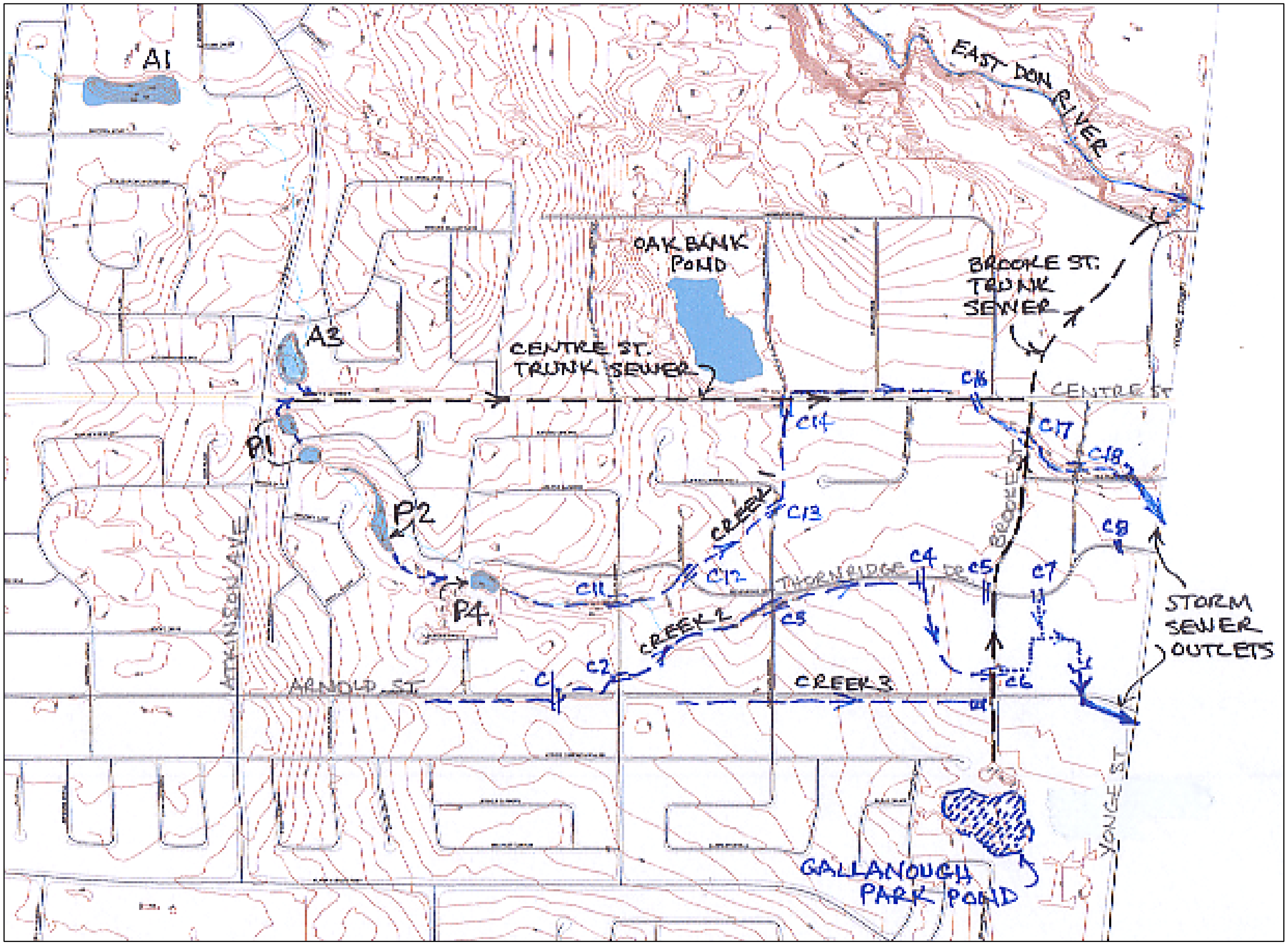
The roads in the older areas (Thornridge Drive, Charles Street, Clarkehaven Street and Brooke Street, etc.) are maintained in a rural section with shallow roadside ditches. In all of the newer subdivisions built since 1980, the roads have an urban section with curbs and storm sewers.

2.3 Existing Drainage Systems

The drainage within the study area consists of three drainage courses. Two of these, designated as Tributaries 1 and 2, have been classified as watercourses by TRCA and are subject to their regulation (per Ontario Regulation 166/06), while the third is a local road ditch system (see Figure 2). Most of the local runoff is conveyed in the road ditches or as overland flow directly to one of these watercourses. The existing road crossing culverts were constructed between 1960 and 1980. The newer subdivisions in the north and west have storm sewers that are connected to the Centre Street Trunk sewer or Ponds P1 or P2 (see Figure 2).

Tributary 1 in the north is the remnants of a much larger system that has been modified through stormwater management facilities and diversion to the Centre Street trunk storm sewer at Atkinson Avenue. The Centre Street trunk storm sewer was designed to convey all flows from north of Centre Street and west of Atkinson Avenue to the East Don River (via connecting to the Brooke Street trunk sewer). The only remaining contribution to the study area from this upstream area is the possible overflow from Pond 1 at the corner of Atkinson Avenue and Centre Street. Since the upstream system is designed to capture the 100-year flow, this overflow would be expected to be very infrequent.

The area east of Atkinson Avenue and south of Centre Street is connected to Pond 2 by storm sewers and overland flow routes. Pond 2 significantly reduces the peak flows to the downstream system. The outflow from Pond 2 and local runoff are connected to a third pond (Pond 4) which further reduces peak flows. Downstream of Pond 4, the watercourse passes through the rear of private lots and several road culverts as it makes its way north to Centre Street, just downstream of the Oakbank Pond. From there it flows along the north side of Centre Street through a series of road and driveway culverts until it crosses back to the south side at the MacDonald House property, through culverts on Brooke Street and Old Jane Street to the entrance to the underground storm sewer system on Old Jane Street just east of Yonge Street. The trunk storm sewer flows to the east under Yonge Street.



Existing Drainage

Figure 2

Tributary 2 starts in the roadside ditch on the south side of Arnold Street east of Atkinson Avenue. There are no SWM facilities on this watercourse. It crosses Arnold Street in a culvert west of Charles Street. From there it flows through backyards and culverts to east of Clarkehaven Street where it flows in the ditch on the south side of Thornridge Drive. It then flows south between the houses and across backyards to Brooke Street north of Arnold Street. At Brooke Street, there is a ditch inlet to the Brooke Street trunk sewer. The flows that are not captured by the ditch inlet pass through a twin culvert to flow through the backyards to the west before entering the underground storm sewer system at an inlet located in an easement north of Arnold Avenue. From this location, a 1,200mm diameter storm sewer conveys the flows to a 1,500mm diameter storm trunk sewer on Arnold Avenue that flows to the east under Yonge Street.

Tributary 3 is located in the roadside ditch along the south side of Arnold Avenue from east of Charles Street to Brooke Street where it enters the Brooke Street trunk sewer via a ditch inlet.

2.4 Thornhill Storm Drainage Improvement Study

As a result of the flooding history in the area and the major flooding that occurred in August 19, 2005 in particular, the City commissioned the Thornhill Storm Drainage Improvement Study (Genivar Ltd., February 2008) to assess the causes of the flooding and identify a recommended solution. This study was carried out under the Class EA process, including public consultation. The watercourse designations and culvert numbering from this study (as shown in Figure 2) have been retained in this study for continuity.

The study identified numerous deficiencies in the drainage system including damaged and undersized culverts, lack of major system flow routes, reduction in tributary capacities through obstructions and modifications carried out on private property and local flooding due to improper local regrading. This study also reported that the Brooke Street sewer is subject to significant surcharge during large storm events. Based on a simplified analysis, it was concluded that the Hydraulic Grade Line (HGL) in the Brooke Street sewer may reach the ground at Arnold Street during major storm events causing a spill onto the surface at this location. This spill could be a major contributor to the flooding in the vicinity of Arnold Street and Brooke Street. However, the majority of the flows in the Brooke Street sewer originate outside of the study area from the subdivisions to the south.

The recommended drainage improvements from the study included:

- Replacement of deficient culverts;
- Construction of a SWM facility in Gallanough Park at Brooke Street south of Arnold Street to reduce peak flows in the Brooke Street Trunk sewer;
- Construction of a storm relief sewer along Thornridge Drive to divert flow from Tributary 2 to the Brooke Street trunk sewer;
- Removal of the twin culverts across Brooke Street north of Arnold Avenue;
- Replacement of deficient catch basins and ditch inlets and
- Improvement of ditches.

The proposed Gallanough SWM facility is an essential component of the flood relief scheme as proposed in the Genivar Report. It would be an expansion of the existing SWM facility at the same location. This would have the two-fold effect of reducing the surcharge of the Brooke Street sewer and opening up capacity in that sewer to accept some additional flow from a relief sewer on Thornridge Drive. Based on the hydraulic analysis of the Brooke Street sewer with the proposed expanded SWM facility, it was determined that the Brooke Street sewer may be able to accept about $4.0m^3/s$ from the proposed future Thornridge relief sewer.

2.5 TRCA Concerns

The Thornhill Storm Drainage Improvement Study evaluated drainage improvements based on capacity assessments of each of the individual drainage components. Flows were developed with the Rational Method. Flood lines were not computed and backwater effects were not considered in developing the recommended solutions.

Tributaries 1 and 2 in the study area are 'designated' as watercourses by TRCA. As a result, they are subject to regulation by the TRCA and permits are therefore required for any grading/fill placement works or alterations of the watercourse. In their review of the Thornhill Storm Drainage Improvement Study, TRCA indicated that they require a more comprehensive assessment of flood control options before they will issue permits for the proposed works on these Tributaries. In particular, they require that flood line mapping be prepared for the study area and that the flood line mapping be used as the basis for a comprehensive assessment of flood control options for the area as a whole. This will ensure that the proposed measures will be effective in reducing the flood elevations as determined through the flood line mapping process.

2.6 Background Data

2.6.1 Culvert Condition Assessment Reports

The City conducted condition assessments of the major culverts in the road reconstruction area in 2005 and 2006. Minor repairs were indicated on most of the culverts. However, three culverts were identified for replacement:

- C11 – 1.8m CSP on Charles Street south of Thornridge,
- C12 – 1.75m CSP on Thornridge east of Raymond and
- C3 – 1.15m x 0.82m CSP on Clarkehaven south of Thornridge.

The culvert locations are shown on Figure 2.

2.6.2 Previous SWM Design Reports

There are studies and design reports available from the City from the subdivision planning and design process for the study area. These reports were used to obtain the details of the existing drainage and SWM concept and the operating relationships for the existing SWM facilities.

The reports consulted were:

- "Review of the A4 Neighbourhood Detention Requirements", MacLaren Engineers, Aug. 1986.
- "Revised Storm Water Management Report for the 518815 Ontario Limited Subdivision in the Town of Vaughan", Fred Schaeffer & Associates, April 1986.

These reports provided operational information for Ponds 2 and 4. Excerpts from the reports are presented in Appendix A.

2.6.3 TRCA SWM Pond Files

TRCA compiles files for all of the SWM facilities in their jurisdiction. The files contain data sheets that summarize the design information for the facilities and include copies of backup reports and commentary that further describe the pond operation and function. These files provided operational information for Ponds 1, A1 and A3. Hydrologic modelling data for Ponds A1 and A3 were also obtained from these files. Copies of the TRCA pond data files used in the study are also given in Appendix A.

2.6.4 Record Plans

The plan and profile drawings for the roads in the study area were obtained from the City. These drawings provided information on the existing drainage boundaries, the location and size of existing inlets and storm sewers and the details of existing culverts.

2.6.5 Topographic Mapping

The City has topographic mapping for the study area with a 1.0m contour interval. This mapping was used as the basis to define catchment boundaries, supplemented by the road plan and profile drawings and field inspection.

More recent mapping was provided by TRCA. This mapping was prepared for the flood line mapping component of the project. It also has 1.0m contour interval.

2.6.6 Satellite Imagery

Satellite imagery for the study area was obtained from the City. This information was used to verify land use, to refine drainage boundaries and to compute impervious areas for each subcatchment.

2.6.7 Field Inspections and Surveys

Detailed surveys were conducted for the road reconstruction project. This survey covered the road right-of-way area and included culvert inverts and ditch inlet elevations. Field inspections were also carried out to confirm culvert sizes, drainage boundaries and the physical condition of the culverts, etc.

3 Targets and Criteria

3.1 City of Vaughan

The analysis and design of the proposed drainage systems have been based on the criteria specified in the City of Vaughan Design Criteria for stormwater management.

The proposed road design in most locations will be semi-urban with subdrains and shallow ditches (see Figure 3). In some areas, urban sections will be used as a result of physical constraints or where they already exist. The minor system ditches are to be designed to convey the 5-year design storm. The target for the major system is to convey the 100-year design storm or the Regional Storm, whichever is greater. This criterion also applies to the watercourses in the study area.

Design storms for the OTTHYMO modelling have been based on the Rainfall Intensity-Duration-Frequency (IDF) curves in the City of Vaughan Design Criteria.

3.2 TRCA

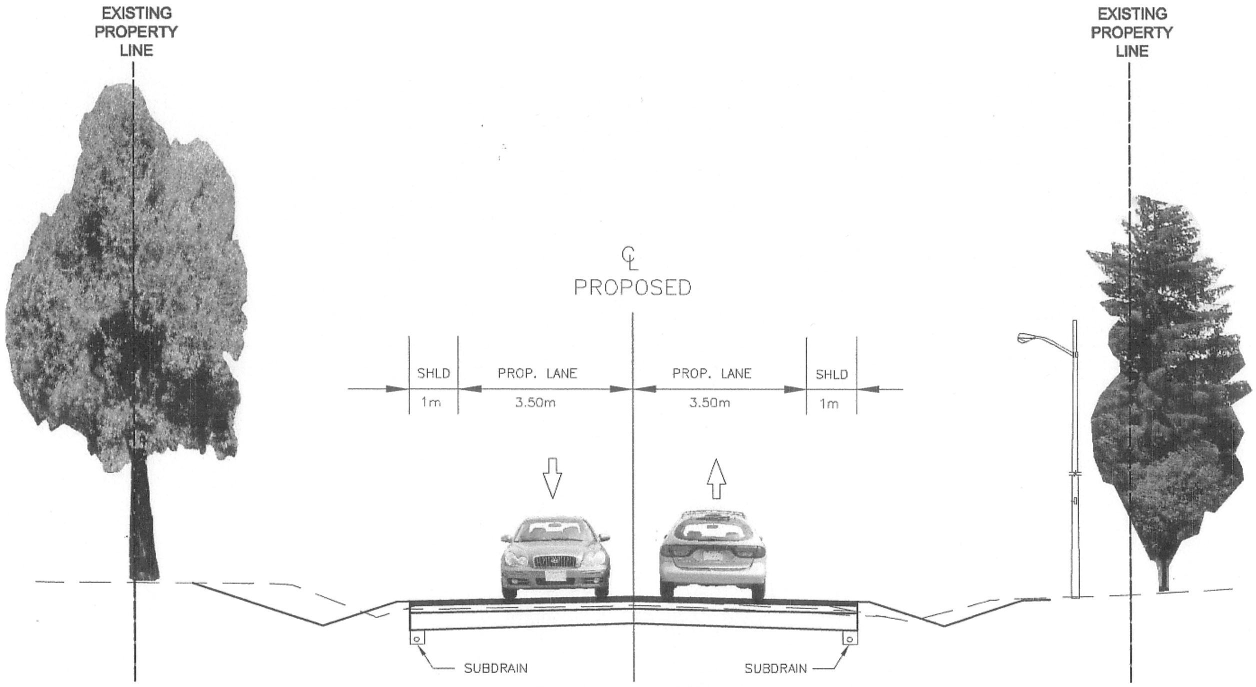
TRCA requires that the flood line mapping be prepared based on the greater of the 100-year storm or the Regional Storm event, whichever is greater. It is also required to demonstrate that the proposed drainage improvements are effective through the preparation of flood line plots before and after the improvements. There should be no increase in the flood elevations with the proposed improvements.

4 Hydrologic Analysis

4.1 Method

The hydrologic analysis was carried out using the Visual OTTHYMO model. Design storms were used for the design of the drainage infrastructure (culverts, sewers, etc.). Design storms were developed from the City of Vaughan IDF curve data based on the Chicago distribution and a duration of six hours. AES design storms were also tested to determine the distribution that is most critical for the study area. For the flood line determination, the standard 24hr Regional Storm hourly rainfall distribution was used and the SCS 12hr distribution was used for the 100-yr analysis in accordance with TRCA requirements.

The study area for the hydrologic analysis was expanded to include all of the natural pre-development drainage area and the existing SWM facilities. This was done to verify that the system operates as intended and that any overflows from the upstream SWM facilities would be accounted for in the evaluation of the flood control requirements.



Proposed Semi-urban Road Cross Section

Figure 3

4.2 Subcatchment Boundaries

Subcatchment boundaries for the OTTHYMO model were defined using the City topographic mapping. This information was supplemented by the road plan and profile drawings, sewer design drawings and field inspections to ensure consistency with existing conditions. The subcatchment definition used in the model is shown in Figure 4. The total drainage area for the natural Tributary 1 drainage area is 209.2ha. A large portion of this area (i.e. catchments 40, 50 and 55 with a total area of 143.6ha) is directed to SWM ponds before discharging to the Centre Street trunk sewer. Therefore, only 65.6.6ha contributes flows to the watercourse east of Atkinson Avenue for most storm conditions. For Tributaries 2 and 3, the total catchment areas are 33.2ha and 7.95ha respectively.

The subcatchments have been defined in sufficient detail to provide flow information for all road crossing culverts and storm inlets of interest in the study area as well as inflows to the SWM ponds. Additional subcatchment refinements have been made where the storm sewers flow in a different direction from the overland flow to account for the flow split between the major and minor systems. This occurs in the vicinity of Ponds 1, 2 and 4 and in areas adjacent to Centre Street where the storm sewers are connected to the Centre Street trunk sewer while the overland flow goes to Tributary 1.

4.3 Land Use

The existing land use in the study area was verified on a lot-by-lot basis using the satellite imagery. The area is generally fully developed. However, there is a commercial redevelopment plan proposed on the Yonge Street frontage north of Arnold Avenue. It has been assumed that the future runoff rates from this development will be controlled to existing rates by on-site SWM measures. There may also be some infilling at the east end of Pondview Road through the splitting of the adjacent lots. If this proposal is developed further, the potential impacts on the drainage systems in the areas will have to be re-evaluated at that time.

For the purpose of this study, it was assumed that there will be no significant changes to the density of the development in the area beyond some redevelopment of the large lots in the Thornridge Drive area. Since many of these lots have already been redeveloped, this would not result in a significant increase in the overall imperviousness in the area.

4.4 Hydrologic Parameters

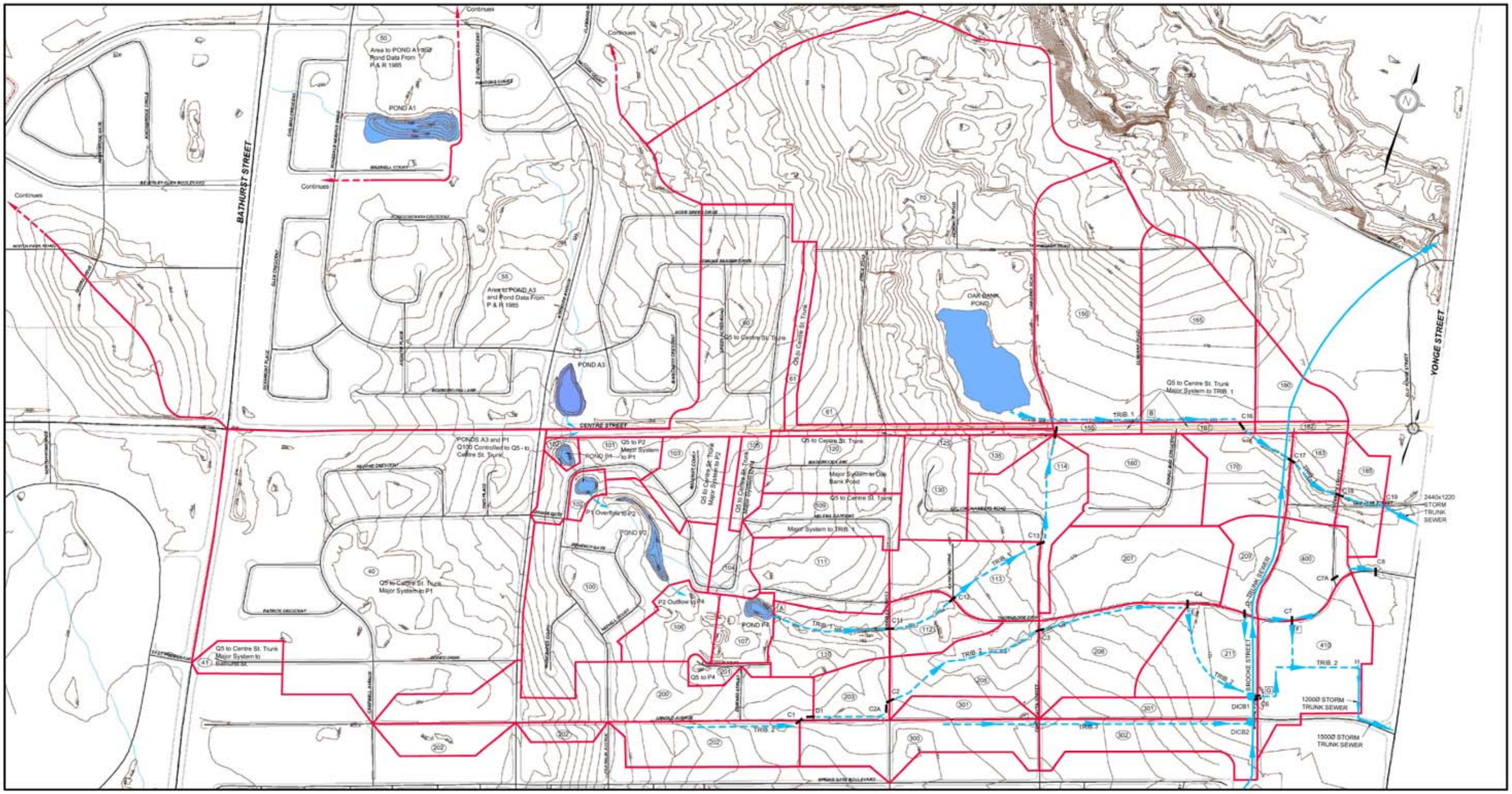
4.4.1 Subcatchment Data

The hydrologic parameters for the OTTHYMO model are summarized in Table 1. For each subcatchment, the impervious area covered by roads, driveways and roofs was measured from the satellite imagery. The directly connected impervious area was taken as 100% of the road pavement plus 50% of the driveway area in each case. Roofs were considered to be not connected. The parameters for institutional and commercial properties were measured separately.

For Tributary 1, the total imperviousness (TIMP) is 18.5% of the area and the connected imperviousness (XIMP) is 14.2% of the area. However, 40% of the Tributary 1 catchment area (85ha) is undeveloped parkland (mostly in the Oakbank Pond area). Excluding the parkland, the values are 31.4% TIMP and 24.1% XIMP. For the catchments north of Centre Street and west of Atkinson Avenue (catchments 50 and 55 in Figure 4) the total drainage area and land use breakdown were taken from the previous planning reports and data from the TRCA pond files (see Section 3.2).

For Tributary 2, the imperviousness values are 25.9%TIMP and 17.0% XIMP. For Tributary 3, the values are 33.6% TIMP and 23.6% XIMP. The NASHYD routine was used for the undeveloped catchments (park areas) in the Tributary 1 catchment. The STANDHYD routine was used for all other areas.

OTTHMO MODEL
SUBCATCHMENT BOUNDARIES



LEGEND:
TRIB. 1 TRIBUTORY #
SUBCATCHMENT #
EXISTING TRIBUTORY
SUBCATCHMENT BOUNDARY
C11 CULVERT & ID #
EXISTING TRUNK SEWERS

FIGURE 4:

4.4.2 Pond Data

The existing SWM ponds were included in the OTTHYMO model (see Figure 4). The operational data for the ponds were taken from the previous planning reports obtained from the City and TRCA. This information is included in Appendix B. For the Oakbank Pond, the stage-storage relationship was estimated from the topographic mapping. The discharge rating curve was calculated from the culvert capacity at the Oakbank Road outlet and the existing road elevations. The specific pond rating curves are given in the OTTHYMO outputs in Appendix B.

4.4.3 Channel Routing Data

A number of channel routing lengths were included in the model for each Tributary. Channel dimensions and hydraulic parameters were estimated from the field observations and the slopes were taken from the topographic mapping. However, storage effects due to flooding and backwater at culverts were not considered in the model. For determining the flows used in the flood line mapping, the channel routing elements were excluded to be consistent with TRCA policy for flood line mapping.

4.5 Existing Condition Design Flows

4.5.1 Design Storm Assessment

A number of design storm types and durations were evaluated to determine which produces the highest design flows for the study area. The storms tested were AES distributions with 6hr, 12hr and 24hr durations and a 6hr Chicago storm. The results for the 100-year storms are presented in Appendix B. It was determined that the Chicago distribution is most critical for this study. The standard 48-hour rainfall data set with 1-hour intervals was used for the Regional Storm and the 12hr SCS distribution was used for the 100-yr flood line mapping.

4.5.2 Simulated Flows

The OTTHYMO model was used to generate design flows for the existing drainage systems. The results are summarized in Tables 2A and 2B. The OTTHYMO outputs are given in Appendix B. The flows from the OTTHYMO model are also compared to the flows computed using the Rational Method from the Genivar study in Table 2A and 2B. For the local areas on Tributary 2, the flows are comparable. However, on Tributary 1, the OTTHYMO flows are significantly higher throughout.

Table 1
Post-development OTTHYMO Model Parameters

Catch. No.	Area (ha)	Imp. Ratio Connect. Imp. (%)	Imp. Ratio Total Imp. (%)	Routine Used	CN	Tp (hrs)	Pervious Areas Ia (mm)	Pervious Areas L (m)	Pervious Areas Slope (%)	Pervious Areas 'n'	Impervious Areas Ia (mm)	Impervious Areas L (m)	Impervious Areas Slope (%)	Impervious Areas 'n'
Tributary 1														
40	25.04	44	55	STANDHYD	-	-	5.0	400	2.0	0.25	1.0	400	1.0	.015
50	81.05	26	35	STANDHYD	-	-	5.0	725	2.0	0.25	1.0	725	1.0	.015
55	37.48	26	34	STANDHYD	-	-	5.0	500	2.0	0.25	1.0	500	1.0	.015
60	7.13	36	45	STANDHYD	-	-	5.0	218	2.0	0.25	1.0	218	1.0	.015
61	1.23	38	50	STANDHYD	-	-	5.0	30	2.0	0.25	1.0	30	1.0	.015
70	32.0	-	-	NASHYD	80	0.50	5.0	-	-	-	-	-	-	-
100	7.80	38	50	STANDHYD	-	-	5.0	228	2.0	0.25	1.0	228	1.0	.015
101	1.62	38	50	STANDHYD	-	-	5.0	30	2.0	0.25	1.0	30	1.0	.015
102	0.68	-	-	NASHYD	74	0.20	5.0	-	-	-	-	-	-	-
103	1.81	38	50	STANDHYD	-	-	5.0	50	2.0	0.25	1.0	50	1.0	.015
104	1.36	44	55	STANDHYD	-	-	5.0	50	2.0	0.25	1.0	50	1.0	.015
105	0.67	38	50	STANDHYD	-	-	5.0	50	2.0	0.25	1.0	50	1.0	.015
106	1.87	-	-	NASHYD	76	0.25	5.0	-	-	-	-	-	-	-
107	1.13	-	-	NASHYD	76	0.25	5.0	-	-	-	-	-	-	-
109	1.96	38	50	STANDHYD	-	-	5.0	50	2.0	0.25	1.0	50	1.0	.015
110	5.34	23	30	STANDHYD	-	-	5.0	190	2.0	0.25	1.0	190	1.0	.015
112	1.51	23	30	STANDHYD	-	-	5.0	100	2.0	0.25	1.0	100	1.0	.015
113	3.43	23	30	STANDHYD	-	-	5.0	150	2.0	0.25	1.0	150	1.0	.015
114	3.19	26	35	STANDHYD	-	-	5.0	150	2.0	0.25	1.0	150	1.0	.015
120	2.63	38	50	STANDHYD	-	-	5.0	50	2.0	0.25	1.0	50	1.0	.015
125	0.53	75	75	STANDHYD	-	-	5.0	30	2.0	0.25	1.0	30	1.0	.015
130	2.18	38	50	STANDHYD	-	-	5.0	50	2.0	0.25	1.0	50	1.0	.015
135	0.84	45	50	50STANDHYD	-	-	5.0	50	2.0	0.25	1.0	50	1.0	.015
150	7.55	23	30	STANDHYD	-	-	5.0	224	2.0	0.25	1.0	225	1.0	.015
155	0.33	75	75	STANDHYD	-	-	5.0	30	2.0	0.25	1.0	30	1.0	.015
160	3.51	23	30	STANDHYD	-	-	5.0	50	2.0	0.25	1.0	50	1.0	.015

165	5.92	23	30	STANDHYD	-	-	5.0	200	2.0	0.25	1.0	200	1.0	.015
167	0.27	75	75	STANDHYD	-	-	5.0	30	2.0	0.25	1.0	30	1.0	.015
170	2.35	-	-	NASHYD	70	0.25	5.0	-	-	-	-	-	-	-
180	1.58	23	30	STANDHYD	-	-	5.0	100	2.0	0.25	1.0	100	1.0	.015
182	0.29	75	75	STANDHYD	-	-	5.0	30	2.0	0.25	1.0	30	1.0	.015
183	1.51	15	20	STANDHYD	-	-	5.0	50	2.0	0.25	1.0	50	1.0	.015
185	1.43	23	30	STANDHYD	-	-	5.0	50	2.0	0.25	1.0	50	1.0	.015
Totals	**209.19**	**30**	**39**											
Tributary 2-3														
200	5.83	36	45	STANDHYD	-	-	5.0	200	2.0	0.25	1.0	200	1.0	.015
201	0.54	60	75	STANDHYD	-	-	5.0	30	2.0	0.25	1.0	30	1.0	.015
202	4.02	36	45	STANDHYD	-	-	5.0	160	2.0	0.25	1.0	160	1.0	.015
203	1.38	38	50	STANDHYD	-	-	5.0	50	2.0	0.25	1.0	50	1.0	.015
205	2.90	23	30	STANDHYD	-	-	5.0	80	2.0	0.25	1.0	80	1.0	.015
206	3.46	23	30	STANDHYD	-	-	5.0	150	2.0	0.25	1.0	150	1.0	.015
207	4.47	26	35	STANDHYD	-	-	5.0	175	2.0	0.25	1.0	175	1.0	.015
209	1.42	44	55	STANDHYD	-	-	5.0	30	2.0	0.25	1.0	30	1.0	.015
211	2.93	23	45	STANDHYD	-	-	5.0	140	2.0	0.25	1.0	140	1.0	.015
300	3.10	36	45	STANDHYD	-	-	5.0	75	2.0	0.25	1.0	75	1.0	.015
301	2.19	44	55	STANDHYD	-	-	5.0	50	2.0	0.25	1.0	50	1.0	.015
302	2.66	36	45	STANDHYD	-	-	5.0	75	2.0	0.25	1.0	75	1.0	.015
400	2.15	36	45	STANDHYD	-	-	5.0	50	2.0	0.25	1.0	50	1.0	.015
410	4.08	23	30	STANDHYD	-	-	5.0	75	2.0	0.25	1.0	75	1.0	.015
Totals	**41.76**	**32**	**42**											

Table 2A
Existing Design Flows Tributary 1

Flow Node (see Fig. 4)	Location	Ott-hymo Hyd ID	Chicago 6-hr DT=5min. [1]						SCS12hr	Genivar		Comments
			2-yr	5-yr	10-yr	25-yr	50-yr	100-yr	100-yr	100-yr	Reg. St.	
			(m3/s)	(m3/s)	(m3/s)	(m3/s)	(m3/s)	(m3/s)	(m3/s)	(m3/s)	(m3/s)	
A	d/s of P4	2110	0.27	0.38	0.49	0.66	0.90	1.09	1.16	-	2.61	
C11	Charles St.	1111	0.41	0.60	0.84	1.17	1.59	1.78	2.07	1.09	2.99	
C12	Thornridge Rd.	9112 (1112)	0.46	0.71	0.99	1.36	1.95	2.21	2.46	1.42	3.18	
C13	Calvin Chambers Rd.	9113 (1113)	0.59	0.93	1.27	1.76	2.51	2.89	3.32	1.47	3.60	
C14	Centre St.	9114 (1114)	0.72	1.13	1.55	2.15	3.07	3.57	4.13	1.71	4.00	
C15	Outflow from Oakbank Pond	8070	0.26	0.33	0.38	0.43	0.49	0.52	0.52	-	5.46	
B	Elmbank Rd.	1155	1.16	1.69	2.26	3.20	4.53	5.18	6.15	3.50	9.08	
C16	Centre St.	9167 (1167)	1.32	2.06	2.77	3.80	5.70	6.57	7.89	4.03	10.07	
C17	Brooke St.	9170 (1170)	1.34	2.13	2.87	3.96	6.04	6.97	8.39	-	10.31	
C18	Elizabeth St.	1183	1.46	2.38	3.23	4.47	6.73	7.70	9.23	-	10.64	
C19	Old Jane St.	1185	1.50	2.47	3.38	4.68	7.01	8.04	9.56	4.36	10.80	

Note: [1] Model contains channel routing elements for Chicago design storm simulations.

Table 2B

Existing Design Flows Tributaries 2 and 3

Flow Node (see Fig. 4)	Location	Ott-hymo Hyd ID	Chicago 6-hr DT=5min. [1]						SCS12hr	Genivar		Comments
			2-yr	5-yr	10-yr	25-yr	50-yr	100-yr	100-yr	100-yr	Reg. St.	
			(m3/s)	(m3/s)	(m3/s)	(m3/s)	(m3/s)	(m3/s)	(m3/s)	(m3/s)	(m3/s)	
C1	Arnold St.	9202 (202)	0.18	0.33	0.46	0.59	0.83	0.93	1.03	-	0.52	
D1	Arnold St.- N. Driveway	1202	0.35	0.62	0.92	1.20	1.86	2.11	2.37	2.49	1.23	
C2	Charles St.	1203	0.40	0.71	1.05	1.36	2.14	2.44	2.70	2.51	1.41	
C3	Clarkehaven	1205	0.49	0.88	1.32	1.80	2.75	3.07	3.39	2.51	1.77	
C4	Thornridge Rd.	207	0.11	0.21	0.32	0.48	0.70	0.81	0.79	0.77	0.52	
E	d/s of C4	9211 (1211)	0.52	1.27	2.03	2.88	4.15	4.77	5.42	-	3.07	
C5	Thornridge Rd.-Brooke St.	209	0.07	0.14	0.19	0.24	0.31	0.35	0.36	0.62	0.18	
C6	u/s of C6	2209	0.68	1.60	2.67	3.85	5.54	6.50	7.62	-	3.93	
G	d/s C6 east of Brooke St.	9309	0.33	0.79	1.24	2.11	3.73	5.32	6.43	-	2.74	
C7	Thornridge east	400	0.12	0.22	0.29	0.38	0.46	0.51	0.53	-	0.27	
F	d/s of C7	1400	0.41	0.91	1.44	2.38	4.11	5.79	6.90	-	3.00	
I1	Culvert Inlet	1401	0.49	1.16	1.83	2.93	4.97	6.81	7.83	-	3.51	Existing 1500 dia. Storm sewer to Yonge St.
DICB1	Brooke St. at Arnold	9310	0.68	1.08	1.18	1.18	1.19	1.19	1.25	-	1.20	Max. Capacity DICB1~1.18m3/s per 600mm connection
DICB2	Arnold/Brooke St.- to storm sewer	9311	0.35	0.35	0.35	0.35	0.35	0.35	0.35	-	0.36	Capacity of connecting pipe
	Total Brooke St. inflow	9312	0.86	1.43	1.53	1.53	1.54	1.54	1.60	-	1.55	

Note: [1] Model contains channel routing elements for Chicago design storm simulations.

5 Hydraulic Analysis

5.1 Existing Culverts

5.1.1 Method

The existing road culverts associated with the three watercourses in the study area were analysed with the CulvertMaster model for 25-year, 50-year and 100-year return period flows to assess their capacity compared to the computed design flows. Culvert sizes and invert elevations were taken from the survey data. Tailwater elevations were based on the calculated normal flow depths in the downstream channels.

5.1.2 Results of Analysis

The results of the culvert capacity analysis are summarized in Table 3. The CulvertMaster outputs are given in Appendix C.

The upstream culverts on Tributary 1 south of Centre Street (C11 to C13) have adequate capacity, although two of them (C11 and C12) are in poor condition. The culverts at the downstream end at Brooke Street and Elizabeth Street (C17 and C18) are somewhat undersized, even for the 25-year flow. At the Brooke Street structure (C18), the road may overtop for the 25-year flow. The Elizabeth Street culvert (C17) may overtop for the 50-year flow. These are both heritage structures that are in relatively good condition. The need to upgrade the capacity of these structures was investigated further using the HEC-RAS analysis (see Section 5.2).

Virtually all of the culverts on Tributary 2 east of Charles Street (C3 to C7) are undersized for the 25-year flow and the road is overtopped at all locations for the 100-year flow.

5.2 Existing Flood Line Analysis

5.2.1 Method

Flood lines were developed for the larger of the SCS 12hr 100-year or Regional Storm flows using the HEC-RAS model. <u>The Regional Storm flows were used for Tributary 1 while the 100-year flows were used for Tributaries 2 and 3.</u> The flow data were obtained from the hydrologic analysis for the road project (see Tables 2A and 2B). The model cross sections were derived from the TRCA mapping while the culvert data were taken from the project survey data. A field inspection was also undertaken to verify the culvert data and to determine n-values and other hydraulic modelling parameters.

Details of the HEC-RAS and flood line mapping work are presented in Appendix D.

5.2.2 Existing Flood Lines

The results of the flood line analysis for the existing conditions are shown in Figure 5. The most significant flooding area is on Tributary 2 east of Brooke Street south of Thornridge Drive. At this location, the Tributary 2 channel has been significantly obstructed by infilling and construction in the rear of the lots. There is also a significant flooding area at the intersection of Brooke Street and Arnold Avenue. Upstream of Brooke Street on Tributary 2, one house and about half of Thornridge Drive between Clarkehaven and Brooke Street are flooded.

On Tributary 1, the flood line inundates Centre Street from west of Thornbank Road to Oakbank Road along with a number of houses. South of Centre Street to west of Clarkehaven Avenue, three additional houses are within the flood line.

6 Existing Deficiencies

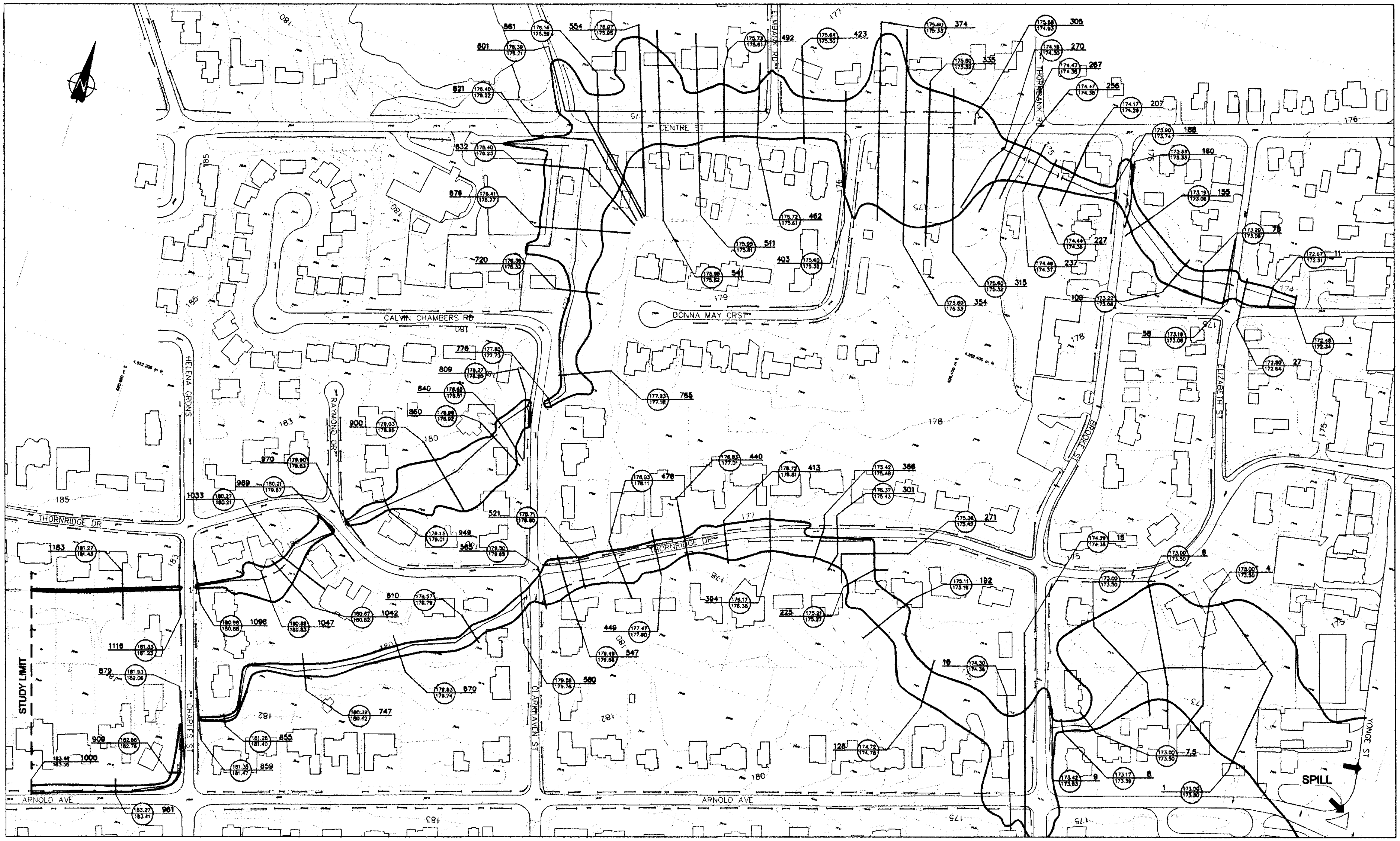
The identified deficiencies are similar to those from the Thornhill Storm Drainage Improvement Study for Tributaries 2 and 3. Additional deficiencies have been identified on Tributary 1 due to the larger design flows used in this study. However, these areas are not reported to have significant flooding problems and are therefore not considered a high priority for remediation.

The most significant deficiency is in the channel on Tributary 2 east of Brooke Street. This is the area known to have frequent flooding problems. The watercourse in this location has been greatly disturbed by construction and regrading on the rear lots of the houses. The large culverts on Tributary 1 at Brooke Street and Old Jane Street are both somewhat undersized for the100-year storm. There are also numerous other culverts with capacity deficiencies throughout the area. The culvert deficiencies are identified Table 3.

Table 3
Existing Culvert Analysis

Culv. No.	Location	Existing Culvert	U/S Inv.	D/S Inv.	U/S Obv. Elev.	Min. Road Elev.	Cover to u/s Invert	Cover to u/s Obvert	Hydraulic Analysis (CulvertMaster) [1] 25-yr Q	25-yr HW	25-yr Clearance	25-yr Freeboard	50-yr Q	50-yr HW	50-yr Clearance	50-yr Freeboard	100-yr Q	100-yr HW	100-yr Clearance	100-yr Freeboard	Condition Assess-ment [2]
Tributary 2																					
C2	Charles St.	1.63m x 1.12m CSP Arch	181.46	181.12	182.58	183.28	1.82	0.70	1.36	182.32	0.26	0.96	2.14	182.63	-0.05	0.65	2.44	182.87	-0.29	0.41	Good
C2A	Charles St. Driveway (#120 Arnold Ave.)	1.63m x 1.12m CSP Arch	181.69	181.43	182.81	183.45	1.76	0.64	1.36	182.53	0.28	0.92	2.14	182.63	0.18	0.82	2.44	182.74	0.07	0.71	Good
C3	Clarkehaven St. south of ThornridgeDr. (9+980)	1.15m 0.82m CSP Arch	178.21	178.05	179.03	180.32	2.11	1.29	1.8	179.37	-0.34	0.95	2.75	180.23	-1.20	0.09	3.07	180.37	-1.34	-0.05	Replace (City + Genivar)
C6	Brooke St. north of Arnold (9+873)	2 @ 0.8m CSP	173.39	173.39	174.19	174.32	0.93	0.13	2.11	174.39	-0.20	-0.07	3.73	174.45	-0.26	-0.13	5.32	174.48	-0.29	-0.16	Good
Tributary 1																					
C11	Charles St. south of Thornridge (9+953)	1800mm CSP	180.85	180.52	182.65	182.47	1.62	-0.18	1.17	181.72	0.93	0.75	1.59	181.88	0.77	0.59	1.78	181.94	0.71	0.53	Replace (City + Genivar)
C12	Thornridge Dr. west of Raymond (1+374)	1750mm CSP	179.38	178.99	181.13	181.17	1.78	0.03	1.36	180.33	0.80	0.83	1.95	180.53	0.60	0.63	2.21	180.62	0.51	0.54	Replace (City + Genivar)
C13	Calvin Chambers Dr. North of Thornridge (10+134)	1.63m x 1.12m CSP Arch	177.10	176.96	178.22	178.86	1.76	0.64	1.76	178.03	0.19	0.83	2.51	178.3	-0.08	0.56	2.89	178.45	-0.23	0.41	Repair (City)
C17	Brooke St. north of Old Jane St. (10+298)	1.85m x 0.9m Conc.	172.68	172.55	173.58	174.36	1.68	0.78	3.96	174.03	-0.45	0.33	6.04	174.58	-1.00	-0.22	6.97	174.64	-1.06	-0.28	Repair (City)
C18	Elizabeth St. north of Old Jane St. (10+163)	1.85m x 0.9m Conc.	171.95	171.91	172.85	173.38	1.43	0.53	4.47	173.42	-0.57	-0.04	6.73	173.56	-0.71	-0.18	7.70	173.61	-0.76	-0.23	Repair (City)
Other Road Culverts																					
C4	Thornridge Dr. between Clarkehaven and Brooke St. (1+772)	0.7m x 0.4m CSP Arch	175.16	175.09	175.56	176.19	1.03	0.63	0.48	176.14	-0.58	0.05	0.7	176.22	-0.66	-0.03	0.81	176.24	-0.68	-0.05	Replace (Genivar)
C5	Thornridge Dr. west of Brooke St. (1+919)	0.4m CSP	175.49	175.48	175.89	176.11	0.61	0.21	0.24	176.12	-0.23	-0.02	0.31	176.13	-0.24	-0.03	0.35	176.13	-0.24	-0.03	Replace (Genivar)
C7	Thornridge Dr. at 2+018	0.45m CSP	173.72	173.47	174.17	174.34	0.61	0.16	0.38	174.38	-0.21	-0.04	0.46	174.39	-0.22	-0.05	0.51	174.39	-0.22	-0.05	Replace (Genivar)
C7A	Elizabeth St. north of Thornridge (10+008)	400mm CSP	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	Replace (Genivar)
C8	Thornridge Dr.between Elizabeth St.and Yonge St. (2+170)	400mm CSP	176.12	175.96	176.52	176.51	0.39	-0.01	-	-	-	-	-	-	-	-	-	-	-	-	Good

Notes: [1] Clearance is the distance between the water elevation and the u/s culvert obvert. Freeboard is the distance from the road elevation to the water elevation.
[2] Previous condition assessments by the City of Vaughan and the Thornhill Drainage Study by Genivar.



Flood Line - Existing Conditions

Figure 5

7 Proposed Drainage System Improvements

7.1 Option 1

7.1.1 Flood Relief Works

The primary relief option is based on the recommendations of the Thornhill Storm Drainage Study with a combination of culvert improvements, relief sewers and flow diversion. This option makes use of the opportunities afforded by the proposed road improvements to construct the drainage improvements at the same time. Drainage improvements outside of the road improvement area were not considered at this time. Only opportunities within the road improvement area (i.e. south of Centre Street) were evaluated to reduce flooding on Tributary 1

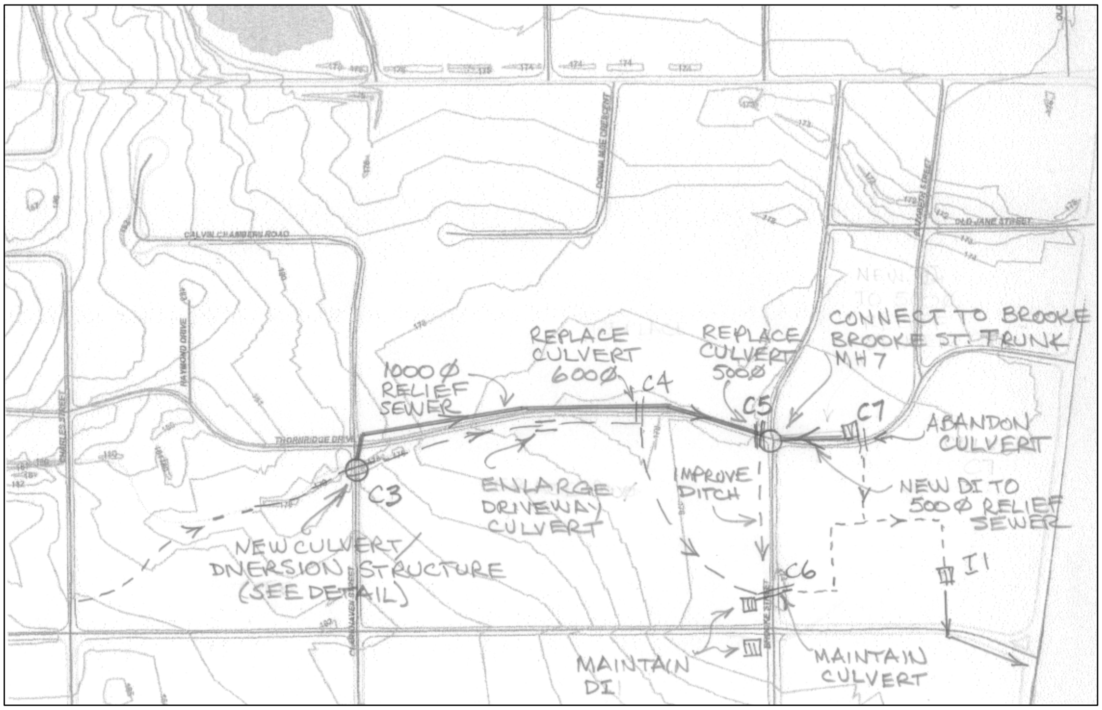
As stated previously, it is assumed that the Gallanough Park SWM pond will be expanded as part of the flood control scheme and the design flows from the pond will be controlled to the level reported in the Thornhill Storm Drainage Study. Without this pond, the additional capacity in the Brooke Street trunk to accept flows from the Thornridge Drive area may be limited. This is discussed further in Section 7.2.1 In addition to the pond, the other primary elements of this option are:

- Construction of a relief sewer on Thornridge Drive from Charles Street to Brooke Street to divert flows from Tributary 2 to the Brooke Street trunk sewer. This will reduce the flows through the rear lots on Tributary 2 and to the flooding areas east of Brooke Street in particular.
- Elimination of the damaged Culvert C7 on Thornridge Drive and the construction of a diversion sewer to Brooke Street. This will further reduce the flows on Tributary 2 east of Brooke Street.
- Replacement of undersized and damaged culverts at other locations

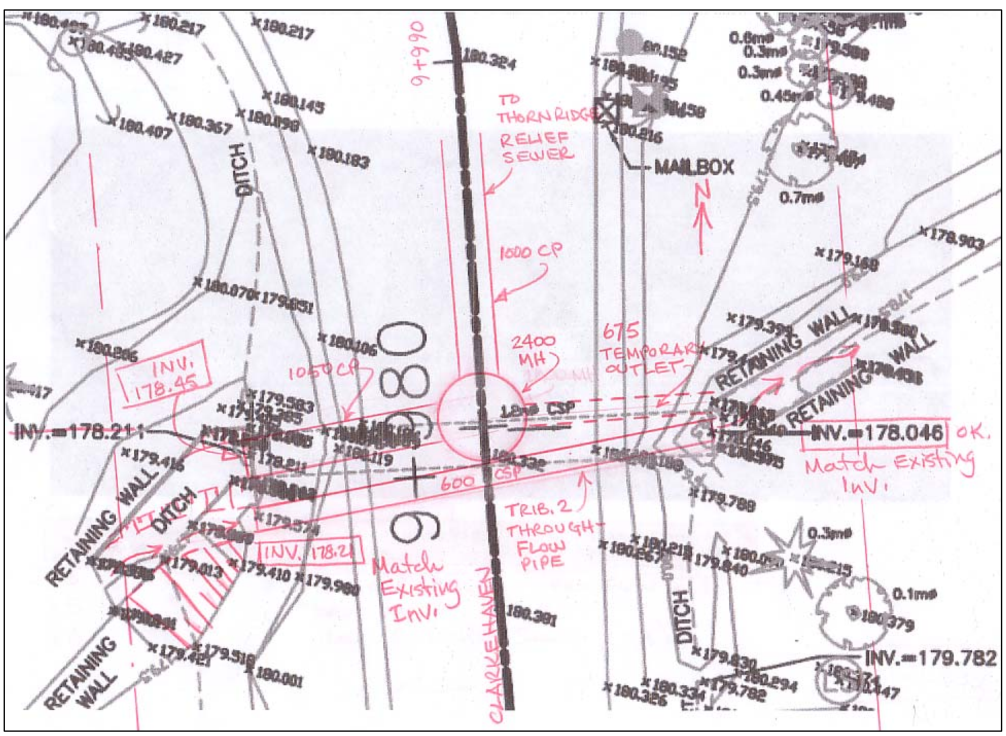
Relief Option 1 is shown schematically in Figure 6. The individual elements in this relief option are listed in Table 4.

7.1.2 Other Drainage Improvements

Most of the existing CSP road culverts in the study area are 30 to 40 years old and nearing the end of their normal design life. In addition, they are also installed at very shallow depths (typically 0.15m). This provides insufficient depth for road reconstruction, which requires a road structure depth of about 0.54m. Therefore, it is proposed to replace all of the smaller CSP road culverts, regardless of their condition, with new CSP culverts. The existing twin 800mm diameter CSP pipes at culvert C6 are also too shallow for the new road construction. It is proposed to replace these culverts with a new 1800mm x 500mm concrete box structure. All of these culvert replacements are also listed in Table 4 as part of Option 1.



a) Schematic



b) Culvert 3 Detail

Relief Option 1

Figure 6

Table 4
Option 1 Components

Item No.	Location	Description	Comments
1	Brooke St. north of Old Jane St. (10+298)	Rehabilitate concrete structure	Heritage Structure (C17) Tributary 1
2	Elizabeth St. north of Old Jane St. (10+163)	Rehabilitate concrete structure	Heritage Structure (C18) Tributary 1
3	Old Jane St. east of Elizabeth St. (20+140)	Rehabilitate concrete structure	Inlet to C19 Tributary 1
4	Clarkehaven St. south of ThornridgeDr. (9+980)	New concrete culvert 12m @ 600mm dia.	Base flow culvert - u/s invert 178.22m
5	Clarkehaven St. south of ThornridgeDr. (9+980)	New concrete culvert 6m @ 1050mm dia.	Diversion Sewer inlet - u/s invert 178.52m
6	Clarkehaven St. south of Thornridge Dr. (9+980)	2400mm dia. Manhole	Connected to 1.05m culvert and 1.0m relief sewer
7	Clarkehaven St.from 9+980 to Thornridge Dr. intersection (10+000)	New concrete storm sewer 20m @ 1.0m Dia.	Relief sewer
8	Thornridge Dr. intersection (1+534) to north east shoulder (1+543)	New concrete storm sewer 10m @ 1.0m Dia.	Relief sewer
9	Thornridge Dr. from Clarkehaven to 1+772	New concrete storm sewer 238m @ 1.0m Dia.	Relief sewer
10	Thornridge Dr. from 1+772 to Brooke St. (1+924)	New concrete storm sewer 152m @ 1.35m Dia.	Relief sewer
11	Thornridge Dr. in north ditch at 2+018	New DIMH	Connection to relief sewer; replaces C7
12	Thornridge Dr. from 2+018 to Brooke St. (1+924)	New concrete storm sewer 94m @ 0.5m Dia.	Relief sewer - Abandon C7
13	Driveway at Thornridge Dr. #65 (south side)	New culvert 12m @ 1.05m x 0.7m CSP Arch	Replace existing culvert
14	Thornridge Dr. between Clarkehaven and Brooke St. (1+772)	New culvert 12m @ Twin 450mm Dia. CP	Replace existing culvert (C4)
15	Thornridge Dr. west of Brooke St. (1+919)	New culvert 12m @ 500mm Dia. CP	Replace existing damaged culvert (C5)
16	Elizabeth St. north of Thornridge (10+008)	New culvert 15m @ 400mm Dia. CP	Replace existing damaged culvert; Deepen ditch.
17	Thornridge Dr.between Elizabeth St.and Yonge St. (2+170)	New culvert 20m @ 400mm Dia. CP	Replace existing damaged culvert (C8)
18	West side of Brooke St. from Thornridge Rd to 9+870	Improved ditching; erosion protection	Conveys discharge from C5 to C6

Table 4
Option 1 Components

Item No.	Location	Description	Comments
19	Brooke St. north of Arnold Ave. (9+873)	New 1.8m x 0.61m Conc. Box culvert	Replacement to provide sufficient depth for road reconstruction.
20	Charles St. south of Thornridge (9+953)	New culvert 14.2m @ 1800mm x 900mm Conc. Box	Replace existing damaged culvert (C11) Tributary 1
21	Thornridge Dr. west of Raymond (1+374)	New culvert 14.4m @ 1800mm x 900mm Conc. Box	Replace existing damaged culvert (C12) Tributary 1
22	Calvin Chambers Dr. North of Thornridge (10+134)	Repair existing 1.63mx1.12m CSP arch pipe	(C13) Tributary 1
23	Arnold St. at Brooke St. (south west corner) (9+815)	New standard Ditch Inlet	Replace existing ditch inlets (DICB2) Tributary 3
24	Clarkehaven at Calvin Chambers Rd. (10+180)	New culvert 15m @ 400mm Dia. CP	Upgrade existing CSP road culvert
25	Clarkehaven north side of Thornridge intersection (10+010)	New culvert 15m @ 400mm Dia. CP	Upgrade existing CSP road culvert
26	Raymond Dr. north side of Thornridge intersection (10+009)	New culvert 15m @ 400mm Dia. CP	Upgrade existing CSP road culvert
27	Thornridge Dr. west of Charles (1+242)	New culvert 15m @ 400mm Dia. CP	Upgrade existing CSP road culvert
28	Charles St. north of Thornridge (10+052)	New culvert 13m @ 400mm Dia. CP	Upgrade existing CSP road culvert
29	Clarkehaven north side of Arnold intersection (9+831)	New culvert 13m @ 400mm Dia. CP	Upgrade existing CSP road culvert
30	Old Jane St. west of Elizabeth St. intersection (20+086)	New culvert 15m @ 400mm Dia. CP	Upgrade existing CSP road culvert

7.2 Analysis of Drainage System Improvements

7.2.1 Brooke Street Trunk Sewer

To verify that the Brooke Street sewer can accommodate additional flow, a hydraulic grade line analysis was done on the sewer using a range of design flows. The details of the analysis are given in Appendix E.

In the previous Thornhill Storm Drainage Study report by Genivar, the upstream inflow from the proposed Gallanough Park pond was13.97m^3/s and at Centre Street it was 13.48m^3/s. The peak flow reduction from the pond was 3.96m^3/s. The additional inflows at Arnold Street and the Thornridge Relief sewer connections in the Genivar report were 3.96m^3/s (i.e. exactly equal to the peak flow reduction from the pond) giving a total flow in the Brooke St. trunk sewer of 31.41m^3/s at the East Don River outlet. With this level of flow, the sewer is basically flowing full without surcharge.

By adding incremental flows at the Thornridge Relief sewer location, it was found that the trunk sewer may be able to accept additional inflows of up to 10.0m^3/s (with a total flow of over 41m^3/s to the East Don River) before the HGL elevation rises to the street elevation at Arnold Avenue. However, since no information is available on the previous pond analysis and the final pond design capacity has yet to be confirmed, it is preferable to maintain some capacity and flexibility for the future pond design. As a result, the diversion of about 4.0m^3/s as proposed in the Thornhill Drainage Improvement Study is considered appropriate and acceptable, resulting in minor surcharge of the trunk sewer after construction of the proposed Gallanough Park SWM pond.

7.2.2 Revised Design Flows

The Option 1 relief concept is based on diverting flows from the Thornridge Area to the Brooke Street trunk after the Gallanough Park SWM pond is constructed. The design flows resulting from this scheme were simulated with the OTTHYMO model. The model outputs are given in Appendix B. The design flows are summarized in Table 5.

With this scheme, the flow diversion to the Brooke Street trunk for the 100-year design flood is 4.14m^3/s. This is comparable to the diversion flow assumed in the Genivar Report (3.96m^3/s). The proposed measures will also reduce the 100-year peak flows east of Brooke Street from 6.81m^3/s to 4.43m^3/s.

7.2.3 Flood Line Analysis

The flood line resulting from the implementation of the Option 1 works is shown in Figure 7. The HEC-RAS analysis is reported in Appendix D. On Tributary 2, there is a reduction in the flood area along Thornridge Drive and the road is no longer overtopped. However, there is no significant improvement in the flooding area east of Brooke Street where the reduced flows still exceed the capacity of the existing channel and the 1,200mm outlet sewer.

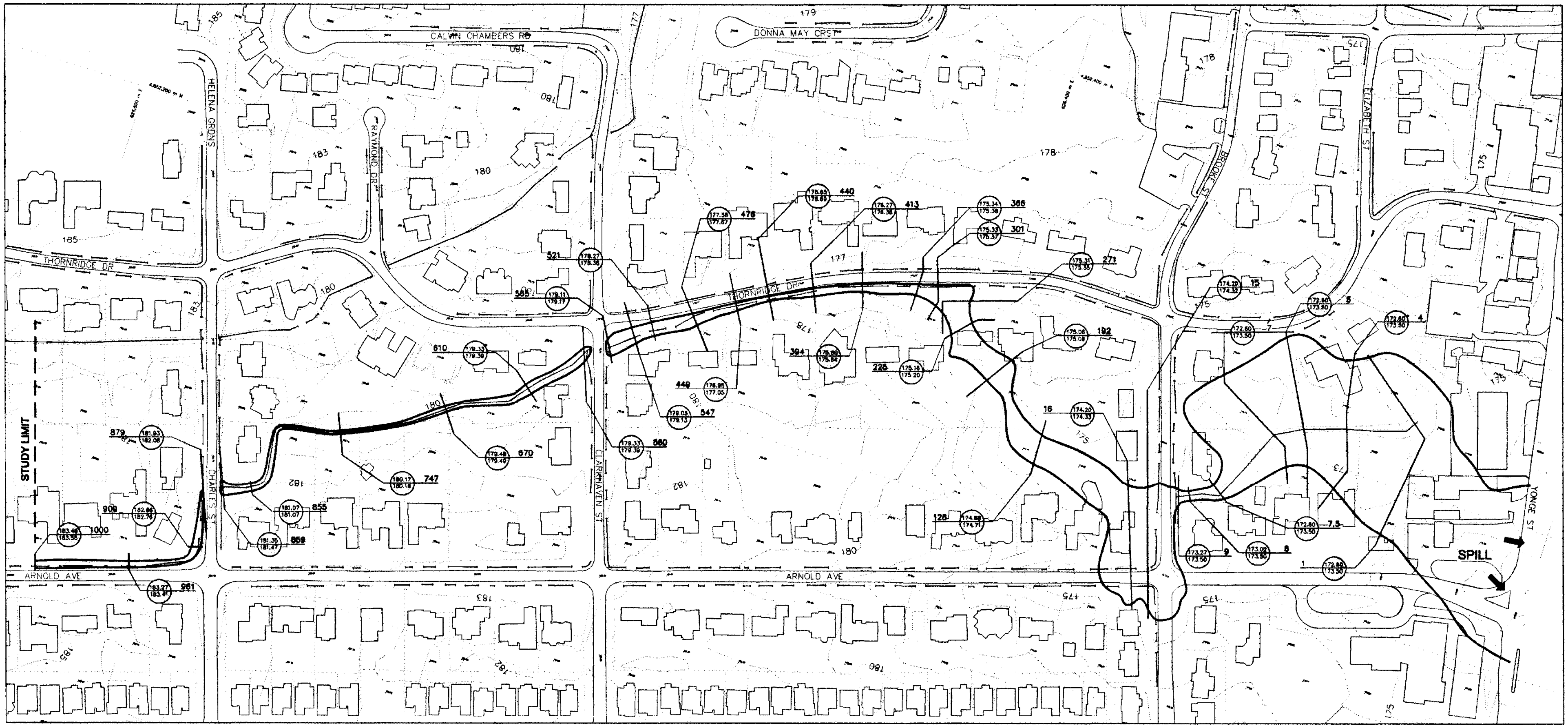
On Tributary 1, it was determined using the HEC-RAS model that enlarging the culverts at Brooke Street and Old Jane Street (C17 and C18) will have no significant benefit to the upstream flood elevations on Centre Street. Since these culverts are in good condition, the replacement of these culverts is not required at this time.

Table 5

Relief Option 1 - Design Flows - Tributaries 2 and 3

Flow Node (see Fig. 4)	Location	Ott-hymo Hyd ID	Chicago 6-hr DT=5min. [1]						SCS12hr	Genivar		Comments
			2-yr	5-yr	10-yr	25-yr	50-yr	100-yr	100-yr	100-yr	Reg. St.	
			(m3/s)	(m3/s)	(m3/s)	(m3/s)	(m3/s)	(m3/s)	(m3/s)	(m3/s)	(m3/s)	
C1	Arnold St.	9202 (202)	0.18	0.33	0.46	0.59	0.83	0.93	1.04	-	0.52	
D1	Arnold St.-N. Driveway	1202	0.35	0.62	0.92	1.20	1.86	2.11	2.39	2.49	1.23	
C2	Charles St.	1203	0.40	0.71	1.05	1.36	2.14	2.44	2.72	2.51	1.41	
C3	Clarkehaven	1205	0.49	0.88	1.32	1.80	2.75	3.07	3.42	2.51	1.77	
	d/s of C3	9313	0.22	0.36	0.51	0.59	0.73	0.78	0.83	-	0.59	600 CP inv=178.22
	Thornridge Relief Culvert	9313	0.18	0.46	0.79	1.15	1.89	2.20	2.59	-	1.18	1050 CP inv=178.37
C4	Thornridge Rd.	207	0.11	0.21	0.32	0.48	0.70	0.81	0.80	0.77	0.52	
E	C4 to C6	9211 (1211)	0.04	0.81	1.26	1.76	2.31	2.62	2.88	-	1.89	
C5	Thornridge Rd.-Brooke St.	209	0.07	0.14	0.19	0.24	0.31	0.35	0.36	0.62	0.18	
C6	Inlet to C6	2209	0.57	1.17	1.96	2.79	4.03	4.61	5.10	-	2.76	
G	d/s C6 east of Brooke St.	9309	0.00	0.20	0.84	1.61	2.84	3.44	3.89	-	1.58	
C7	Thornridge east	400	0.12	0.22	0.29	0.38	0.46	0.51	0.53	-	0.27	
I1	Culvert Inlet	1400	0.10	0.45	1.26	2.18	3.69	4.43	4.83	-	2.08	Existing 1500 dia. Storm sewer to Yonge St.
DICB1	Brooke St. at Arnold	9310	0.57	0.98	1.12	1.18	1.18	1.18	1.21	-	1.18	Limiting Capacity per connecting pipe
DICB2	Arnold/Brooke St.- to storm sewer	9311	0.18	0.35	0.35	0.35	0.35	0.36	0.35	-	0.36	Limiting Capacity per connecting pipe
	Total Brooke St. inflow	9001	1.02	1.89	2.46	2.95	3.80	**4.14**	**4.69**	-	2.98	Genivar Q100=3.96

Note: [1] Model contains channel routing elements for Chicago design storm simulations.



Flood Lines – Relief Option 1

Figure 7

7.3 Option 2

7.3.1 Flood Relief Works

The flood control measures in Option 1 do not solve all of the existing flooding problems in the area. The flooding on Tributary 1 is primarily the result of undersized culverts on Centre Street and the driveways on the north side of the street. However, except for the flooding of Centre Street itself, there are only a few houses affected. Since these areas are not included in the present road reconstruction project, drainage improvements at these locations are not proposed at this time. The improvement of drainage conditions at these locations can be carried out as opportunities arise with future road improvements and redevelopment or when the drainage structures have reached the end of their design life.

If the additional surcharge capacity of the Brooke Street trunk is confirmed, it may be possible to consider a relief sewer along the south side of Centre Street connected to the Brooke Street trunk. This can be evaluated as part of the overall assessment for the Gallanough Park pond EA, as discussed in Section 8.5.

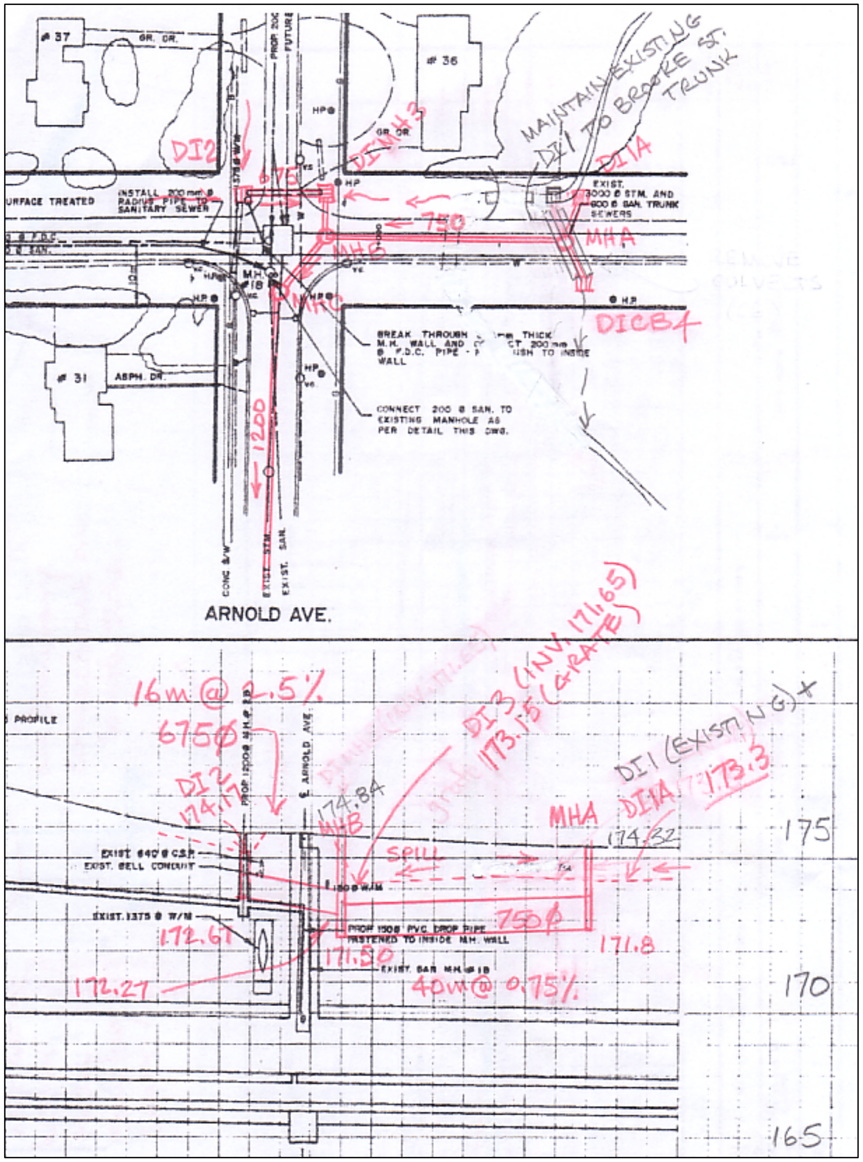
Of more immediate concern is the significant flooding east of Brooke Street on Tributary 2. The relief measures considered in Option 1 do not significantly improve the situation because the problem is caused by the lack of capacity at the outlet and the lack of a suitable channel through private property.

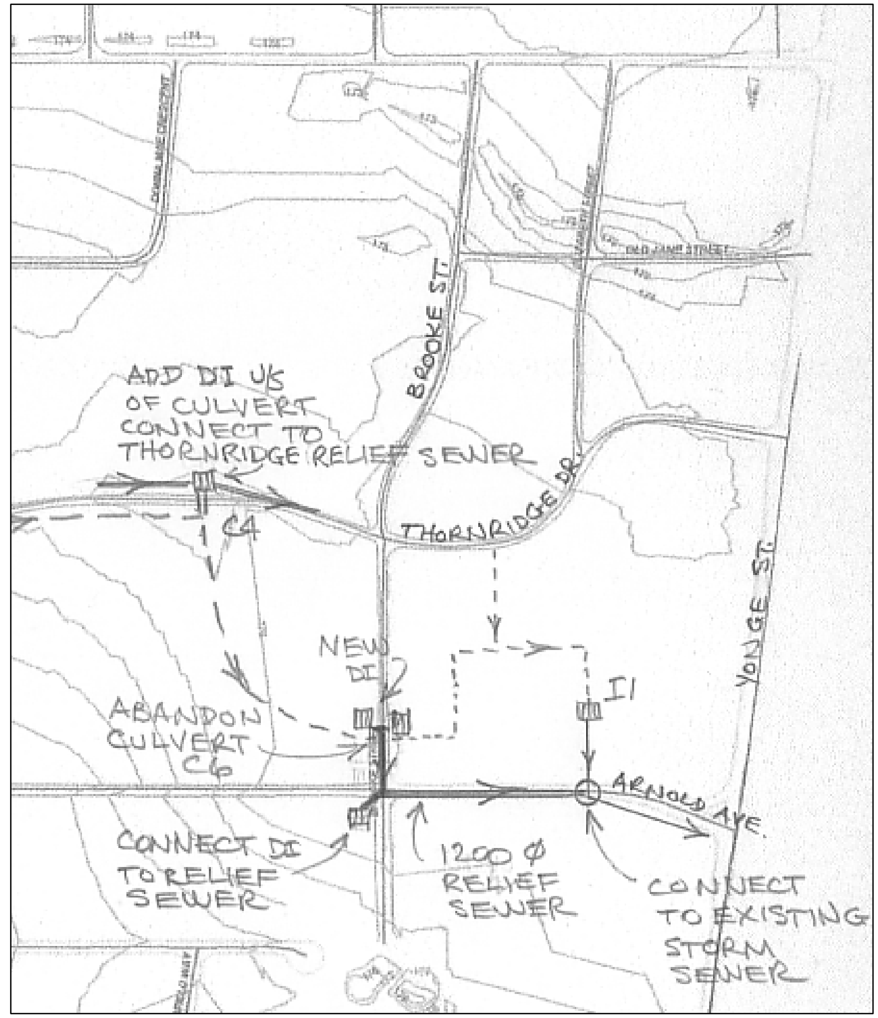
To eliminate this flooding, additional relief measures (designated as Option 2) have been considered to complement the Option 1 measures. Relief Option 2 is shown schematically in Figure 8. Option 2 is primarily a relief sewer (about 1,200mm in diameter) from upstream of the culvert on Brooke Street north of Arnold Avenue (culvert C6) to the existing 1.5m diameter Arnold Avenue trunk storm sewer west of Yonge Street (see Figure 8). Since the Arnold Avenue trunk sewer is the existing outlet for Tributary 2, the relief sewer will result in a minor re-routing of flows around the bottleneck and not a diversion.

The Tributary 3 ditch inlet at Arnold Avenue and Brooke Street (DICB2) would also be connected to the new Arnold Avenue relief sewer, which would free up capacity in the Brooke Street trunk for additional inflows from Thornridge Drive. To take advantage of this additional capacity, a ditch inlet connection to the Thornridge relief sewer at culvert C4 (between Clarkehaven Street and Brooke Street) is also proposed as part of Option 2. The Thornridge Drive relief sewer (Option 1) has been designed to accommodate this potential additional inflow.

The Option 2 measures are listed in Table 6.

Table 6 Option 2 Components			
Item No.	**Location**	**Description**	**Comments**
1	South west corner of Brooke St. at Arnold Ave. (9+815 west)	Remove existing DICB; Seal connection to Brooke St. trunk sewer.	Replaced by new DI connected to Arnold Ave. relief sewer.
2	Brooke St. north of Arnold Ave. (9+873 - west)	New ditch inlet and 7.0m of 600mm lead	New DI to relief sewer; Maintain existing DI to Brooke St. Trunk sewer.
3	Brooke St. north of Arnold Ave. (9+873 - east)	Catch basin and 7.0m of 300mm lead	Collect local runoff from east side of Brooke St.
4	Brooke St. north of Arnold Ave. (9+870 to 9+830)	New concrete storm sewer 40m @ 750mm Dia.	Relief sewer
5	Brooke St. north of Arnold Ave. (9+830 to 9+830 west)	New concrete storm sewer 7m @ 750mm Dia.	Relief sewer
6	Brooke St. north of Arnold Ave. (9+830 - west)	New ditch inlet manhole	Relief sewer
7	From Brooke St. 9+830 west to south west corner of Brooke St. at Arnold Ave. (9+815 west)	New concrete storm sewer 15m @ 750mm Dia.	Relief sewer
8	From Brooke St. north Arnold Ave. (9+830) to Arnold Ave east of Brooke St. (20+010)	New concrete storm sewer 15m @ 1200mm Dia.	Relief sewer
9	From Arnold Ave. (20+010) to Arnold Ave (20+170+/-)	New concrete storm sewer 160m @ 1200mm Dia.	Connect to existing 1500mm dia storm sewer
10	Thornridge Dr. at 1+772 - north (culvert C4)	Ditch inlet and 3m of 500mm lead	Connect to Thornridge Dr. relief sewer.





Option 2 Schematic and Details

Figure 8

Table 7
Relief Option 2 - Design Flows - Tributaries 2 and 3

Flow Node (see Fig. 4)	Location	Ott-hymo Hyd ID	Chicago 6-hr DT=5min. [1]						SCS12hr	Genivar		Comments
			2-yr	5-yr	10-yr	25-yr	50-yr	100-yr	100-yr	100-yr	Reg. St.	
			(m3/s)	(m3/s)	(m3/s)	(m3/s)	(m3/s)	(m3/s)	(m3/s)	(m3/s)	(m3/s)	
C1	Arnold St.	9202 (202)	0.18	0.33	0.46	0.59	0.83	0.93	1.04	-	0.52	
D1	Arnold St.-N. Driveway	1202	0.35	0.62	0.92	1.20	1.86	2.11	2.39	2.49	1.22	
C2	Charles St.	1203	0.40	0.71	1.05	1.36	2.14	2.44	2.72	2.51	1.39	
C3	Clarkehaven	1205	0.49	0.88	1.32	1.80	2.75	3.07	3.42	2.51	1.75	
	d/s of C3	9313	0.22	0.36	0.51	0.59	0.73	0.78	0.83	-	0.59	600 CP inv=178.22
	Thornridge Relief Culvert	9313	0.18	0.46	0.79	1.15	1.89	2.20	2.59	-	1.16	1050 CP inv=178.37
DI4	Inflow to Thornridge Rd.Relief Sewer at C4	9207	0.11	0.20	0.32	0.47	0.59	0.62	0.62	-	0.52	
	Thornridge Relief Sewer from west	9314	0.26	0.63	1.07	1.62	2.46	2.79	3.22	-	1.67	
C7	Thornridge Relief Sewer from east	400	0.12	0.22	0.29	0.38	0.46	0.51	0.53	-	0.28	
	Total Brooke St. inflow at Thornridge	9001	0.36	0.75	1.27	1.88	2.83	3.24	**3.75**	-	1.93	
E	d/s of C4	1207	0.28	0.49	0.74	0.93	1.32	1.53	1.55	-	1.00	
C5	Thornridge Rd.-Brooke St.	209	0.07	0.14	0.19	0.24	0.31	0.35	0.36	0.62	0.18	
C6	u/s of C6	1209	0.35	0.75	1.11	1.50	1.98	2.29	2.61	-	1.54	
DICB1	Brooke St. at Arnold	9209	0.18	0.37	0.56	0.74	0.84	0.93	1.01	-	0.74	
	Total Brooke St. inflow	9002	0.53	1.12	1.82	2.61	3.67	**4.18**	**4.76**	-	2.67	Genivar Q100=3.96
G	d/s C6 east of Brooke St.	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-	0.00	All flow diverted to Brooke St. trunk or Arnold St. Relief sewer
I1	Culvert Inlet	410	0.10	0.26	0.43	0.60	0.88	1.02	0.94	-	0.50	
DI 1A	Brooke St. at C6 to Arnold Relief Sewer	9209	0.18	0.37	0.56	0.74	0.84	0.93	1.01	-	0.74	
DICB2	Arnold/Brooke St.- to Relief Sewer	2301	0.31	0.69	0.98	1.29	2.25	2.61	2.81	-	1.07	
	Arnold/Brooke St.- to Relief Sewer	3301	0.49	1.04	1.53	2.02	3.07	**3.53**	**3.82**	-	1.82	
	Total Arnold Ave. Outlet	9003	0.57	1.27	1.95	2.60	3.88	**4.18**	**4.76**	-	2.32	Existing 1500mm storm sewer

Note: [1]. Model contains channel routing elements for Chicago design storm simulations.

7.3.2 Hydraulic Analysis

To quantify the effectiveness of the Option 2 relief scheme, the OTTHYMO model and HEC-RAS model were revised to reflect the Option 2 relief scheme. The revised design flows are summarized in Table 7. Option 2 design flows were used with the HEC-RAS model to determine the effectiveness of the works in reducing the extent of the flood lines. The revised flood lines are shown in Figure 9. The details of the HEC-RAS modelling are given in Appendix D.

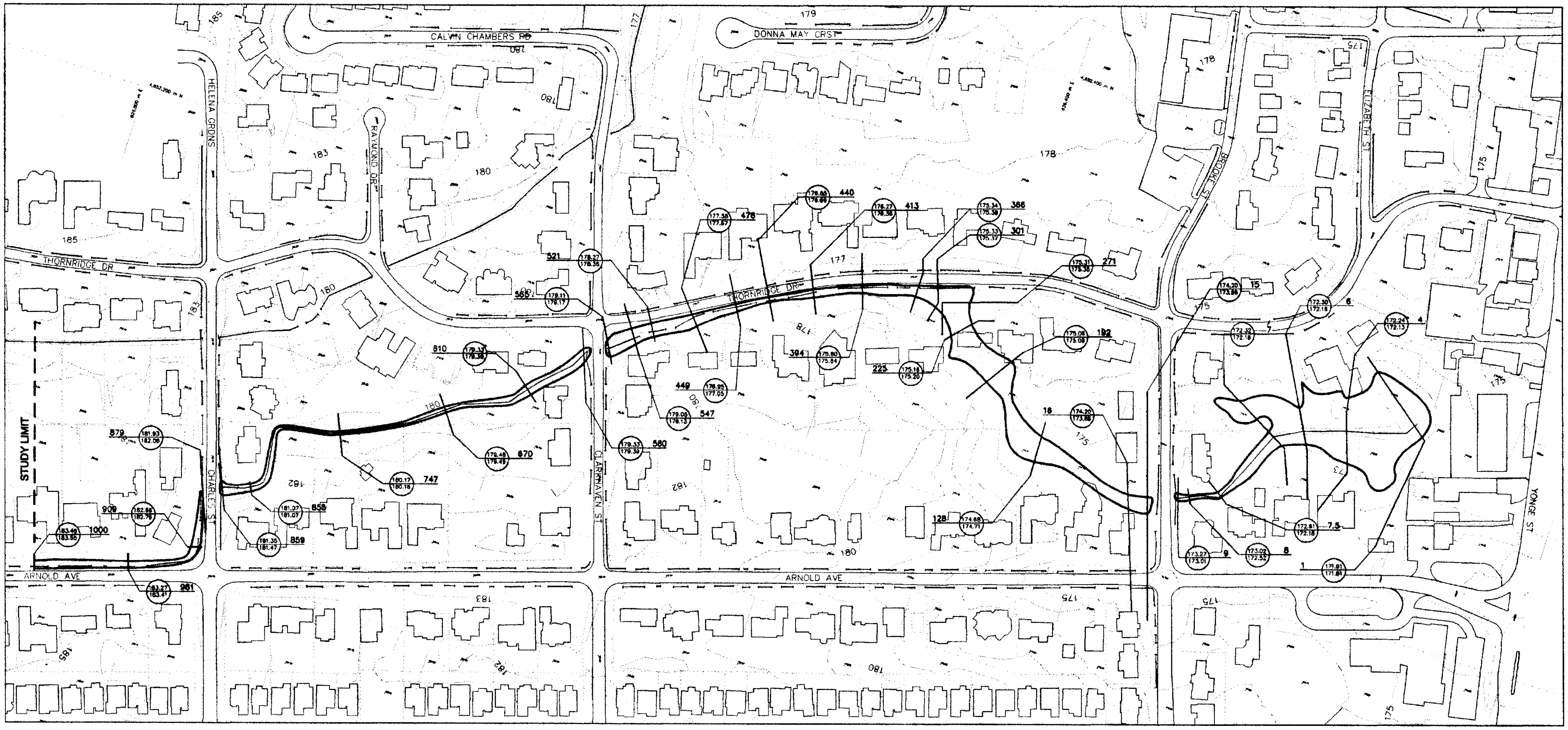
The Option 2 scheme significantly reduces the flood elevations and the extent of the flood lines east of Brooke Street. The peak flows to the Arnold Street trunk sewer are also reduced, as shown in Table 8. The simulated 100-year peak flows discharging to the outlet sewer at Yonge Street for Option 2 is 4.18m^3/s compared to 4.43m^3/s for Option 1 and 6.81m^3/s for the existing condition.

7.3.3 Implementation Issues

Relief Option 2 requires works on Arnold Avenue, which is outside the scope of the road reconstruction project. There are also numerous existing utilities in the Arnold Avenue right-of-way between Brooke Street and Yonge Street, which will have to be considered in locating a new 1,200mm diameter storm sewer. However, a preliminary assessment indicates that the construction of a large relief sewer is possible.

Option 2 is based on the ability of the existing Arnold Avenue trunk sewer to convey the additional flows without impacting the downstream drainage systems. The design flows used in this study did not consider the effects of the ponding upstream of the 1,200mm diameter pipe at the downstream end of Tributary 2. Under present conditions, this ponding will reduce the peak flows entering the Arnold Street storm sewer. Further analysis of the potential impacts on the downstream sewer system east of Yonge Street is required to verify the allowable discharge to the Arnold Street trunk sewer from the study area. The detailed assessment of the Gallanough Park pond expansion will also have a bearing on the total flows that have to be accommodated at Brooke Street and Arnold Avenue. These assessments are outside the scope of the present study.

Relief Option 2 also represents a significant change to the scheme recommended in the Thornhill Drainage Improvement Study. Additional EA work would be required before proceeding with design. The proposed approach is to include the EA assessment of this option in the EA for the Gallanough Park pond, which is scheduled to begin in 2009. This will allow the joint consideration of design capacities and relief requirements in the Brooke Street trunk sewer, the Thornridge Drive relief sewer and the Arnold Street relief sewer. This approach will satisfy the EA requirements while providing the opportunity to confirm the feasibility of the scheme.



Option 2 Flood Lines

Figure 9

Table 8

Tributary 2 Outlet Design Flows (m^3/s) [1]

	Diversion to Brooke St. Trunk		1200mm Dia. Inlet		Arnold Ave. Relief Sewer	1500mm Dia. Arnold Ave Trunk	
Condition	**Des. Q100 [2]**	**Future Available Capacity [3]**	**Des. Q100**	**Max. Flood Capacity [4]**	**Des. Q100**	**Total Q100 Design Flow**	**Flood Capacity [5]**
Existing	1.54	n/a	6.81	**Est. 4.0**	n/a	**6.81**	9.51
Relief Option 1	**4.14**	**Est. 4.0**	4.43		n/a	4.43	
Relief Option 2	**4.18**		**1.02**		3.53	**4.18**	

Notes: [1] Design flows using the 6-hr Chicago Storm
[2] Inflows from the Thornridge study area.
[3] Available capacity without surcharge after construction of the Gallanough Park SWM pond.
[4] Limiting capacity (with inlet control) for maximum flood elevation before spill to Yonge St.
[5] Full flow capacity of the 1500mm pipe without surcharge.

7.4 Additional Relief Options

Improvements to the 1200mm diameter outlet structure on Tributary 2 are currently being considered by others, with the intent to further relieve the threat of flooding in the downstream sections of Tributary 2 and the rear of the lots fronting on Yonge Street. The improved inlet capacity proposed by would draw down the flood elevations between Brooke St. and the inlet. However, it does not address the poor conditions and lack of security in this reach due to interference from the property owners. Therefore, flow reduction or even total flow diversion in this reach may still be necessary as a long-term solution. If it provides adequate interim protection to the Yonge St. property, there is a benefit to installing the additional inlet capacity in advance of the other relief works. It will also provide additional options to the ultimate relief scheme, perhaps reducing the size or eliminating the need for the Option 2 Arnold St. relief sewer.

Additional relief measures such as a relief sewer on Centre Street may also be considered as part of the overall flood control concept. The consideration of inlet improvements at this location should be included in the Class EA evaluation of the proposed Gallanough Park pond improvements.

8 Staging Issues

8.1 Thornridge Relief Sewer

Ideally, storm sewers would be installed under the road before the road work is done. However, the road reconstruction is scheduled for 2009 while the Thornridge relief sewer construction is being deferred until the evaluation of the Gallanough Park pond is completed. Therefore, the relief sewer alignment has been placed on the north side of the road outside of the pavement limits to minimize disturbance to the new road when the sewer is installed in the future. However, some parts of the reconstructed road will be affected when the relief sewer is installed. These are:

- Clarkehaven Street from culvert C3 to Thornridge Drive;
- Thornridge Drive at culvert C4
- Brooke Street and Thornridge Drive intersection and
- Brooke Street at culvert C6.

8.2 Interim Measures

Where possible, the proposed future drainage improvements will be installed with the new road construction. However, since the overall relief scheme is not being installed with the roads at this time, it is necessary to maintain the existing drainage system for the interim condition. In some locations, this requires existing culverts to be replaced or restored to provide proper drainage and prevent flooding. At Culvert C3 on Clarkehaven Street, the existing culvert (which is in poor condition) will be replaced to serve until the Thornridge Drive relief sewer connection is constructed at this location. Similarly, at culvert C7 on Thornridge Drive east of Brooke Street, the existing damaged culvert will be replaced by a temporary 300mm CP. When the proposed ditch inlet and relief sewer is installed, this culvert may be abandoned.

8.3 Culvert Staging

During the installation or repair of culverts on the watercourses (Tributaries 1 and 2), it is necessary to isolate the stream channel from the construction area to protect the stream from sedimentation. This may be achieved through installation of a temporary coffer dam with sheet piling or a berm made from pea-gravel bags. These methods will require some de-watering (i.e. pumping) to keep the construction area free of excess water. The height of the dam is usually set to about the elevation of the two-year flow in the watercourse.

It is also necessary to maintain adequate flow capacity during the construction period to prevent flooding. By-pass capacity up to about a two year flow may be provided but there are practical limitations on the amount of flow that can be accommodated. Flow by-pass can be achieved either through pumping or a ‘flume’, usually in the form of a temporary culvert. Due to the short duration of the installation period at these culverts, by-pass pumping is proposed at most of the locations. Similar treatments may also be required at the locations where structure repair and rehabilitation is proposed. The details of these temporary works will be confirmed at the final stages of the design.

The construction staging plan for each of the watercourse culverts to be replaced is summarized in Table 9. The 2-year design flows at the locations where culvert repair is to be done are given in Table 10. The details of the stream protection measures to be applied at each of these locations will depend on the size of the culvert, the type and degree of rehabilitation required and site constraints and sensitivities. The details will be presented on the design drawings.

8.4 Permit Requirements

Permits are required from TRCA for works carried out on Tributaries 1 and 2 and for works within the regulated area. Although many culverts are to be replaced in the project area, only a few are located on a watercourse. These are C3 and C6 on Tributary 2 and C11, C12, on Tributary 1. Structures to be repaired on Tributaries 1 and 2 are C2, C2A, C13, C17, C18 and C19. All of the other culverts are located on road ditches. Two culverts, C4 and C19A are not on a watercourse but are within the regulated area. The proposed culvert works that will require TRCA permits are summarized in Tables 9 and 10.

These works may also require a ‘Permit to Take Water’ from MOE for dewatering during construction.

Table 9
Temporary By-pass Requirements for Culvert Replacements

Culvert No.	Existing Size (mm)	Watercourse	Reason for Replacement	Proposed Size (mm)	Isolation Method	Proposed By-Pass Method	2-yr Design Flow (m^3/s)	Comments
C11	1800 CSP	Tributary 1	Poor Condition	1800 x 900 Conc. Box	Pea-gravel bag berm	Pumping (Low flow only)	0.41	Temporary by-pass details to be confirmed.
C12	1800 CSP	Tributary 1	Poor Condition	1800 x 900 Conc. Box	Pea-gravel bag berm	Pumping (Low flow only)	0.50	Temporary by-pass details to be confirmed.
C19A	n/a	Tributary 1	New local drainage outlet	500mm CSP	Pea-gravel bag berm	Pumping (Low flow only)	0.05	Not on watercourse - within regulated area
C3	1150 x 820 CSP Arch	Tributary 2	Under-sized	1150 x 820 CSP Arch	Pea-gravel bag berm	Pumping (Low flow only)	0.49	Temporary by-pass details to be confirmed.
C4	700 x 400 CSP Arch	Tributary 2	Obvert interferes with new road structure	Twin 450 CP	Pea-gravel bag berm	Pumping (Low flow only)	0.11	Not on watercourse - within regulated area
C6	Twin 800 CSP	Tributary 2	Obvert interferes with new road structure	1800 x 610 Conc. Box	Pea-gravel bag berm	Pumping (Low flow only)	0.68	Temporary by-pass details to be confirmed.

Table 10 **By-pass Flows for Culverts to be Repaired**				
Culvert No.	**Size**	**Watercourse**	**Work Required**	**2-yr Flow (m^3/s)**
C2	1.63 x 1.12 CSP Arch	Tributary 2	Rehabilitation	0.40
C2A	1.63 x 1.12 CSP Arch	Tributary 2	Rehabilitation	0.40
C13	1.63 x 1.12 CSP Arch	Tributary 1	Rehabilitation	0.65
C17	1.85 x 0.9 Conc.	Tributary 1	Repair Concrete	1.34
C18	1.85 x 0.9 Conc.	Tributary 1	Repair Concrete	1.46
C19	2.4m x 1.2m Conc.	Tributary 1	Repair Concrete	1.50

9 Conclusions

1. The results of this study generally agree with the drainage deficiencies and flooding conditions reported in the Thornhill Drainage Improvement Study. However, the more detailed hydrologic computations carried out with the OTTHYMO model have resulted in higher design flow values, particularly in the downstream reaches in the east side of the study area.

2. The network of control ponds on the Tributary 1 system east of Clarkehaven and north of Centre Street appears to operate as intended in the planning reports. The detention storage volumes are not exceeded by the 100-year storm flows and the discharge rates are controlled to the expected design flows or lower for this event.

3. The Regional Storm is the critical design event for flood line mapping on Tributary 1 while the 100-year design storm is critical for the Tributary 2 and 3 systems

4. The principal area of flooding concern is east of Brooke Street and north of Arnold Avenue. The causes of the flooding in this area are the deficiency in the capacity of the 1,200mm diameter storm sewer outlet and the obstruction of the Tributary due to grading, filling and construction on the rear lots of the houses.

5. As a result of the higher flow values, additional areas of flooding concern were identified on Tributary 1 along Centre Street between Thornbank Road to Oakbank Road and just upstream (west) of Clarkehaven Street. These locations do not represent urgent problems. However, possible relief of the Centre Street area to the Brooke Street trunk sewer and other improvement to the drainage systems in these areas can be investigated as part of the Gallanough Park pond EA study. The flood line mapping and HEC-RAS model developed for this study can be used in the future to assess individual opportunities as they arise.

6. The Thornhill Drive relief sewer, as proposed in the Thornhill Drainage Improvement Study, will reduce flows in the flood prone areas of Thornridge Drive, Brooke Street and Arnold Avenue and. provide an improved drainage condition in these areas. However, there will not be a significant reduction in the potential for flooding during major storm events such as the 100-year or Regional Storms.

7. The existing Brooke Street sewer may be able to accept additional flows if some surcharge is allowed. However, until the Class EA and design analysis of the Gallanough Park pond expansion is carried out, the feasibility of this option is unknown. Therefore, diverting significantly more flow to the Brook Street Trunk sewer than proposed in the Thornhill Drainage Improvement Study ($3.96 m^3/s$) was not considered at this time. The potential for increasing inflows above this amount needs to be considered as part of the detailed assessment of the combined pond/Brooke Street trunk system.

8. To effect a significant reduction in the flood line elevations east of Brooke Street and to reduce the risk of future flooding in this area, a new, secure major system flow path to the outlet is required. The relief sewer proposed on Arnold Avenue (Option 2) may achieve this goal. However, it is based on the ability of the existing 1500mm diameter trunk sewer to convey the additional flows without impacting the downstream drainage systems. This option also represents a significant change to the approved EA report for the Thornhill Drainage Improvement Study. Therefore, this option requires further review under the EA process, perhaps as part of the Class EA for the Gallanough Park SWM pond.

9. The Thornhill Relief sewer concept is based on the prior construction of the Gallanough Park pond to free up capacity in the Brooke Street trunk sewer. Therefore, the construction of the relief sewer should be deferred until either the pond is constructed or it is demonstrated that the Brooke Street trunk sewer can accommodate the additional flows. However, the City should proceed with the other Option 1 drainage improvements that are associated with the road reconstruction project. This would include replacement of all road culverts and restoration/improvement of the roadside ditches. These works are beneficial in the short term and they are consistent with the long term objectives for flood control in the area. The improvement of the capacity at the trunk sewer outlet of Tributary 2, as proposed by the local developer, would also be beneficial in the short term and provide additional options for the overall relief scheme for the study area.

10. Even without the Thornridge relief sewer installed, the re-construction of the roads with improved ditches and culvert replacements will result in a significant improvement in the local drainage conditions for minor storm events during the interim period.

11. The scope of the Gallanough Park pond EA should be designed to consolidate all of the previous studies with new analyses to develop a comprehensive drainage and flood control plan for the entire study area, including Tributary 1, 2 and 3 areas. To achieve this objective, the EA studies should include:

    - Confirming the existing flows to the Brooke Street trunk,
    - Verifying the capacity of the Brooke Street trunk and the two other trunk sewer outlets to Yonge Street, including surcharge capacity,
    - Evaluating options for the possible expansion of the Gallanough Park pond,
    - Confirming and refining previously proposed flood relief options including the Thornridge Drive relief sewer and
    - Developing a plan for flood relief for the Tributary 1 flooding areas and other local measures, as appropriate.