JTB Environmental Systems Inc.

Fluvial Geomorphology Natural Channel Design Coastal Processes Erosion Control

VAN GAAL DRAIN EROSION ASSESSMENT

RICHMOND, ONTARIO

Submitted to
David Schaeffer Engineering Ltd
OTTAWA, ON

Submitted by
JTB Environmental Systems Inc
CAMBRIDGE, ON

26 October 2012

INTRODUCTION

A residential development situated on the Richmond Lands south of Perth Street and west of Fortune Crescent in the Town of Richmond is proposed and, as a consequence of that proposed land use change, an environmental study has been commissioned to establish stormwater discharge criteria for the receiving watercourse (Van Gaal/Arbuckle Drain), and to provide a detailed natural channel design option for the stormwater connection and reaches of the receiving drain.

A previous environmental report authored by Kilgour & Associates with Parish Geomorphic has been submitted and incorporated in the DSEL stormwater report ("Preliminary Stormwater Management Analysis, Mattamy Richmond Lands. March 2010" *referred to hereafter as the DSEL Report*). That report summarizes the surrounding environmental conditions; that information is not repeated in this report.

PURPOSE OF THE STUDY

JTBES was contacted by DSEL to complete an additional erosion threshold analysis for the drain. The previous erosion analysis did not appear to factor in sensitivity to erosion for the reach between Perth Street and Fortune Avenue, and it did not include any information between Fortune Avenue and the Jock River outlet.

There has been some concern expressed by the City of Ottawa that the previous study did not review erosion sites downstream of Fortune Street (although it is recognized that meander assessment of that reach, denoted VG-R1, was completed). There have been reports by local landowners of existing and worsening erosion problems on the drain within the residential area downstream of the Fortune Street.

The purpose of this study is to review the erosion thresholds set out in the DSEL Report and determine if they are appropriate given the existing erosion concerns within reaches VG-R2 and VG-R1.

This study is concentrated on that section of the Van Gaal/Arbuckle Drain (*hereafter referred to as the "Drain"*) flowing between Perth Street and the Jock River. This includes a portion of Reach VG-R2 in the DSEL Report but does not include any of the other reaches in that study.

This report constitutes the first phase of the natural channel design solution for the site development application (determination of erosion thresholds and optimal stormwater connection sites); the following report will represent the detailed design for the connection and Drain.

BACKGROUND INFORMATION

The majority of the background information defined in this section is derived from the DSEL Report and associated appendices, and is focussed on the geomorphology component of the study.

The DSEL Report divided the surface watercourses into a number of reaches for geomorphic analysis (refer to Figure 9: Reach and Meander belt width delineations, p. 36). The main section of the drain is identified as VG-R2 and is located at the confluence of three straight drain segments along a hedgerow approximately 500-600m upstream of Perth Street. It flows downstream to the Fortune Street culvert. Along its path it is joined by Reach VG-R3-3, which in itself is a combination of two other drain segments (VG-R3-1 and VG-R3-2) approximately 150 m upstream of the Fortune Street culvert. This latter section of VG-R2 between the confluence and the culvert contains the cumulative flow from all surface water drains on the proposed development lands.

There are two other surface water features, JED-1 and JED-2 which appear to be disconnected from the VG-series of reaches; these join the Jock River south of Ottawa Street.

Within the previous study area, site constraints regarding meander belt and "critical discharge rate" were established for flows directed to the drain (p. 44, DSEL Report).

The geomorphic study determined that four erosion threshold sites were required; one each on VG-R2, VG-R3-2, VG-R3-3 and JED-1. The threshold station for VG-R2, which will receive stormwater pond discharge downstream of Perth Avenue, is located approximately 300m north of Perth Avenue, which is well upstream of the development site. This is the only threshold erosion site on the main drain down to the Jock River. Correspondence relating to the decision to not have a site in the immediate area of the connection indicates that the synoptic-level geomorphic assessments (RGA, RSAT) did not point to any particular problems in that reach, therefore no erosion sites were assessed.

With respect to surficial geology through which the drains flow, the DSEL Report states (pg. 38) that between Perth Avenue and Ottawa Street are "thin deposits of clay overlying a till deposit overlying inferred bedrock". This indicates the material which is subject to erosion is comprised of compacted clays and silts within the weathered zone with heavier compacted clay as the bedrock material (non-weathered): this constitutes the cohesive bank and bed materials; further there are the unconsolidated, weathered clays and silts that are found on the bed of the drain (whose source is both collapsed bank materials as well as transported in-channel materials from upstream).

Technically, erosion refers to the removal of material from its in-situ condition, which is interpreted in this case to represent bank materials; however large accumulations of silt and clay on the bed, when removed and not replaced by upstream sources, also constitutes erosion (as opposed to a transport event) as a consequence of its removal is deepening of the channel (entrenchment) with corresponding side wall collapse over time.

Therefore, thresholds of erosion in this report will refer to both the cohesive bank material and the unconsolidated accumulations of sediment on the bed of the drain.

METHODOLOGY

The methodology used in this study has two components: a field assessment component as well as a desktop modelling component.

Field Assessment:

The length of the Drain from the Jock River to upstream of Perth Street was walked on two occasions in May, 2012. The initial site walk was undertaken to review the Drain in context and included a centreline walk in the channel as well as multiple tangent walks across the floodplain areas to review conditions and look for indicators of flood effects. No measurements were taken during this walk. In addition, the walk was used to determine appropriate reach breaks, which were decided upon using external controls on the Drain (crossings at Fowler, Fortune and Perth). This resulted in three principle reaches (Jock River to Fowler Culvert (Reach 1), Fowler Culvert to Fortune Culvert (Reach 2), and Fortune Culvert to Perth Culvert (Reach 3)); reaches were kept at a broad scale and it is recognized that there could be multiple sub-reaches in each.

The purpose of the second site walk was to document areas of concern with respect to function of the Drain as well as documenting sites of erosion. Walking upstream along the centreline of the channel, GPS locations, photos and notes were taken at all locations of concern. Notes were made regarding the apparent severity of erosion, the overall stability of the channel in light of the erosion, and the priority which the erosion site may need attention. These were documented on a High-Medium-Low scale and recorded (see results below).

During the site walk sections were identified for erosion threshold analysis. In all, four sections were established for detailed study: two between Perth Street and Fortune Street, one between Fortune Street and Fowler Street, and one downstream of Fowler Street. Three of the sites were selected because of severe erosion of the banks; the fourth site was selected because of high silt accumulations on the bed.

At each section a detailed survey using a GRX-1 Differential GPS was completed. The survey followed standard survey techniques for watercourses and floodplains and included all breaks in slope, top of bank, bottom of bank, in-channel and floodplain ground shots. Water surface elevation was recorded at the time of survey. Data from the survey, including the occupied point for the base station, has been recorded and can be revisited to a high degree of certainty for future section surveys if needed.

Notations regarding the nature of bed and bank materials were collected at each site (including calibre) for erosion threshold analysis. Energy gradients were measured in the field and compared to existing conditions HEC-RAS gradients for the 2-year summer flow.

Desktop Analysis:

Results from the survey were entered into hydraulic software and calculations were run to determine channel parameters based on increased stage for the bankfull channel. Areas above the bankfull elevation were not modelled at this time as they were outside the main concern of the study.

Results from the channel parameter delineation were then run against erosion indices for the material found in the bed and banks of the Drain, to determine erosion sensitivity with respect to stage. This information was converted to a velocity/erosion potential relationship which forms the basis of the conclusions found later in this report.

Further, assessment of the approved RVCA HEC-RAS pre- and post-development flows for the Drain (during both summer storms (when the Jock River does not back up flow to the Drain) and spring melt/rain on snow events (when the Jock River does back up into the Drain) was completed to determine changing channel parameters under higher flow events.

Results were used to determine the erosion thresholds for the Drain south of Perth Street to the Jock River. These thresholds were then used to set design criteria for the outfall and Drain south of the stormwater connection, and to provide for further recommendations regarding Drain erosion mitigation.

RESULTS

General Reach Characteristics

Reach locations are shown in the following figure.

Reach 1 is a relatively flat reach which is controlled during certain flow events by the level of the Jock River. Backwater effects tend to make this a depositional reach, with some accumulations of silt and clay on the bed to thicknesses of 0.30m. That said, the entire reach is not depositional which indicates under certain storm events, when the Jock River is not affected, transport through the reach is the dominant process.

There is a lack of overhead cover in this reach with the exception of an area immediately downstream of Fowler Avenue. Erosion in this reach is somewhat limited to bank undercutting where adjacent landowners cut their lawns right to the edge of the Drain; however there is one major bank erosion site which is putting a residence at risk.

There is one drop structure downstream of Fowler Avenue which seems to control water elevation to the culvert. Flow does go around the structure and there is bank erosion downstream as a result. The purpose of the structure is unknown.

Reach 2 is adjacent to residential development and streetscapes for the majority of the reach, with a church and cemetery along the south side for a portion of the reach. The Drain appears to be affected by Jock River water levels in the lower section of the reach, which results in a depositional environment with loose silts to depths of 0.40m upstream of the Fowler Avenue culvert. As a consequence of these accumulations, downcutting is the dominant erosion process though there are some areas where bank erosion is occurring.

Mid-reach there is an abrupt turn in the direction of the Drain which has resulted in a deep scour pool and outside bank erosion. Climax vegetation is holding the bank together for the most part; however it is clear that treefall will occur at this location in the future as the bank beneath the roots continues to recede.

Downstream of Fortune Avenue the Drain takes a number of 90-degree turns; first as it exits the culvert and then flows adjacent to the roadway, then as it turns to the north-east away from the road (this is at a location where roadside storm drainage enters the Drain from the south-east) and then again turns south-east. Each of these abrupt changes in direction are potential problem areas.

Two drainages enter the Drain in this reach, one along Fortune Avenue and the other where Maitland Street curves and becomes Strachan Street.

These two reaches (1 and 2) appear to be naturally-formed for the most part and have some natural built-in resilience to flow which is not found upstream in Reach 3.

Reach 3 is more reflective of a dug drain than the downstream reaches. The Drain is narrow and entrenched with no floodplain access until depths reach upwards of a metre or more, meaning that a concentrated energy condition is persistent through the reach. There is no formal ‘functional’ floodplain (as flows get out of the Drain they spread across the farm fields to the south and west of the Drain and, to a lesser degree, to the north and east to the residential areas).

Banks in this reach are vertical and eroding rapidly. Sediment delivery to the reach is high and the Drain does not have the ability to re-work the sediment using continual flow energy, as the Drain dries up completely at times during the year. As a consequence, the bed contains heavy accumulations of silts and clays to depths of +0.40m.

Erosion is rampant in this reach. The Drain is trying to achieve a form which allows it to function properly to the flow inputs from upstream (and one additional drain input at Reach VG-3 (refer to the DSEL Report) and residential drainage along a ditch leading from Queen Charlotte Street). The reach is highly stressed and adjusting rapidly, with large clump erosion in many areas.

There is one location in the reach where a CSP with concrete cap confines the Drain. This was likely used as a farm crossing in the past and does not appear to be currently in use. Its presence results in a

significant impact to the function of the Drain and there is considerable erosion both upstream and downstream of this location.

With respect to planform pattern, the Drain in Reach 3 is comprised of a series of straight sections with abrupt changes in direction. The Drain is attempting to create a meandering pattern (which results in considerable erosion); this process is stunted by the inconsistency of flow during the year and as a result would require many years to create a final pattern. This means that erosion in this section will continue for long periods of time if there is not an intervention/remediation event.

Erosion Database

The erosion assessment resulted in documentation of 51 sites of concern between the Jock River and Perth Street; 11 in Reach 1, 17 in Reach 2, and 23 in Reach 3. As indicated above, each site was assessed as to the severity of erosion, the overall stability of the bed and banks, and the priority in which an intervention would be required. Severity is based on the amount of erosion and the apparent rapidity of bank retreat (as well as the amount of unconsolidated silt and clay on the bed); stability is based on the resilience of the reach and is indicated by presence of floodplain connectivity, vegetation, and appropriate planform; and priority is based on the degree of erosion and whether there are infrastructure elements at risk.

Appendix A contains the erosion results for each reach, as well as the GPS coordinates (easing, northing and elevation) of the site. Note the GPS readings are based on a 6-degree grid and are read from a hand-held Garmin GPS Unit, which results in positional error of +3 to +5m depending on overhead cover. Elevation is provided for information only and is not to be used in any calculations as some points were taken from the channel centreline in the Drain and others from the floodplain or roadway. Appendix B has representative photos from each of the 51 sites.

Results are summarized in the table below.

Reach	Severity			Stability			Priority Class		
	High	Medium	Low	High	Medium	Low	High	Medium	Low
1	1	3	7	3	7	1	1	2	8
2	0	7	10	1	12	4	0	6	11
3	8	14	1	1	2	20	4	18	1

Results indicate clearly that, **under existing conditions**, Reach 3 has the highest severity of erosion, the lowest stability and the greatest number of priority erosion sites.

Causes of Existing Erosion on the Van Gaal Drain

Erosion on the Drain is caused by a number of factors, some of which are natural and others which are induced as a result of changes in land use/hydrologic behaviour.

Natural erosion delivers sediment to the Drain through a number of possible mechanisms, including sheetwash, frost heave and desiccation fracturing, gravity failures due to oversteepening of the banks, and natural weathering of the clays (caused by repeated wet/dry cycles) which weakens the structural bonds in the clay matrix. Once operated upon by these mechanisms flowing water is easily able to erode and transport this weakened material. Large clumps of bank, once in the active channel, get quickly broken down into constituent clay particles which are cohesionless and very susceptible to erosion by flowing water.

Further, as banks become partly separated by slumps, flow from upstream can get behind the failing portion of the bank and hydraulic pressure forces the bank to fail more quickly. All of these processes (with the exception of frost heaving due to the time of year of the assessment) were visible along the drain.

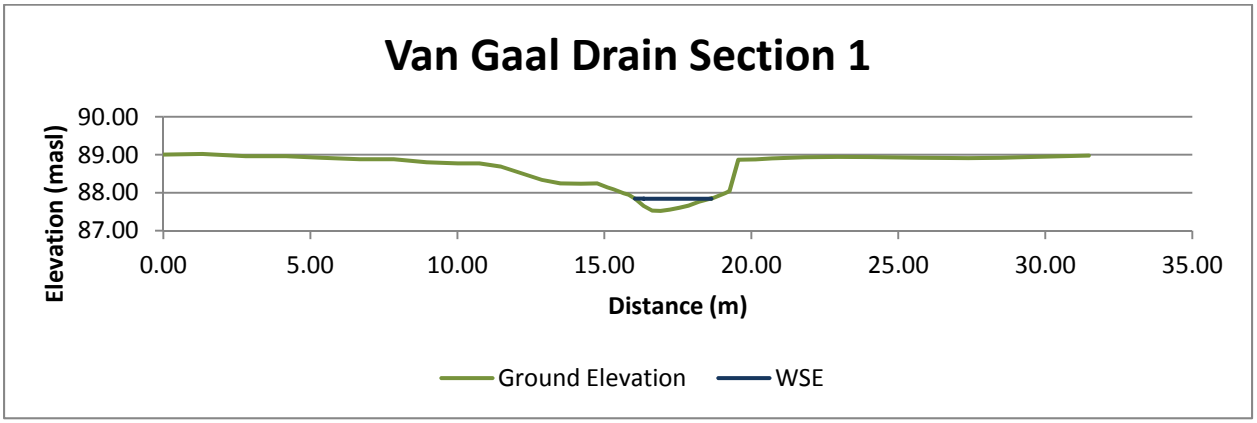
Induced changes are the result of human activity upstream in the watershed. In this case, a recent small residential development along Rochelle Drive/Mira Court upstream of Perth Street may have changed the hydrologic properties of overland flow in the area. The increased impervious surface, and apparent lack of stormwater detention, delivers runoff quickly to the Drain during storms, creating a first pulse of fast flow through the Drain during storm events. When additional storm inlets are added to the mix (for instance the drain at Queen Charlotte Street) the cumulative effect of this fast rise in stage and velocity could result in erosion.

Finally, there is the construction of the Drain itself to consider. It is not known whether the Drain cross-section was determined using flow analysis at the time of design (though the fact that the 2-year flow is well outside the cross-sectional area of the Drain under current conditions may be telling); if the necessary hydrologic calculations were not used to size the Drain then there is a chance it is undersized for the flows. This is currently evident as the Drain appears to be widening in response to flows, though it may be a combination of factors that is causing this to occur and, given the upstream development, may have sent the Drain past a stability threshold and initiated erosion at the scale which is evident today.

Sensitive Reaches/ Cross-sectional Analysis

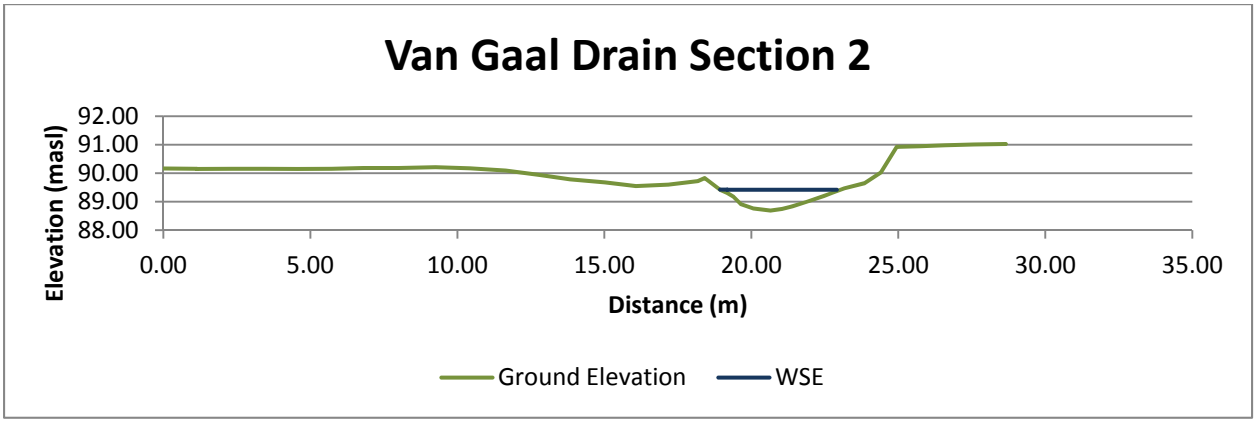
As indicated in the erosion database section, there are a number of sensitive sections on the Drain. Four sections which were particularly sensitive to erosion were selected for cross-sectional and hydraulic analysis: two in Reach 3 (one upstream and one downstream of the VC-R3 inlet) and one each in reaches 1 and 2. The location of the sections is shown in following figure.

Section 1 is found in Reach 3 upstream of the VG-R3 inlet and just upstream of the Queen Charlotte Street drain. This section was selected as it represented both an erosional component (the banks are eroding and the channel is widening) and a depositional component (there is a silt accumulation on the bed). The cross-sectional plot showing the shape of the section is shown below; water elevation at the time of the survey is also indicated.



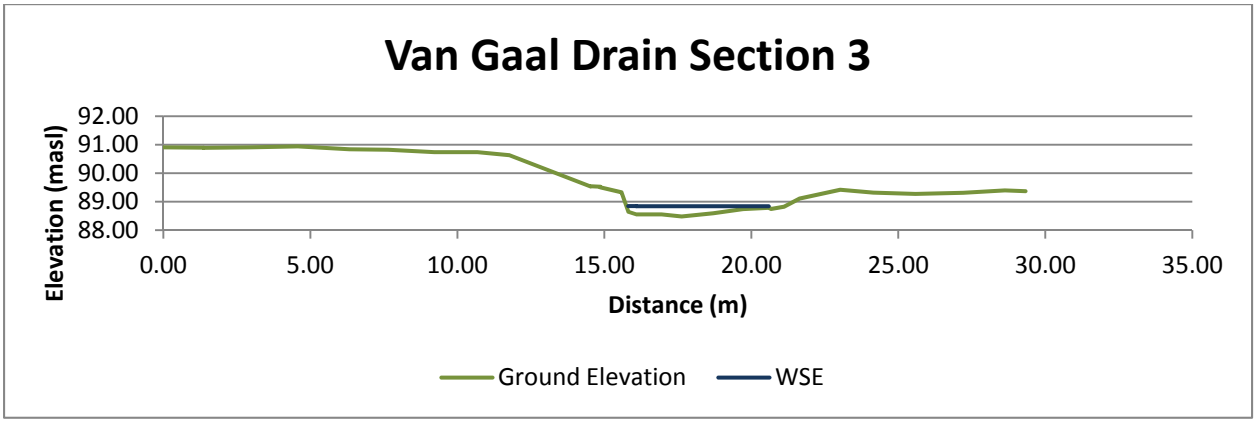
Following is a photo showing the drain at the section location.

Section 2 is also located in Reach 3 and is located upstream of the Fortune Street culvert where the Drain takes an abrupt, 90-degree turn. The outside bank is rapidly eroding at this site and the section is, as seen in the section plot below, trying to adapt to the high sediment inputs.



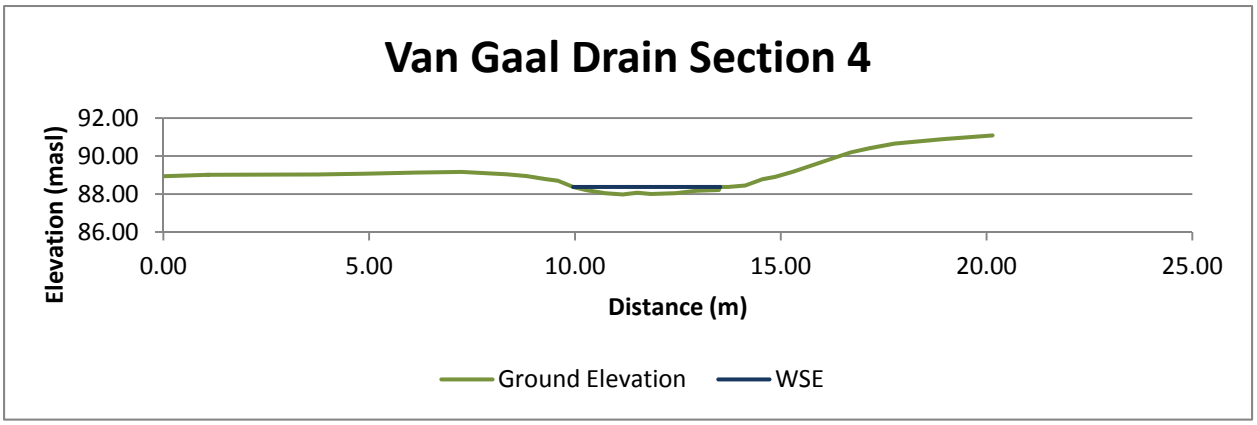
Outside bank erosion is the dominant process operating at this location. A section photo follows.

Section 3 is a depositional site upstream of Fowler Street in a section where there is strong floodplain access to the south. The lack of concentrated flow at higher stages results in a lower overall velocity and deposition of fines is the result.



Deposition and remobilization are the dominant processes operating at this location. A section photo follows.

Section 4 is the only high severity/high priority erosion site in Reach 1 and it is located at a bend adjacent to a residence. The lack of vegetation protecting the top of bank, coupled with the sharp bend and erodible materials has resulted in rapid bank retreat.



Erosion is the dominant process here, even though this is in the backwater influence zone of the Jock River. A photo of the site follows.

Critical to our analysis are Sections 1 and 2 as they are within the proposed development site; however the mobilization of large quantities of sediment at Section 3 and the high degree of risk to infrastructure/private property at Section 4 requires them both to be included in the analysis, particularly when the function of the Drain is considered.

Flow Analysis

Surveys from each section were completed and the data input into software for hydraulic analysis. Details regarding reach slopes at the 2-year flow were extracted from the HEC-RAS Summer conditions model.

The analysis was limited to in-channel flows (and not overbank flows) as the question at hand related to erosion thresholds under the worst case scenario. Based on the hydraulic calculations (which are provided in Appendix C) and the grain size information provided in the DSEL Report, erosion thresholds were determined which apply to all four sections.

EROSION THRESHOLDS

Previous Study

Table 8 (pg. 52) of the DSEL Report sets the criteria for erosion thresholds for Reaches VG-R2, VG-R3 and VG-R3-2 and indicates the following parameters will dictate flows up to and including the two-year level. Some of the bankfull parameters are summarized below, refer to Table 8 in the DSEL Report for the full table.

Parameter	VG-R2	VG-R3	VG-R3-2
Bed Material D_{50} (mm)	0.002	0.0009	0.0001
Bed Material D_{84} (mm)	0.08	3.11	0.02
Average Bankfull Velocity (m sec^{-1})	0.59	1.00	0.70
Bankfull Discharge (m^3 sec^{-1})	1.35	1.41	0.50
Critical Discharge (m^3 sec^{-1})	0.33	0.55	0.06

The DSEL Report indicates that erosion thresholds determined by Parish Geomorphic are as follows:

Reach VG-R2: 0.33cms

Reach VG-R3-2: 0.06cms

Reach VG-R3: 0.55cms

This means that all sections downstream of the connection of VG-R3 will have a cumulative discharge of 0.94cms (0.33+0.06+0.55). This discharge affecting portions of Reach VG-R2 is 284% higher than the stated threshold for that reach.

The erosion thresholds from the DSEL Report were analyzed in the cross-sections (1-4) which represent the sensitive reaches downstream of Perth Avenue. The table below shows the channel parameters from the flow analysis results (Appendix C) using the critical discharge for the reach (for Section 1) and the cumulative discharge for the reach downstream of the VG-R3-3 input (for Sections 2, 3 and 4).

Parameter	Section 1	Section 2	Section 3	Section 4
Critical Q / Cumulative Q *(m^3 sec^{-1})*	0.33	0.94	0.94	0.94
Velocity *(m sec^{-1})*	0.49	0.72	0.58	0.67
Depth *(m)*	0.39	0.60	0.44	0.52
Bed Shear *(N m^{-2})*	6.12	11.26	7.35	9.53
Bed Shear *(N m^{-2})*	6.20	9.08	5.26	7.28

Current Study

Results from the geomorphic analysis indicate the Van Gaal Drain system is a sediment rich as well as energy rich (at times of flowing water) system, which erodes, transports and deposits bed material under rising and falling hydrographs under existing conditions.

Mobilization of bed materials which have been deposited from upstream will occur under almost all flows and should be encouraged as the system needs to flush out these large deposits of silts and clays. Establishing a threshold discharge based on these surficial deposits is not appropriate as their transport requires very low velocities. Since the bedrock layer is comprised of tight, cohesive clays and is highly resistant to erosion by flowing water, that material is also unsuitable for establishing thresholds. Therefore, given these two points and the fact that the Drain is eroding its banks in multiple locations, the most appropriate erosion threshold for use in this analysis is the bank erosion threshold.

Erosion along banks can be caused by flows that exceed the theoretical critical velocity for entrainment of the cohesive bank material. Assessment of the conditions of the creek show that the banks are comprised of consolidated clay materials, ranging from coarse to fine clay. When these materials are exposed to flowing water, velocities of between 0.225 metres per second (coarse clay) and 0.400 metres per second (fine clay) are required to entrain (erode) these materials (ref. Hjulstrom, 1935).

Analysis shows that stormwater discharge at a rate not exceeding 0.225 metres per second velocity is the optimal discharge, based on the following:

1. It is the minimum threshold for bank erosion of coarse clay materials according to Hjulstrom;
2. It will not entrain any of the few riffles found in the system (comprised of gravels with sands interspersed), and
3. It will allow for the flushing of fine sediments, exposing the natural bed of the creek.

Therefore, it is recommended that the threshold discharge for stormwater to the Van Gaal Drain should not exceed a value of 0.225 metres per second velocity.

The table below shows how that critical velocity would be represented in the channel sections for the sensitive reaches.

Parameter	Section 1	Section 2	Section 3	Section 4
Velocity *(m sec $^{-1}$)*	0.225	0.225	0.225	0.225
Representative Q *(m^3 sec^{-1})*	0.020	0.020	0.050	0.030
Depth *(m)*	0.12	0.11	0.13	0.12
Bed Shear *(N m^{-2})*	1.88	2.06	2.17	2.20
Bed Shear *(N m^{-2})*	1.65	1.50	1.41	1.50

This condition of threshold release at 0.225 m/sec should be applied to as many storm events as is possible and should not be limited to a 2-year or less event. The reason for this relates back to erosion on the Drain: runoff from the impervious land surfaces which is directed to the stormwater pond will arrive at the pond faster than runoff from 'natural' surfaces and as a consequence the pond will begin discharging excess volumes before the Drain has increased flow from other sources. At times when the Drain is dry (particularly summer periods) the banks are at their most sensitive for erosion and the lack of buffering volumes of flow in the Drain during these events means that all energy concentrating in the Drain will be able to act on the banks and bed. By limiting velocities to below the threshold some erosion protection is provided for the banks.

Cumulative flows from other sections of the Drain (ie DSEL Report reaches VG-R3-2 and VG-R3) should also be controlled to the threshold velocity as opposed to the reported volumes. Doing so decreases the cumulative impacts from these drains as velocity does not accumulate in the same manner as flow volumes.

IMPLICATIONS

Existing Erosion

The analysis clearly shows that there are significant erosion sites on the Van Gaal Drain that have their cause in a number of areas. Addition of stormwater flows from the proposed site, even if controlled to the threshold rate, will not prevent existing erosion from continuing. It must be well understood that existing erosion will continue to occur for the simple reason that once erosion scars develop in banks they become weak points and as such are susceptible to continual erosion unless an intervention is undertaken. For those sites downstream of the stormwater connection point erosion will continue to occur, the rates of erosion may be lower as there will be some control on velocities which does not occur at present. For those sites upstream of the connection point, the degree and rates of erosion that are currently occurring will continue and that material which is eroded into the Drain will transport to the downstream reach. This continual influx of high sediment loads from upstream will complicate the erodibility of the downstream section.

Future Erosion

Controlling flow velocity from the proposed site stormwater system will not exacerbate existing erosion. While it will decrease erosion potential for the low flows at the start of a storm event, the dynamics of the Drain system will result in continued existing erosion and possible future erosion at locations which may not be displaying definitive erosion scars at present.

In order for future erosion to be minimized it would be necessary to undertake a redesign of the Van Gaal Drain south of Perth Street to Fowler Street. While this would address erosion in the Reach 3 section of the study area it would not fully address the erosion in Reach 1.

MITIGATING EROSION from DEVELOPMENT SITE

Existing erosion along the Drain will continue once the site has been developed and while the degree of erosion may be somewhat addressed using the thresholds outlined in this study, the fact of the matter is that all erosion will not cease. The challenge for the design of the site is to ensure that changing the existing land use does not exacerbate erosion in the Drain and further the development should mitigate some of the existing erosion if implemented properly.

This condition assumes the Drain remains in its current configuration. With that condition in place, application of the erosion thresholds will not exacerbate erosion. There is an opportunity to mitigate some of the existing erosion in Reach 3 in a manner which will reduce some stress on reaches 2 and 1, which would be an overall benefit to the Drain system. Considering use of the Drain by aquatic species there is an added benefit to modification of the form and function of the Drain from the homogeneous nature it currently displays to a more diverse state. This can be done using natural channel design principles.

Natural Channel Design Principles

The purpose of natural channel design is to create/modify a system that is not properly functioning to a state where it is more in equilibrium with processes acting upon it. Doing so builds into the system a natural resilience to flow variability which is found in all stable, functioning watercourse systems.

With respect to the Drain, and specifically Reach 3 from Perth Street to Fortune Street, it currently is classified as a straight channel with steep, vertical eroding banks that prevent connection to a floodplain during frequent flow events. Low flow events occupy the same channel width as high flow events which means that, as the Drain dries up, water depth is spread over a wide area resulting in shallow water which is not conducive to fish health. In addition, the concentration of flow during multiple events concentrates energy and erosion. This combination of factors acts to further entrench the Drain and create sidewall erosion as it tries to create a stable form over time.

Given the modelled flows it is possible to create a channel corridor with a stable low flow fish channel that functions under dry conditions (until the Drain dries up completely) connected to a moderate flow volume floodplain which is vegetated (creating habitat as well as roughness to slow velocities). A third terrace representing high flow volumes would then complete the channel section and can be used to create a different type of habitat for wildlife.

RECOMMENDATIONS

Based on the results of this study the following recommendations are made:

1. Stormwater discharge from new facilities to the Drain be controlled to a maximum velocity of 0.225 metres per second for all flows up to and including the 2-year event, and to as many return events as is possible above the 2-year event.
2. Because of the existing erosion problem in the Drain, pre-construction monitoring of existing

erosion sites, including creation of a full database of erosion characteristics (length/height/depth) should be completed at repeated intervals to document changes (including rates of change). This is necessary to distinguish between existing erosion and any potential impacts that may occur during and after the site is developed.

3. Consideration should be given to rehabilitation of the Drain in Reach 3 to create a functional system which will act to control concentrated flow energy and spread it over a wider channel area, thereby decreasing velocities moving to the downstream reaches.

SUMMARY

This study reports on the development of erosion thresholds for stormwater discharge from a proposed development site in Richmond, Ontario, concentrating on the Van Gaal Drain south of Perth Street to the Jock River. The study has documented all instances of erosion/deposition currently occurring in the Van Gaal Drain south of Perth Street, which is important as these sites will continue to erode in the post-development condition even if erosion thresholds are strictly adhered to.

Based on the Drain characteristics it has been determined that the erosion threshold for stormwater release should be based on a critical velocity for erosion of coarse clay, which comprises the material making up the banks of the Drain. The bed of the Drain, being partly comprised of weathered silts and clays, will remain mobile under all flows and this should be encouraged as it acts as a flushing mechanism. The clay bedrock of the Drain, which is exposed in some areas, is more resistant to erosion than the coarse clay banks and as such will be stable under threshold flows.

The threshold flow is determined through analysis to be 0.225 metres per second velocity; flows from the stormwater ponds should not exceed this flow rate for storms below the 2-year event and if possible the higher return flows should also be restricted to this flow rate wherever possible.

APPENDIX A

EROSION DATASHEETS

Site Number	Easting	Northing	Elevation	Severity	Stability	Priority Class	Observation
Reach 1: Jock River to Fowler							
1	434547	5004164	91 m				Confluence with Jock River. No evidence of active erosion, some temporary silt deposition
2	434524	5004135	92 m				Upstream of first 90-degree bend, some minor undercutting on banks, silt deposits on bed
3	434486	5004143	92 m				Downstream side of pedestrian trail crossing; some silt depotsion; banks stable
4	434468	5004139	93 m				Upstream side of trail crossing; some undercutting and meandering; silt on bed
5	434449	5004147	93 m				Channel somewhat entrenched and disconnected from floodplain; undercutting minor
6	434436	5004142	97 m				Vertical banks where lawn cutting to edge, evidence of recent erosion; downcutting
7	434431	5004133	90 m				Wood retaining wall projects to creek, flow deflection scour on opposite side of bend
8	434404	5004129	94 m				High eroding bank near house; evidence of rapid retreat
9	434384	5004134	94 m				Straight section, some undercutting; large accumulations of silt (+0.30m)
10	434379	5004145	92 m				Downstream of drop structure, moderate bank erosion both sides, evidence of rapid retreat
11	434372	5004147	94 m				Downstream side of Fortune Ave culvert; significant deposition of silts on bed
Reach 2: Fowler to Fortune							
12	434341	5004130	101 m				Overloose bed sediments to depth of +0.20m; banks stable with minor undercuts
13	434307	5004142	99 m				Overloose bed sediments to depth of +0.20m; banks stable with minor undercuts
14	434313	5004131	97 m				Clump erosion on outside bend, moderate undercutting, grasses holding bank together
15	434296	5004133	96 m				Overloose bed sediments to depth of +0.20m; banks stable with minor undercuts
16	434254	5004123	101 m				Large silt accumulations on bed, vegetating; flow deflection causing bank erosion
17	434232	5004117	100 m				High bank on left side eroding quickly, disconnected from floodplain
18	434209	5004114	97 m				Storm inlet, right bank protected (wood ties), left bank depositional. Silt accumulations on bed.
19	434181	5004110	92 m				Long, straight reach is downcutting; bank erosion and toppling trees on left bank
20	434153	5004100	85 m				90-degree bend, deep recirculation pool, bank erosion and debris accumulation
21	434133	5004071	96 m				Steep riffle over short distance, some minor bank erosion occurring here on right bank
22	434104	5004067	91 m				Bank erosion and slight undercutting on left bank; some silt accumulation on bed
23	434070	5004075	95 m				Channel slightly entrenching with disconnection from floodplain developing
24	434057	5004072	103 m				Entrenching channel with clump erosion; silt accumulations on the bed
25	434045	5004065	85 m				90-degree bend with storm input on left, gabion baskets protecting road, some clump erosion
26	434037	5004069	92 m				90-degree bend along road, reverberation erosion on opposite bank; trying to meander
27	434029	5004078	95 m				Steep gradient reach downstream of culvert, some clump erosion
28	434021	5004080	92 m				Downstream side of Fowler culvert

Legend:			
Severity	Stability	Priority	
			High
			Moderate
			Low

Site Number	Easting	Northing	Elevation	Severity	Stability	Priority Class	Observation
Reach 3: Fortune to Perth							
29	434002	5004074	93 m				Upstream side of Fowler culvert; culvert undersized: flow extends to both walls
30	433987	5004061	93 m				Major bank erosion on left bank at 90-degree turn; evidence of rapid retreat
31	433966	5004079	91 m				Lengthy series of bank slumps; channel is widening and trying to meander near roadway
32	433950	5004096	99 m				Channel entrenching around series of bends, disconnected/absent floodplain
33	433939	5004088	96 m				Large clump erosion and undercutting, roots not holding bank together, silt accumulations
34	433917	5004099	92 m				Entrenched/disconnected floodplain; channel trying to meander; clump erosion
35	433903	5004101	92 m				Major bank erosion on left bank at 90-degree turn; evidence of rapid retreat
36	433895	5004106	96 m				Bank erosion caused by channel widening, attempting to meander; large clump erosion
37	433877	5004109	90 m				Drain inlet from left bank; drain entrenched and trying to meander, delivering silt to main drain
38	433850	5004126	95 m				Major bank erosion on right bank toward back yards; entrenched channel
39	433872	5004173	95 m				Severe bank erosion on left bank, evidence of rapid retreat
40	433770	5004182	94 m				Moderate erosion as channel starts to migrate/meander; disconnected from floodplain
41	433741	5004179	92 m				Active meandering with bank erosion (clumps) on both sides; disconnected floodplain
42	433727	5004176	92 m				Major clump erosion and meandering/widening; both banks affected
43	433712	5004176	96 m				Small CSP and concrete access to opposite side of creek; localized erosion on both sides
44	433691	5004174	92 m				Large bank failure, silt accumulations on bed (+0.20m); channel widening/meandering
45	433677	5004179	95 m				Drain inlet from right side, accelerated bank erosion (large) on right bank; silt accumulations
46	433637	5004192	95 m				Narrow section of channel trying to widen/meander, large clump erosion both sides
47	433607	5004212	92 m				Extreme clump erosion/widening and downcutting of channel; meandering
48	433564	5004260	97 m				Heavy silt accumulations on bed, narrow channel tryng to widen
49	433534	5004286	95 m				Clump erosion within narrow channel; attempting to meander; silt accumulations
50	433528	5004301	97 m				Major clump erosion as channel widens downstream of Perth Road
51	433501	5004308	94 m				Downstream side, Perth Road culvert; silt accumulations; channel attempting to widen

Legend:			
Severity	Stability	Priority	
			High
			Moderate
			Low

APPENDIX B

PHOTOS (TO FOLLOW IN FINAL DRAFT)

PROJECT	RICHMOND SUBDIVISION: VAN GAAL DRAIN, RICHMOND, ONTARIO
REACH	1: JOCK RIVER TO FOWLER STREET
Site Number 1	


PROJECT	RICHMOND SUBDIVISION: VAN GAAL DRAIN, RICHMOND, ONTARIO
REACH	1: JOCK RIVER TO FOWLER STREET
Site Number 2	


PROJECT	RICHMOND SUBDIVISION: VAN GAAL DRAIN, RICHMOND, ONTARIO
REACH	1: JOCK RIVER TO FOWLER STREET
Site Number 3	


PROJECT	RICHMOND SUBDIVISION: VAN GAAL DRAIN, RICHMOND, ONTARIO
REACH	1: JOCK RIVER TO FOWLER STREET
Site Number 4	


PROJECT	RICHMOND SUBDIVISION: VAN GAAL DRAIN, RICHMOND, ONTARIO
REACH	1: JOCK RIVER TO FOWLER STREET
Site Number 5	


PROJECT	RICHMOND SUBDIVISION: VAN GAAL DRAIN, RICHMOND, ONTARIO
REACH	1: JOCK RIVER TO FOWLER STREET
Site Number 6	


PROJECT	RICHMOND SUBDIVISION: VAN GAAL DRAIN, RICHMOND, ONTARIO
REACH	1: JOCK RIVER TO FOWLER STREET
Site Number 7	


PROJECT	RICHMOND SUBDIVISION: VAN GAAL DRAIN, RICHMOND, ONTARIO
REACH	1: JOCK RIVER TO FOWLER STREET
Site Number 8	


PROJECT	RICHMOND SUBDIVISION: VAN GAAL DRAIN, RICHMOND, ONTARIO
REACH	1: JOCK RIVER TO FOWLER STREET
Site Number 9	


PROJECT	RICHMOND SUBDIVISION: VAN GAAL DRAIN, RICHMOND, ONTARIO
REACH	1: JOCK RIVER TO FOWLER STREET
Site Number 10	


PROJECT	RICHMOND SUBDIVISION: VAN GAAL DRAIN, RICHMOND, ONTARIO
REACH	1: JOCK RIVER TO FOWLER STREET
Site Number 11	


PROJECT	RICHMOND SUBDIVISION: VAN GAAL DRAIN, RICHMOND, ONTARIO
REACH	2: FOWLER STREET TO FORTUNE AVENUE
Site Number 12	


PROJECT	RICHMOND SUBDIVISION: VAN GAAL DRAIN, RICHMOND, ONTARIO
REACH	2: FOWLER STREET TO FORTUNE AVENUE
Site Number 13	


PROJECT	RICHMOND SUBDIVISION: VAN GAAL DRAIN, RICHMOND, ONTARIO
REACH	2: FOWLER STREET TO FORTUNE AVENUE
Site Number 14	


PROJECT	RICHMOND SUBDIVISION: VAN GAAL DRAIN, RICHMOND, ONTARIO
REACH	2: FOWLER STREET TO FORTUNE AVENUE
Site Number 15	


PROJECT	RICHMOND SUBDIVISION: VAN GAAL DRAIN, RICHMOND, ONTARIO
REACH	2: FOWLER STREET TO FORTUNE AVENUE
Site Number 16	


PROJECT	RICHMOND SUBDIVISION: VAN GAAL DRAIN, RICHMOND, ONTARIO
REACH	2: FOWLER STREET TO FORTUNE AVENUE
Site Number 17	


PROJECT	RICHMOND SUBDIVISION: VAN GAAL DRAIN, RICHMOND, ONTARIO
REACH	2: FOWLER STREET TO FORTUNE AVENUE
Site Number 18	


PROJECT	RICHMOND SUBDIVISION: VAN GAAL DRAIN, RICHMOND, ONTARIO
REACH	2: FOWLER STREET TO FORTUNE AVENUE
Site Number 19	


PROJECT	RICHMOND SUBDIVISION: VAN GAAL DRAIN, RICHMOND, ONTARIO
REACH	2: FOWLER STREET TO FORTUNE AVENUE
Site Number 20	


PROJECT	RICHMOND SUBDIVISION: VAN GAAL DRAIN, RICHMOND, ONTARIO
REACH	2: FOWLER STREET TO FORTUNE AVENUE
Site Number 21	


PROJECT	RICHMOND SUBDIVISION: VAN GAAL DRAIN, RICHMOND, ONTARIO
REACH	2: FOWLER STREET TO FORTUNE AVENUE
Site Number 22	


PROJECT	RICHMOND SUBDIVISION: VAN GAAL DRAIN, RICHMOND, ONTARIO
REACH	2: FOWLER STREET TO FORTUNE AVENUE
Site Number 23	


PROJECT	RICHMOND SUBDIVISION: VAN GAAL DRAIN, RICHMOND, ONTARIO
REACH	2: FOWLER STREET TO FORTUNE AVENUE
Site Number 24	


PROJECT	RICHMOND SUBDIVISION: VAN GAAL DRAIN, RICHMOND, ONTARIO
REACH	2: FOWLER STREET TO FORTUNE AVENUE
Site Number 25	


PROJECT	RICHMOND SUBDIVISION: VAN GAAL DRAIN, RICHMOND, ONTARIO
REACH	2: FOWLER STREET TO FORTUNE AVENUE
Site Number 26	


PROJECT	RICHMOND SUBDIVISION: VAN GAAL DRAIN, RICHMOND, ONTARIO
REACH	2: FOWLER STREET TO FORTUNE AVENUE
Site Number 27	


PROJECT	RICHMOND SUBDIVISION: VAN GAAL DRAIN, RICHMOND, ONTARIO
REACH	2: FOWLER STREET TO FORTUNE AVENUE
Site Number 28	


PROJECT	RICHMOND SUBDIVISION: VAN GAAL DRAIN, RICHMOND, ONTARIO
REACH	3: FORTUNE AVENUE TO PERTH ROAD
Site Number 29	


PROJECT	RICHMOND SUBDIVISION: VAN GAAL DRAIN, RICHMOND, ONTARIO
REACH	3: FORTUNE AVENUE TO PERTH ROAD
Site Number 30	


PROJECT	RICHMOND SUBDIVISION: VAN GAAL DRAIN, RICHMOND, ONTARIO
REACH	3: FORTUNE AVENUE TO PERTH ROAD
Site Number 31	


PROJECT	RICHMOND SUBDIVISION: VAN GAAL DRAIN, RICHMOND, ONTARIO
REACH	3: FORTUNE AVENUE TO PERTH ROAD
Site Number 32	


PROJECT	RICHMOND SUBDIVISION: VAN GAAL DRAIN, RICHMOND, ONTARIO
REACH	3: FORTUNE AVENUE TO PERTH ROAD
Site Number 33	


PROJECT	RICHMOND SUBDIVISION: VAN GAAL DRAIN, RICHMOND, ONTARIO
REACH	3: FORTUNE AVENUE TO PERTH ROAD
Site Number 34	


PROJECT	RICHMOND SUBDIVISION: VAN GAAL DRAIN, RICHMOND, ONTARIO
REACH	3: FORTUNE AVENUE TO PERTH ROAD
Site Number 35	


PROJECT	RICHMOND SUBDIVISION: VAN GAAL DRAIN, RICHMOND, ONTARIO
REACH	3: FORTUNE AVENUE TO PERTH ROAD
Site Number 36	

PROJECT	RICHMOND SUBDIVISION: VAN GAAL DRAIN, RICHMOND, ONTARIO
REACH	3: FORTUNE AVENUE TO PERTH ROAD
Site Number 37	


PROJECT	RICHMOND SUBDIVISION: VAN GAAL DRAIN, RICHMOND, ONTARIO
REACH	3: FORTUNE AVENUE TO PERTH ROAD
Site Number 38	


PROJECT	RICHMOND SUBDIVISION: VAN GAAL DRAIN, RICHMOND, ONTARIO
REACH	3: FORTUNE AVENUE TO PERTH ROAD
Site Number 39	


PROJECT	RICHMOND SUBDIVISION: VAN GAAL DRAIN, RICHMOND, ONTARIO
REACH	3: FORTUNE AVENUE TO PERTH ROAD
Site Number 40	


PROJECT	RICHMOND SUBDIVISION: VAN GAAL DRAIN, RICHMOND, ONTARIO
REACH	3: FORTUNE AVENUE TO PERTH ROAD
Site Number 41	


PROJECT	RICHMOND SUBDIVISION: VAN GAAL DRAIN, RICHMOND, ONTARIO
REACH	3: FORTUNE AVENUE TO PERTH ROAD
Site Number 42	


PROJECT	RICHMOND SUBDIVISION: VAN GAAL DRAIN, RICHMOND, ONTARIO
REACH	3: FORTUNE AVENUE TO PERTH ROAD
Site Number 43	


PROJECT	RICHMOND SUBDIVISION: VAN GAAL DRAIN, RICHMOND, ONTARIO
REACH	3: FORTUNE AVENUE TO PERTH ROAD
Site Number 44	


PROJECT	RICHMOND SUBDIVISION: VAN GAAL DRAIN, RICHMOND, ONTARIO
REACH	3: FORTUNE AVENUE TO PERTH ROAD
Site Number 45	


PROJECT	RICHMOND SUBDIVISION: VAN GAAL DRAIN, RICHMOND, ONTARIO
REACH	3: FORTUNE AVENUE TO PERTH ROAD
Site Number 46	

PROJECT	RICHMOND SUBDIVISION: VAN GAAL DRAIN, RICHMOND, ONTARIO
REACH	3: FORTUNE AVENUE TO PERTH ROAD
Site Number 47	

PROJECT	RICHMOND SUBDIVISION: VAN GAAL DRAIN, RICHMOND, ONTARIO
REACH	3: FORTUNE AVENUE TO PERTH ROAD
Site Number 48	

PROJECT	RICHMOND SUBDIVISION: VAN GAAL DRAIN, RICHMOND, ONTARIO
REACH	3: FORTUNE AVENUE TO PERTH ROAD
Site Number 49	


PROJECT	RICHMOND SUBDIVISION: VAN GAAL DRAIN, RICHMOND, ONTARIO
REACH	3: FORTUNE AVENUE TO PERTH ROAD
Site Number 50	


APPENDIX C

FLOW DATA

Van Gaal Drain Cross-Section Number 1 GPS Location: 5004196 433681

WSE	DEPTH (m)	DISCHARGE (m^3 sec^{-1})	VELOCITY (m sec^{-1})	FLOW AREA (m^2)	WETTED P (m)	WIDTH (m)	BED SHEAR (N m^{-2})	BANK SHEAR (N m^{-2})	CURVE SHEAR (N m^{-2})
87.52	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
87.53	0.01	0.00	0.04	0.00	0.39	0.39	0.16	0.09	0.10
87.54	0.02	0.00	0.07	0.01	0.52	0.39	0.31	0.21	0.23
87.55	0.03	0.00	0.09	0.01	0.65	0.39	0.47	0.34	0.37
87.56	0.04	0.00	0.12	0.02	0.75	0.39	0.63	0.47	0.52
87.57	0.05	0.00	0.14	0.03	0.84	0.39	0.78	0.61	0.67
87.58	0.06	0.01	0.15	0.04	0.93	0.39	0.94	0.75	0.82
87.59	0.07	0.01	0.17	0.05	1.03	0.39	1.10	0.89	0.98
87.60	0.08	0.01	0.18	0.06	1.12	0.39	1.26	1.04	1.14
87.61	0.09	0.01	0.20	0.07	1.20	0.39	1.41	1.19	1.31
87.62	0.10	0.02	0.21	0.08	1.28	0.39	1.57	1.34	1.47
87.63	0.11	0.02	0.22	0.09	1.35	0.39	1.73	1.49	1.64
87.64	0.12	0.02	0.23	0.11	1.43	0.39	1.88	1.65	1.81
87.65	0.13	0.03	0.25	0.12	1.51	0.39	2.04	1.80	1.99
87.66	0.14	0.04	0.26	0.14	1.58	0.39	2.20	1.96	2.16
87.67	0.15	0.04	0.27	0.15	1.64	0.39	2.35	2.12	2.33
87.68	0.16	0.05	0.29	0.17	1.69	0.39	2.51	2.28	2.51
87.69	0.17	0.05	0.30	0.18	1.74	0.39	2.67	2.44	2.69
87.70	0.18	0.06	0.31	0.20	1.80	0.39	2.83	2.61	2.87
87.71	0.19	0.07	0.32	0.22	1.85	0.39	2.98	2.77	3.05
87.72	0.20	0.08	0.33	0.24	1.91	0.39	3.14	2.93	3.23
87.73	0.21	0.09	0.34	0.26	1.96	0.39	3.30	3.10	3.41
87.74	0.22	0.10	0.35	0.27	2.01	0.39	3.45	3.27	3.59
87.75	0.23	0.11	0.36	0.29	2.07	0.39	3.61	3.43	3.78
87.76	0.24	0.12	0.37	0.31	2.12	0.39	3.77	3.60	3.96
87.77	0.25	0.13	0.38	0.34	2.19	0.39	3.92	3.77	4.15
87.78	0.26	0.14	0.39	0.36	2.25	0.39	4.08	3.94	4.33
87.79	0.27	0.15	0.40	0.38	2.32	0.39	4.24	4.11	4.52
87.80	0.28	0.16	0.41	0.40	2.39	0.39	4.39	4.28	4.71
87.81	0.29	0.18	0.41	0.42	2.46	0.39	4.55	4.45	4.90
87.82	0.30	0.19	0.42	0.45	2.52	0.39	4.71	4.63	5.09
87.83	0.31	0.20	0.43	0.47	2.59	0.39	4.87	4.80	5.28
87.84	0.32	0.22	0.44	0.50	2.66	0.39	5.02	4.97	5.47
87.85	0.33	0.23	0.44	0.52	2.78	0.39	5.18	5.15	5.66
87.86	0.34	0.25	0.45	0.55	2.84	0.39	5.34	5.32	5.85
87.87	0.35	0.26	0.46	0.58	2.89	0.39	5.49	5.50	6.04
87.88	0.36	0.28	0.46	0.61	2.95	0.39	5.65	5.67	6.24
87.89	0.37	0.30	0.47	0.63	3.00	0.39	5.81	5.85	6.43
87.90	0.38	0.32	0.48	0.66	3.06	0.39	5.96	6.02	6.63
87.91	0.39	0.34	0.49	0.69	3.11	0.39	6.12	6.20	6.82
87.92	0.40	0.36	0.50	0.72	3.17	0.39	6.28	6.38	7.02
87.93	0.41	0.38	0.51	0.75	3.22	0.39	6.44	6.56	7.21
87.94	0.42	0.40	0.51	0.78	3.28	0.39	6.59	6.73	7.41
87.95	0.43	0.43	0.52	0.82	3.33	0.39	6.75	6.91	7.60
87.96	0.44	0.45	0.53	0.85	3.42	0.39	6.91	7.09	7.80
87.97	0.45	0.47	0.53	0.88	3.50	0.39	7.06	7.27	8.00
87.98	0.46	0.49	0.54	0.91	3.59	0.39	7.22	7.45	8.20
87.99	0.47	0.51	0.54	0.95	3.65	0.39	7.38	7.63	8.40
88.00	0.48	0.54	0.55	0.98	3.72	0.39	7.53	7.81	8.60
88.01	0.49	0.57	0.56	1.02	3.78	0.39	7.69	8.00	8.80
88.02	0.50	0.59	0.56	1.06	3.85	0.39	7.85	8.18	8.99
88.03	0.51	0.62	0.57	1.09	3.91	0.39	8.00	8.36	9.20
88.04	0.52	0.65	0.58	1.13	3.98	0.39	8.16	8.54	9.40
88.05	0.53	0.68	0.58	1.17	4.02	0.39	8.32	8.72	9.60
88.06	0.54	0.72	0.59	1.21	4.07	0.39	8.48	8.91	9.80
88.07	0.55	0.75	0.60	1.25	4.11	0.39	8.63	9.09	10.00
88.08	0.56	0.78	0.61	1.29	4.15	0.39	8.79	9.27	10.20
88.09	0.57	0.82	0.62	1.32	4.20	0.39	8.95	9.46	10.40
88.10	0.58	0.85	0.63	1.36	4.25	0.39	9.10	9.64	10.61
88.11	0.59	0.89	0.63	1.40	4.30	0.39	9.26	9.83	10.81
88.12	0.60	0.92	0.64	1.45	4.35	0.39	9.42	10.01	11.01
88.13	0.61	0.96	0.65	1.49	4.41	0.39	9.57	10.20	11.22
88.14	0.62	1.00	0.65	1.53	4.46	0.39	9.73	10.38	11.42
88.15	0.63	1.04	0.66	1.57	4.50	0.39	9.89	10.57	11.63
88.16	0.64	1.08	0.67	1.61	4.55	0.39	10.05	10.76	11.83
88.17	0.65	1.12	0.67	1.66	4.60	0.39	10.20	10.94	12.04
88.18	0.66	1.16	0.68	1.70	4.64	0.39	10.36	11.13	12.24

WSE	DEPTH (m)	DISCHARGE (m^3 sec^{-1})	VELOCITY (m sec^{-1})	FLOW AREA (m^2)	WETTED P (m)	WIDTH (m)	BED SHEAR (N m^{-2})	BANK SHEAR (N m^{-2})	CURVE SHEAR (N m^{-2})
88.19	0.67	1.20	0.69	1.74	4.69	0.39	10.52	11.32	12.45
88.20	0.68	1.24	0.70	1.79	4.74	0.39	10.67	11.50	12.66
88.21	0.69	1.29	0.70	1.83	4.79	0.39	10.83	11.69	12.86
88.22	0.70	1.33	0.71	1.88	4.83	0.39	10.99	11.88	13.07
88.23	0.71	1.38	0.72	1.92	4.88	0.39	11.14	12.07	13.28
88.24	0.72	1.22	0.62	1.97	6.19	0.39	11.30	12.26	13.48
88.25	0.73	1.27	0.63	2.02	6.26	0.39	11.46	12.45	13.69
88.26	0.74	1.32	0.64	2.08	6.34	0.39	11.62	12.63	13.90
88.27	0.75	1.38	0.64	2.14	6.41	0.39	11.77	12.82	14.11
88.28	0.76	1.43	0.65	2.20	6.48	0.39	11.93	13.01	14.31
88.29	0.77	1.49	0.66	2.27	6.56	0.39	12.09	13.20	14.52
88.30	0.78	1.54	0.66	2.33	6.63	0.39	12.24	13.39	14.73
88.31	0.79	1.60	0.67	2.39	6.71	0.39	12.40	13.58	14.94
88.32	0.80	1.66	0.68	2.45	6.78	0.39	12.56	13.77	15.15
88.33	0.81	1.72	0.68	2.52	6.86	0.39	12.71	13.96	15.36
88.34	0.82	1.78	0.69	2.58	6.93	0.39	12.87	14.15	15.57
88.35	0.83	1.85	0.70	2.65	6.98	0.39	13.03	14.35	15.78
88.36	0.84	1.92	0.71	2.71	7.04	0.39	13.18	14.54	15.99
88.37	0.85	1.99	0.71	2.78	7.09	0.39	13.34	14.73	16.20
88.38	0.86	2.05	0.72	2.85	7.14	0.39	13.50	14.92	16.41
88.39	0.87	2.13	0.73	2.91	7.19	0.39	13.66	15.11	16.62
88.40	0.88	2.20	0.74	2.98	7.24	0.39	13.81	15.30	16.84
88.41	0.89	2.27	0.75	3.05	7.30	0.39	13.97	15.50	17.05
88.42	0.90	2.34	0.75	3.12	7.35	0.39	14.13	15.69	17.26
88.43	0.91	2.42	0.76	3.18	7.40	0.39	14.28	15.88	17.47
88.44	0.92	2.50	0.77	3.25	7.45	0.39	14.44	16.08	17.68
88.45	0.93	2.57	0.77	3.32	7.51	0.39	14.60	16.27	17.90
88.46	0.94	2.65	0.78	3.39	7.56	0.39	14.75	16.46	18.11
88.47	0.95	2.73	0.79	3.46	7.61	0.39	14.91	16.66	18.32
88.48	0.96	2.81	0.80	3.53	7.66	0.39	15.07	16.85	18.53
88.49	0.97	2.90	0.80	3.61	7.72	0.39	15.23	17.04	18.75
88.50	0.98	2.98	0.81	3.68	7.77	0.39	15.38	17.24	18.96
88.51	0.99	3.06	0.82	3.75	7.82	0.39	15.54	17.43	19.17
88.52	1.00	3.15	0.82	3.82	7.87	0.39	15.70	17.63	19.39
88.53	1.01	3.24	0.83	3.90	7.92	0.39	15.85	17.82	19.60
88.54	1.02	3.32	0.84	3.97	7.98	0.39	16.01	18.02	19.82
88.55	1.03	3.41	0.84	4.04	8.03	0.39	16.17	18.21	20.03
88.56	1.04	3.50	0.85	4.12	8.08	0.39	16.32	18.41	20.25
88.57	1.05	3.60	0.86	4.19	8.13	0.39	16.48	18.60	20.46
88.58	1.06	3.69	0.86	4.27	8.18	0.39	16.64	18.80	20.68
88.59	1.07	3.78	0.87	4.34	8.23	0.39	16.79	18.99	20.89
88.60	1.08	3.88	0.88	4.42	8.28	0.39	16.95	19.19	21.11
88.61	1.09	3.97	0.88	4.50	8.33	0.39	17.11	19.38	21.32
88.62	1.10	4.07	0.89	4.57	8.38	0.39	17.27	19.58	21.54
88.63	1.11	4.17	0.90	4.65	8.43	0.39	17.42	19.78	21.76
88.64	1.12	4.27	0.90	4.73	8.48	0.39	17.58	19.97	21.97
88.65	1.13	4.37	0.91	4.81	8.53	0.39	17.74	20.17	22.19
88.66	1.14	4.47	0.92	4.88	8.58	0.39	17.89	20.37	22.40
88.67	1.15	4.58	0.92	4.96	8.63	0.39	18.05	20.56	22.62
88.68	1.16	4.68	0.93	5.04	8.68	0.39	18.21	20.76	22.84
88.69	1.17	4.79	0.93	5.12	8.73	0.39	18.36	20.96	23.06

Van Gaal Drain Cross-Section Number 2 GPS Location: 5004083 433975

WSE	DEPTH (m)	DISCHARGE (m^3 sec^{-1})	VELOCITY (m sec^{-1})	FLOW AREA (m^2)	WETTED P (m)	WIDTH (m)	BED SHEAR (N m^{-2})	BANK SHEAR (N m^{-2})	CURVE SHEAR (N m^{-2})
88.69	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
88.70	0.01	0.00	0.04	0.00	0.16	0.16	0.19	0.13	0.14
88.71	0.02	0.00	0.07	0.00	0.32	0.32	0.38	0.26	0.28
88.72	0.03	0.00	0.09	0.01	0.49	0.48	0.56	0.39	0.43
88.73	0.04	0.00	0.11	0.01	0.65	0.64	0.75	0.52	0.57
88.74	0.05	0.00	0.12	0.02	0.81	0.80	0.94	0.65	0.71
88.75	0.06	0.00	0.14	0.03	0.93	0.92	1.13	0.78	0.86
88.76	0.07	0.01	0.16	0.04	1.05	1.04	1.31	0.92	1.01
88.77	0.08	0.01	0.18	0.05	1.12	1.11	1.50	1.06	1.17
88.78	0.09	0.01	0.20	0.06	1.19	1.17	1.69	1.20	1.32
88.79	0.10	0.02	0.22	0.07	1.25	1.23	1.88	1.35	1.49
88.80	0.11	0.02	0.23	0.09	1.32	1.30	2.06	1.50	1.64
88.81	0.12	0.02	0.25	0.10	1.39	1.36	2.25	1.64	1.81
88.82	0.13	0.03	0.26	0.11	1.45	1.43	2.44	1.79	1.97
88.83	0.14	0.04	0.28	0.13	1.52	1.49	2.63	1.94	2.13
88.84	0.15	0.04	0.29	0.14	1.59	1.55	2.81	2.08	2.29
88.85	0.16	0.05	0.31	0.16	1.65	1.61	3.00	2.23	2.45
88.86	0.17	0.06	0.32	0.17	1.71	1.67	3.19	2.38	2.62
88.87	0.18	0.06	0.33	0.19	1.77	1.73	3.38	2.53	2.78
88.88	0.19	0.07	0.34	0.21	1.84	1.79	3.57	2.68	2.94
88.89	0.20	0.08	0.35	0.23	1.90	1.85	3.75	2.83	3.11
88.90	0.21	0.09	0.37	0.25	1.96	1.90	3.94	2.98	3.28
88.91	0.22	0.10	0.38	0.27	2.02	1.96	4.13	3.13	3.44
88.92	0.23	0.11	0.39	0.29	2.07	2.00	4.32	3.28	3.61
88.93	0.24	0.12	0.40	0.31	2.11	2.04	4.50	3.44	3.78
88.94	0.25	0.13	0.41	0.33	2.16	2.08	4.69	3.59	3.95
88.95	0.26	0.15	0.43	0.35	2.20	2.12	4.88	3.75	4.12
88.96	0.27	0.16	0.44	0.37	2.25	2.16	5.07	3.90	4.29
88.97	0.28	0.17	0.45	0.39	2.30	2.20	5.25	4.06	4.46
88.98	0.29	0.19	0.46	0.41	2.34	2.24	5.44	4.21	4.63
88.99	0.30	0.20	0.47	0.44	2.39	2.28	5.63	4.37	4.80
89.00	0.31	0.22	0.48	0.46	2.43	2.32	5.82	4.52	4.98
89.01	0.32	0.24	0.49	0.48	2.48	2.36	6.01	4.68	5.15
89.02	0.33	0.25	0.50	0.51	2.53	2.41	6.19	4.83	5.32
89.03	0.34	0.27	0.51	0.53	2.57	2.45	6.38	4.99	5.49
89.04	0.35	0.29	0.52	0.55	2.62	2.49	6.57	5.15	5.66
89.05	0.36	0.31	0.53	0.58	2.66	2.53	6.76	5.30	5.83
89.06	0.37	0.32	0.54	0.61	2.71	2.57	6.94	5.46	6.01
89.07	0.38	0.34	0.55	0.63	2.76	2.61	7.13	5.62	6.18
89.08	0.39	0.36	0.55	0.66	2.80	2.65	7.32	5.77	6.35
89.09	0.40	0.39	0.56	0.68	2.85	2.69	7.51	5.93	6.52
89.10	0.41	0.41	0.57	0.71	2.89	2.73	7.69	6.09	6.70
89.11	0.42	0.43	0.58	0.74	2.94	2.77	7.88	6.25	6.87
89.12	0.43	0.45	0.59	0.77	2.99	2.81	8.07	6.40	7.04
89.13	0.44	0.47	0.60	0.79	3.03	2.85	8.26	6.56	7.22
89.14	0.45	0.50	0.61	0.82	3.08	2.89	8.44	6.72	7.39
89.15	0.46	0.52	0.61	0.85	3.13	2.93	8.63	6.88	7.56
89.16	0.47	0.55	0.62	0.88	3.17	2.97	8.82	7.03	7.74
89.17	0.48	0.57	0.63	0.91	3.22	3.01	9.01	7.19	7.91
89.18	0.49	0.60	0.64	0.94	3.27	3.05	9.20	7.35	8.08
89.19	0.50	0.63	0.64	0.97	3.32	3.10	9.38	7.50	8.25
89.20	0.51	0.65	0.65	1.00	3.36	3.14	9.57	7.66	8.43
89.21	0.52	0.68	0.66	1.04	3.41	3.18	9.76	7.82	8.60
89.22	0.53	0.71	0.67	1.07	3.45	3.22	9.95	7.98	8.78
89.23	0.54	0.74	0.67	1.10	3.50	3.26	10.13	8.14	8.95
89.24	0.55	0.77	0.68	1.13	3.54	3.30	10.32	8.29	9.12
89.25	0.56	0.80	0.69	1.17	3.59	3.34	10.51	8.45	9.30
89.26	0.57	0.84	0.70	1.20	3.63	3.38	10.70	8.61	9.47
89.27	0.58	0.87	0.70	1.23	3.68	3.42	10.88	8.77	9.64
89.28	0.59	0.90	0.71	1.27	3.73	3.46	11.07	8.93	9.82
89.29	0.60	0.94	0.72	1.30	3.77	3.50	11.26	9.08	9.99
89.30	0.61	0.97	0.73	1.34	3.82	3.55	11.45	9.24	10.16
89.31	0.62	1.01	0.73	1.37	3.86	3.58	11.64	9.40	10.34
89.32	0.63	1.04	0.74	1.41	3.91	3.63	11.82	9.56	10.51
89.33	0.64	1.08	0.74	1.45	3.96	3.68	12.01	9.71	10.68
89.34	0.65	1.11	0.75	1.48	4.01	3.72	12.20	9.87	10.86
89.35	0.66	1.15	0.76	1.52	4.06	3.77	12.39	10.02	11.03

WSE	DEPTH (m)	DISCHARGE (m^3 sec^{-1})	VELOCITY (m sec^{-1})	FLOW AREA (m^2)	WETTED P (m)	WIDTH (m)	BED SHEAR (N m^{-2})	BANK SHEAR (N m^{-2})	CURVE SHEAR (N m^{-2})
89.36	0.67	1.19	0.76	1.56	4.11	3.81	12.57	10.18	11.20
89.37	0.68	1.23	0.77	1.60	4.16	3.86	12.76	10.34	11.37
89.38	0.69	1.27	0.78	1.64	4.21	3.91	12.95	10.49	11.54
89.39	0.70	1.31	0.78	1.68	4.27	3.96	13.14	10.65	11.71
89.40	0.71	1.35	0.79	1.72	4.32	4.00	13.32	10.80	11.88
89.41	0.72	1.39	0.79	1.76	4.37	4.05	13.51	10.96	12.05
89.42	0.73	1.44	0.80	1.80	4.42	4.10	13.70	11.11	12.22
89.43	0.74	1.48	0.81	1.84	4.47	4.14	13.89	11.27	12.40
89.44	0.75	1.53	0.81	1.88	4.51	4.18	14.07	11.43	12.57
89.45	0.76	1.58	0.82	1.92	4.55	4.22	14.26	11.59	12.75
89.46	0.77	1.62	0.83	1.96	4.60	4.26	14.45	11.75	12.92
89.47	0.78	1.67	0.83	2.01	4.64	4.29	14.64	11.91	13.10
89.48	0.79	1.72	0.84	2.05	4.70	4.35	14.83	12.06	13.27
89.49	0.80	1.77	0.84	2.09	4.75	4.40	15.01	12.22	13.44
89.50	0.81	1.81	0.85	2.14	4.81	4.45	15.20	12.37	13.61
89.51	0.82	1.86	0.85	2.18	4.86	4.50	15.39	12.53	13.78
89.52	0.83	1.91	0.86	2.23	4.92	4.55	15.58	12.68	13.95
89.53	0.84	1.97	0.86	2.27	4.97	4.60	15.76	12.83	14.12
89.54	0.85	2.02	0.87	2.32	5.03	4.65	15.95	12.99	14.29
89.55	0.86	2.07	0.88	2.37	5.09	4.70	16.14	13.14	14.46

Van Gaal Drain Cross-Section Number 3 GPS Location: 5004153 434250

WSE	DEPTH (m)	DISCHARGE (m^3 sec^{-1})	VELOCITY (m sec^{-1})	FLOW AREA (m^2)	WETTED P (m)	WIDTH (m)	BED SHEAR (N m^{-2})	BANK SHEAR (N m^{-2})	CURVE SHEAR (N m^{-2})
88.48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
88.49	0.01	0.00	0.04	0.00	0.20	0.20	0.17	0.11	0.12
88.50	0.02	0.00	0.06	0.00	0.39	0.39	0.33	0.22	0.24
88.51	0.03	0.00	0.08	0.01	0.59	0.59	0.50	0.33	0.37
88.52	0.04	0.00	0.10	0.02	0.79	0.78	0.67	0.44	0.49
88.53	0.05	0.00	0.12	0.02	0.98	0.98	0.83	0.56	0.61
88.54	0.06	0.00	0.13	0.04	1.18	1.17	1.00	0.67	0.73
88.55	0.07	0.01	0.11	0.05	2.23	2.23	1.17	0.71	0.78
88.56	0.08	0.01	0.13	0.07	2.36	2.36	1.34	0.82	0.91
88.57	0.09	0.01	0.16	0.09	2.50	2.48	1.50	0.94	1.03
88.58	0.10	0.02	0.18	0.12	2.63	2.61	1.67	1.05	1.16
88.59	0.11	0.03	0.20	0.15	2.76	2.74	1.84	1.17	1.29
88.60	0.12	0.04	0.21	0.18	2.85	2.84	2.00	1.29	1.42
88.61	0.13	0.05	0.23	0.20	2.95	2.93	2.17	1.41	1.55
88.62	0.14	0.06	0.25	0.23	3.05	3.03	2.34	1.53	1.68
88.63	0.15	0.07	0.26	0.26	3.15	3.13	2.50	1.65	1.81
88.64	0.16	0.08	0.28	0.30	3.25	3.22	2.67	1.77	1.95
88.65	0.17	0.10	0.29	0.33	3.33	3.29	2.84	1.89	2.08
88.66	0.18	0.11	0.31	0.36	3.41	3.36	3.01	2.02	2.22
88.67	0.19	0.13	0.32	0.40	3.48	3.43	3.17	2.14	2.35
88.68	0.20	0.14	0.34	0.43	3.56	3.50	3.34	2.27	2.49
88.69	0.21	0.16	0.35	0.47	3.64	3.57	3.51	2.39	2.63
88.70	0.22	0.18	0.36	0.50	3.72	3.64	3.67	2.52	2.77
88.71	0.23	0.20	0.37	0.54	3.80	3.71	3.84	2.64	2.91
88.72	0.24	0.22	0.39	0.58	3.87	3.78	4.01	2.77	3.04
88.73	0.25	0.24	0.40	0.61	3.95	3.85	4.17	2.89	3.18
88.74	0.26	0.27	0.41	0.65	4.03	3.92	4.34	3.02	3.32
88.75	0.27	0.28	0.41	0.69	4.34	4.22	4.51	3.12	3.43
88.76	0.28	0.30	0.40	0.74	4.65	4.52	4.68	3.22	3.54
88.77	0.29	0.32	0.40	0.78	4.96	4.82	4.84	3.31	3.65
88.78	0.30	0.34	0.40	0.83	5.27	5.12	5.01	3.41	3.75
88.79	0.31	0.37	0.42	0.89	5.34	5.18	5.18	3.54	3.89
88.80	0.32	0.40	0.43	0.94	5.41	5.24	5.34	3.67	4.03
88.81	0.33	0.44	0.44	0.99	5.48	5.30	5.51	3.79	4.17
88.82	0.34	0.47	0.45	1.04	5.54	5.36	5.68	3.92	4.31
88.83	0.35	0.51	0.47	1.10	5.57	5.38	5.84	4.05	4.46
88.84	0.36	0.55	0.48	1.15	5.61	5.41	6.01	4.18	4.60
88.85	0.37	0.59	0.49	1.21	5.64	5.43	6.18	4.32	4.75
88.86	0.38	0.64	0.50	1.26	5.67	5.45	6.34	4.45	4.90
88.87	0.39	0.68	0.52	1.32	5.70	5.47	6.51	4.59	5.04
88.88	0.40	0.73	0.53	1.37	5.73	5.49	6.68	4.72	5.19
88.89	0.41	0.77	0.54	1.43	5.76	5.51	6.85	4.86	5.34
88.90	0.42	0.82	0.55	1.48	5.79	5.53	7.01	4.99	5.49
88.91	0.43	0.87	0.57	1.54	5.82	5.56	7.18	5.12	5.64
88.92	0.44	0.92	0.58	1.59	5.85	5.58	7.35	5.26	5.79
88.93	0.45	0.97	0.59	1.65	5.89	5.60	7.51	5.40	5.94
88.94	0.46	1.02	0.60	1.70	5.92	5.62	7.68	5.53	6.09
88.95	0.47	1.07	0.61	1.76	5.95	5.64	7.85	5.67	6.24
88.96	0.48	1.13	0.62	1.82	5.98	5.66	8.01	5.81	6.39
88.97	0.49	1.18	0.63	1.87	6.01	5.68	8.18	5.94	6.54
88.98	0.50	1.24	0.64	1.93	6.04	5.71	8.35	6.08	6.69
88.99	0.51	1.30	0.65	1.99	6.07	5.73	8.52	6.22	6.84
89.00	0.52	1.36	0.66	2.04	6.10	5.75	8.68	6.36	6.99
89.01	0.53	1.42	0.67	2.10	6.13	5.77	8.85	6.49	7.14
89.02	0.54	1.48	0.68	2.16	6.17	5.79	9.02	6.63	7.30
89.03	0.55	1.54	0.69	2.22	6.20	5.81	9.18	6.77	7.45
89.04	0.56	1.60	0.70	2.28	6.23	5.83	9.35	6.91	7.60
89.05	0.57	1.66	0.71	2.33	6.26	5.86	9.52	7.05	7.75
89.06	0.58	1.73	0.72	2.39	6.29	5.88	9.68	7.19	7.91
89.07	0.59	1.79	0.73	2.45	6.32	5.90	9.85	7.33	8.06
89.08	0.60	1.86	0.74	2.51	6.35	5.92	10.02	7.47	8.21
89.09	0.61	1.93	0.75	2.57	6.38	5.94	10.18	7.61	8.37
89.10	0.62	2.00	0.76	2.63	6.41	5.96	10.35	7.75	8.52
89.11	0.63	2.07	0.77	2.69	6.45	5.98	10.52	7.89	8.68
89.12	0.64	2.13	0.77	2.75	6.50	6.03	10.69	8.02	8.82
89.13	0.65	2.20	0.78	2.81	6.56	6.08	10.85	8.16	8.97
89.14	0.66	2.26	0.79	2.87	6.61	6.13	11.02	8.29	9.12

WSE	DEPTH (m)	DISCHARGE (m^3 sec^{-1})	VELOCITY (m sec^{-1})	FLOW AREA (m^2)	WETTED P (m)	WIDTH (m)	BED SHEAR (N m^{-2})	BANK SHEAR (N m^{-2})	CURVE SHEAR (N m^{-2})
89.15	0.67	2.33	0.80	2.93	6.67	6.18	11.19	8.43	9.27
89.16	0.68	2.40	0.80	2.99	6.73	6.22	11.35	8.56	9.42
89.17	0.69	2.47	0.81	3.06	6.78	6.27	11.52	8.70	9.57
89.18	0.70	2.54	0.81	3.12	6.84	6.32	11.69	8.83	9.72
89.19	0.71	2.62	0.82	3.18	6.90	6.37	11.85	8.97	9.86
89.20	0.72	2.69	0.83	3.25	6.95	6.42	12.02	9.10	10.01
89.21	0.73	2.76	0.83	3.31	7.01	6.46	12.19	9.24	10.16
89.22	0.74	2.84	0.84	3.38	7.06	6.51	12.36	9.38	10.31
89.23	0.75	2.92	0.85	3.44	7.12	6.56	12.52	9.51	10.46
89.24	0.76	2.99	0.85	3.51	7.18	6.61	12.69	9.65	10.61
89.25	0.77	3.07	0.86	3.57	7.23	6.66	12.86	9.78	10.76
89.26	0.78	3.15	0.87	3.64	7.29	6.70	13.02	9.92	10.91
89.27	0.79	3.23	0.87	3.71	7.34	6.75	13.19	10.05	11.06
89.28	0.80	3.03	0.80	3.78	8.09	7.49	13.36	10.04	11.04

Van Gaal Drain Cross-Section Number 4 GPS Location: 5004133 434419

WSE	DEPTH (m)	DISCHARGE (m^3 sec^{-1})	VELOCITY (m sec^{-1})	FLOW AREA (m^2)	WETTED P (m)	WIDTH (m)	BED SHEAR (N m^{-2})	BANK SHEAR (N m^{-2})	CURVE SHEAR (N m^{-2})
87.97	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
87.98	0.01	0.00	0.04	0.00	0.10	0.10	0.18	0.14	0.15
87.99	0.02	0.00	0.07	0.00	0.20	0.19	0.37	0.27	0.30
88.00	0.03	0.00	0.09	0.00	0.30	0.29	0.55	0.41	0.45
88.01	0.04	0.00	0.09	0.01	0.60	0.59	0.73	0.51	0.56
88.02	0.05	0.00	0.10	0.02	0.89	0.88	0.92	0.62	0.68
88.03	0.06	0.00	0.11	0.03	1.19	1.17	1.10	0.73	0.81
88.04	0.07	0.01	0.13	0.04	1.49	1.46	1.28	0.84	0.93
88.05	0.08	0.01	0.15	0.05	1.64	1.61	1.47	0.97	1.07
88.06	0.09	0.01	0.17	0.07	1.79	1.76	1.65	1.10	1.21
88.07	0.10	0.02	0.19	0.09	1.95	1.91	1.83	1.22	1.35
88.08	0.11	0.02	0.21	0.11	2.02	1.98	2.02	1.36	1.50
88.09	0.12	0.03	0.23	0.13	2.09	2.04	2.20	1.50	1.65
88.10	0.13	0.04	0.24	0.15	2.16	2.11	2.38	1.64	1.80
88.11	0.14	0.04	0.26	0.17	2.23	2.18	2.57	1.78	1.95
88.12	0.15	0.05	0.28	0.19	2.29	2.24	2.75	1.92	2.11
88.13	0.16	0.06	0.29	0.22	2.36	2.31	2.93	2.05	2.26
88.14	0.17	0.07	0.31	0.24	2.43	2.38	3.12	2.19	2.41
88.15	0.18	0.09	0.32	0.26	2.50	2.44	3.30	2.34	2.57
88.16	0.19	0.10	0.34	0.29	2.57	2.51	3.48	2.48	2.72
88.17	0.20	0.11	0.35	0.31	2.64	2.58	3.67	2.62	2.88
88.18	0.21	0.12	0.35	0.34	2.81	2.74	3.85	2.74	3.02
88.19	0.22	0.13	0.36	0.37	2.98	2.91	4.03	2.87	3.15
88.20	0.23	0.15	0.36	0.40	3.15	3.08	4.21	2.99	3.29
88.21	0.24	0.16	0.37	0.43	3.32	3.24	4.40	3.12	3.43
88.22	0.25	0.18	0.39	0.46	3.35	3.26	4.58	3.27	3.59
88.23	0.26	0.20	0.40	0.50	3.38	3.28	4.76	3.41	3.76
88.24	0.27	0.22	0.42	0.53	3.41	3.30	4.95	3.56	3.92
88.25	0.28	0.24	0.43	0.56	3.44	3.32	5.13	3.71	4.09
88.26	0.29	0.26	0.44	0.60	3.47	3.34	5.31	3.87	4.25
88.27	0.30	0.29	0.46	0.63	3.50	3.36	5.50	4.02	4.42
88.28	0.31	0.31	0.47	0.66	3.54	3.38	5.68	4.17	4.58
88.29	0.32	0.34	0.48	0.70	3.57	3.40	5.86	4.32	4.75
88.30	0.33	0.36	0.50	0.73	3.60	3.43	6.05	4.47	4.92
88.31	0.34	0.39	0.51	0.77	3.63	3.45	6.23	4.62	5.09
88.32	0.35	0.42	0.52	0.80	3.66	3.47	6.41	4.78	5.25
88.33	0.36	0.45	0.53	0.83	3.69	3.49	6.60	4.93	5.42
88.34	0.37	0.47	0.55	0.87	3.72	3.51	6.78	5.08	5.59
88.35	0.38	0.50	0.56	0.90	3.76	3.53	6.96	5.24	5.76
88.36	0.39	0.53	0.57	0.94	3.79	3.55	7.15	5.39	5.93
88.37	0.40	0.55	0.56	0.98	4.02	3.77	7.33	5.50	6.05
88.38	0.41	0.58	0.57	1.01	4.09	3.83	7.51	5.65	6.21
88.39	0.42	0.61	0.58	1.05	4.15	3.90	7.70	5.79	6.37
88.40	0.43	0.64	0.58	1.09	4.22	3.96	7.88	5.94	6.53
88.41	0.44	0.67	0.59	1.13	4.29	4.02	8.06	6.08	6.69
88.42	0.45	0.70	0.60	1.17	4.36	4.08	8.25	6.23	6.85
88.43	0.46	0.74	0.61	1.21	4.42	4.15	8.43	6.37	7.01
88.44	0.47	0.77	0.62	1.25	4.49	4.21	8.61	6.52	7.17
88.45	0.48	0.81	0.62	1.30	4.56	4.27	8.80	6.66	7.33
88.46	0.49	0.85	0.63	1.34	4.59	4.30	8.98	6.82	7.50
88.47	0.50	0.89	0.64	1.38	4.62	4.32	9.16	6.97	7.67
88.48	0.51	0.93	0.66	1.43	4.65	4.35	9.35	7.13	7.84
88.49	0.52	0.98	0.67	1.47	4.68	4.37	9.53	7.28	8.01
88.50	0.53	1.02	0.68	1.51	4.72	4.39	9.71	7.44	8.18
88.51	0.54	1.07	0.69	1.56	4.75	4.42	9.90	7.59	8.35
88.52	0.55	1.11	0.70	1.60	4.78	4.44	10.08	7.75	8.52
88.53	0.56	1.16	0.70	1.65	4.81	4.47	10.26	7.90	8.69
88.54	0.57	1.21	0.71	1.69	4.84	4.49	10.45	8.06	8.87
88.55	0.58	1.26	0.72	1.74	4.87	4.52	10.63	8.22	9.04
88.56	0.59	1.31	0.73	1.78	4.91	4.54	10.81	8.37	9.21
88.57	0.60	1.36	0.74	1.83	4.94	4.56	11.00	8.53	9.38
88.58	0.61	1.41	0.75	1.87	4.97	4.59	11.18	8.69	9.55
88.59	0.62	1.46	0.76	1.92	5.00	4.61	11.36	8.84	9.73
88.60	0.63	1.51	0.77	1.97	5.03	4.64	11.54	9.00	9.90
88.61	0.64	1.57	0.78	2.01	5.06	4.66	11.73	9.16	10.07
88.62	0.65	1.62	0.79	2.06	5.09	4.69	11.91	9.31	10.25
88.63	0.66	1.68	0.80	2.11	5.13	4.71	12.09	9.47	10.42

WSE	DEPTH (m)	DISCHARGE (m^3 sec^{-1})	VELOCITY (m sec^{-1})	FLOW AREA (m^2)	WETTED P (m)	WIDTH (m)	BED SHEAR (N m^{-2})	BANK SHEAR (N m^{-2})	CURVE SHEAR (N m^{-2})
88.64	0.67	1.73	0.80	2.15	5.16	4.73	12.28	9.63	10.60
88.65	0.68	1.79	0.81	2.20	5.19	4.76	12.46	9.79	10.77
88.66	0.69	1.85	0.82	2.25	5.22	4.78	12.64	9.95	10.94
88.67	0.70	1.91	0.83	2.30	5.25	4.81	12.83	10.10	11.11
88.68	0.71	1.96	0.84	2.34	5.28	4.83	13.01	10.26	11.29
88.69	0.72	2.02	0.85	2.39	5.31	4.86	13.19	10.42	11.46
88.70	0.73	2.09	0.85	2.44	5.35	4.88	13.38	10.58	11.64
88.71	0.74	2.14	0.86	2.49	5.40	4.93	13.56	10.73	11.80
88.72	0.75	2.20	0.87	2.54	5.45	4.97	13.74	10.88	11.97
88.73	0.76	2.26	0.87	2.59	5.50	5.02	13.93	11.03	12.14
88.74	0.77	2.32	0.88	2.64	5.55	5.06	14.11	11.19	12.31
88.75	0.78	2.38	0.88	2.69	5.60	5.11	14.29	11.34	12.47
88.76	0.79	2.44	0.89	2.74	5.65	5.15	14.48	11.49	12.64
88.77	0.80	2.50	0.90	2.79	5.70	5.20	14.66	11.64	12.81
88.78	0.81	2.56	0.90	2.85	5.75	5.25	14.84	11.79	12.97
88.79	0.82	2.63	0.91	2.90	5.81	5.30	15.03	11.94	13.14
88.80	0.83	2.69	0.91	2.95	5.87	5.36	15.21	12.09	13.30
88.81	0.84	2.76	0.92	3.01	5.92	5.41	15.39	12.24	13.47
88.82	0.85	2.82	0.92	3.06	5.98	5.46	15.58	12.39	13.63
88.83	0.86	2.89	0.93	3.12	6.03	5.51	15.76	12.54	13.80
88.84	0.87	2.96	0.93	3.17	6.09	5.56	15.94	12.69	13.96
88.85	0.88	3.03	0.94	3.23	6.14	5.61	16.13	12.84	14.13
88.86	0.89	3.10	0.94	3.28	6.20	5.66	16.31	12.99	14.29
88.87	0.90	3.17	0.95	3.34	6.25	5.72	16.49	13.14	14.45
88.88	0.91	3.24	0.95	3.40	6.31	5.77	16.68	13.29	14.62
88.89	0.92	3.31	0.96	3.46	6.37	5.82	16.86	13.44	14.79
88.90	0.93	3.39	0.96	3.51	6.42	5.87	17.04	13.59	14.95