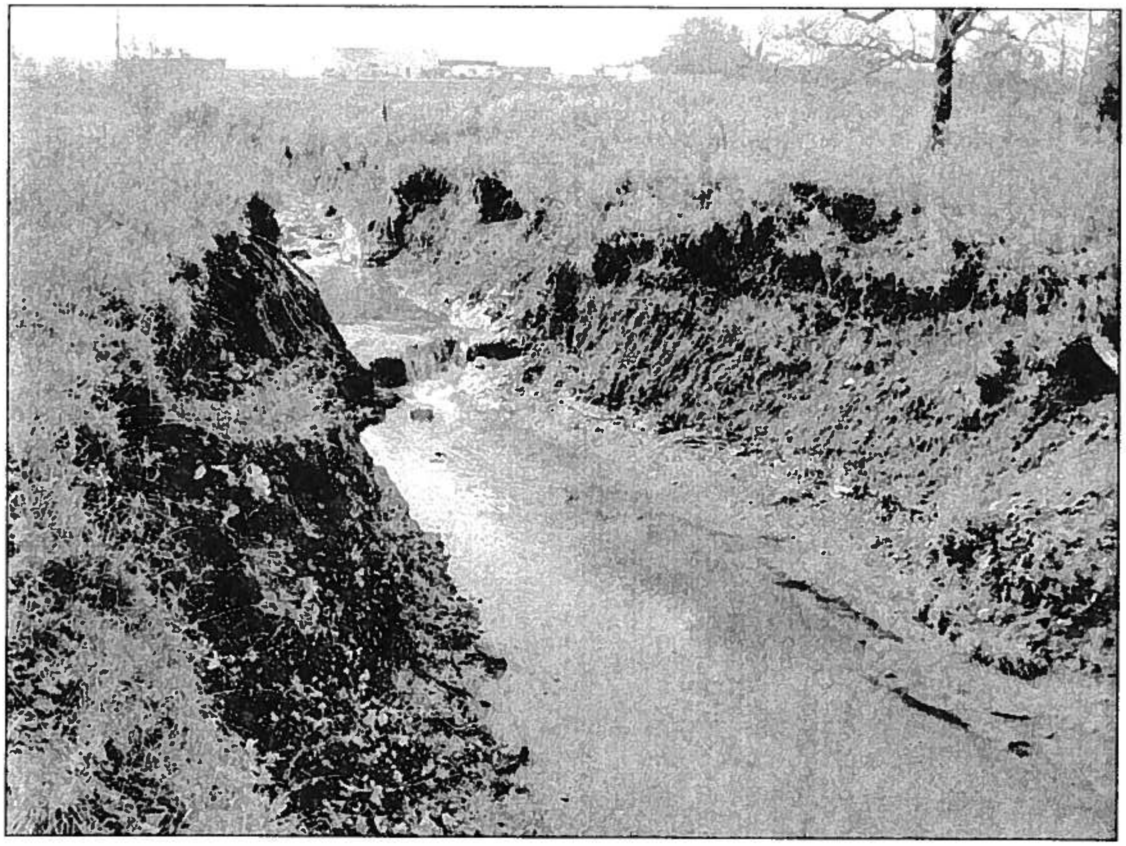
BURNSIDE

Appendix C
Telfer Creek and Kenny Drain Erosion Analysis

Erosion Thresholds Analysis
Telfer Creek and Kenny Drain
East Side Master Servicing Plan
City of Owen Sound



Submitted to:

R.J. Burnside & Associates Ltd.
3 Ronell Cres
Collingwood ON, L9Y 4J6

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AquaLogic Consulting
1-9 Ellen St., Mississauga, Ont., L5M 1R8
Tel: (905) 819-9076 Fax: (416) 850-3749
bill.degeus@sympatico.ca

Erosion Thresholds Analysis
Telfer Creek and Kenny Drain
East Side Master Servicing Plan
City of Owen Sound

Erosion threshold analysis has been undertaken for Telfer Creek and the Kenny Drain regarding proposed urban expansion in the southeast area of the City of Owen Sound. Key points in each watercourse system were field surveyed for geomorphic channel relationships. Detailed measurements were undertaken and used in subsequent geomorphic modeling of erosion threshold indicators. The results of modeling have been used to establish channel stability flow regime thresholds. The resultant stability discharge levels are recommended for erosion potential treatment through the requisite stormwater management program. Stormwater analysis alternatives were considered with respect to maintaining exceedance levels at or below thresholds and the Stability Discharge Index (SDI) approach is recommended as the preferred methodology for providing erosion potential control.

Telfer Creek Characterization

Telfer Creek is a low gradient 2nd order headwater watercourse with an upstream drainage area of approximately 2.5km^2 above the CP Railway study limit. The watercourse falls within the Cape Rich Steps physiographic region and is characterized as a partially altered glacial bottomland spillway feature. Parts of the watercourse have been straightened and diverted to facilitate local and agricultural drainage. Natural sections of the creek display subtle irregular meander patterns. The feature appears to be intermittent over most of its length with the uppermost sections being ephemeral. The watercourse is highly vegetation controlled with much of the study area displaying heavy encroachment from herbaceous and shrub thicket vegetation. Near the downstream limits of the study area the creek flows through mature forest conditions. Most of the feature is partially entrenched but channel stability is very high and channel bed forms are indistinct due to the encroaching vegetation influence. Downstream from the study area the creek becomes confluent with other watercourses and the combined system displays permanent flow and distinct alluvial channel form.

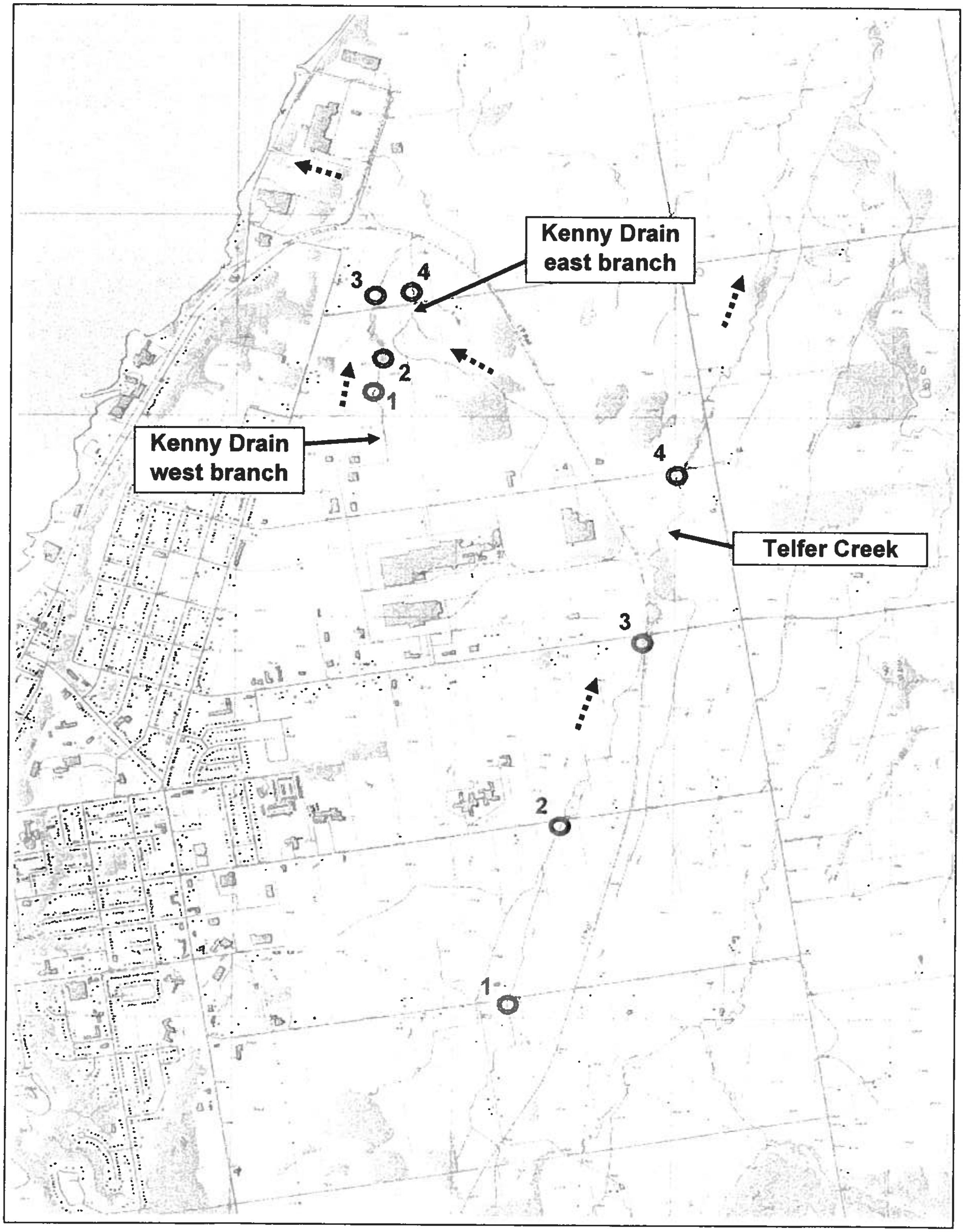
Kenny Drain Characterization

The Kenny Drain is characterized by a 2nd order east branch and a 1st order west branch (excluding roadside ditches) within the study area, having a combined drainage area of approximately 2.2km^2 at the CP Railway study limit. The watercourse falls within the Cape Rich Steps physiographic region. The east branch is similar to Telfer Creek, characterized as a low gradient glacial spillway with heavy vegetation encroachment and high levels of channel stability. The west branch, however, has a distinct mix of both natural and altered elements. The upper section of the Kenny Drain has been straightened, steepened, and entrenched to facilitate urban industrial and commercial drainage. This forced alignment of the watercourse has resulted in an unstable erosive corridor for several hundred metres from above 16th Ave E. downstream to just above 26th St. E. Within this reach the channel bed has contacted a transition from a dense till layer to a red shale bedrock layer and distinct knick-point drops occur in the channel. The till and bedrock layers are generally more resistant than the bank materials and channel down-cutting has likely slowed while channel widening is the current dominant process. Below the culvert crossing under 26th St. E. the watercourse displays a forced topographic drop and is again entrenched for several tens of metres before a transition to a more stable natural alignment in a terrace area above the CP Railway. The east and west branches are confluent at the railway and the combined feature passes through an old arch culvert and is then channelized, all the way to Owen Sound/Georgian Bay. Below the railway a flow diversion weir diverts some flow to an off-line wetland feature. The furthest downstream watercourse section is a large trapezoidal rip-rap channel that flows over the lowest terrace of the Cape Rich Steps, connecting to Owen Sound/Georgian Bay.

Erosion Threshold Analysis

Representative cross-sections were analyzed at several locations representing characteristic conditions, sensitivity to active channel processes, and relative proximity to potential stormwater pond outlet locations. All sections for the Kenny Drain and three sections for Telfer Creek were located within the study area while one section for Telfer Creek was located outside the study area as a check below the confluence with the next tributary to the east. Cross-section locations are shown in Figure 1.

Figure 1: Cross-section locations (grid = 1km, N▲, base map ref: MNR OBM 1:10,000)



Cross-section measurements were made at points of well defined active flow shape and flow stage, representing the 1.5-2yr storm event. Evidence of significant backwater conditions was avoided in favour of observable tailwater flow indicators. Channel bed and bank geometry and flow stage indicators were measured at each cross-section for use in geomorphic modeling. Channel bed substrates were measured through random-step Wolman pebble counts and characterized using the Wentworth sediment distribution scale. Longitudinal profile measurement was made to establish the channel slope and energy grade through each section.

Cross-sections were specifically measured in the field as top of bank sections, to the point on one or both sides of the channel that flood plain or tableland connection was achieved. This method allows definition of the full hydraulic range of flow depths that work on the channel. Subsequent analysis of exceedance conditions is based on the full range of flows for the most sensitive locations. This is specifically important for assessment of erosion thresholds in the highly entrenched sections of the Kenny Drain west branch.

Numerical models were created for each cross-section location. Each model required input of the channel bed substrate data, cross-section dimensions, and gradient. Modeling tests were initially done to determine the active flow regime, hydraulic geometry, hydraulic ratios, and erosion indicator thresholds. The detailed modeling results are appended. Table 1 presents a summary of the erosion threshold and channel stability indicator results for each location.

Table 1: Active channel discharge, erosion threshold, and stability indicator results

	active discharge (cms)	tractive force (N s^{-2})	velocity (m s^{-1})	stream power (watts m^{-1})	Froude #
Telfer Creek 1	0.66	6.5	0.58	17	0.36
Telfer Creek 2	0.91	18.5	0.89	83	0.63
Telfer Creek 3	1.03	19.0	0.92	90	0.62
Telfer Creek 4	1.38	22.5	0.99	149	0.69
Kenny Drain 1	0.69	16.8	0.92	52	0.60
Kenny Drain 2	0.71	29.9	1.24	125	0.95
Kenny Drain 3	0.74	12.7	0.85	42	0.56
Kenny Drain 4	0.63	17.6	0.86	60	0.63

The results of erosion threshold characterization were then cross-referenced to critical stability criteria. Table 2 presents general threshold criteria as implemented for typical small watercourse channel types in south and central Ontario.

Table 2: Critical stability threshold criteria

	low flow morphology	
	riffle / run	pool / glide
semi-alluvial firm to dense till channels	D_{84} pavement	D_{100} pavement plus vegetation control
alluvial cohesionless channels	D_{50} pavement	D_{84} pavement plus vegetation control

Notes:

1) Vegetation control criteria varies depending on the native vegetation types and overrides D_{84} and/or D_{100} criteria for silt-clay where thresholds are influenced by the degree of conglomerate or till density and chemical bonding, i.e. individual particles are easily mobilized but aggregations are more resistant, therefore a range of thresholds might apply

2) Step-pool, cascade-step-pool, and gully type channels require case by case study, due to the degree of entrenchment and specific long term channel evolution stage reflected in the feature

The criteria for both semi-alluvial and alluvial channels applies to the study area given the heterogeneous soil and sediment types and variable channel bed conditions that range from swampy groundwater saturated to dense till and bedrock.

In general terms the entire watershed study area is in a state of subtle long term adjustment as a response to historical land clearing for agriculture, channel alteration for drainage, later conversion of rural property to Highway and local industry, and most recently the conversion to mixed urban development in the City or Owen Sound area. In geomorphic terms it is reasonable to identify that most of Telfer Creek and the Kenny Drain east branch appears to be relatively stable under current channel geometry conditions. Much of the Kenny Drain west branch however is in an advanced state of entrenchment and is identified as unstable. In each case, predictive channel evolution is required to determine the relative future state for dynamic stability. The future stability state thus becomes the criteria or target condition for flow regime management using stormwater controls.

Telfer Creek

Natural channel vegetative control under existing channel geometry conditions is the appropriate target for Telfer Creek. This criterion is a simple reflection of post-development conditions matching existing conditions because existing conditions define the preferred state for the watercourse. Telfer Creek in the study area does not have distinct low flow morphology with riffle-pool complexes so the stability criteria noted in Table 2 for riffle/run bed forms is superseded by vegetation control. Vegetation control criteria overrides stability thresholds of individual particles and provides an appropriate natural channel threshold target for post development flows. In this regard conservative velocity and tractive force targets representing a stable vegetation controlled channel are 1.2m s^{-1} and 40N m^2 respectively (Fischenich 2001), with targets as high as 1.8m s^{-1} and 80N m^{-2} possible with high to very high levels of biotechnical rooting density.

Based on the results summarized in Table 1 it can seen that there are no adverse violations of vegetation control criteria, under the measured active flow regime in Telfer Creek. All tractive force and average velocity measurements are at or below conservative criteria. It can be seen in the appended cross-section photographs that virtually all sections have good to excellent vegetative cover and there is limited evidence of adverse erosion. This is not to say that naturally dynamic erosion and deposition cycles are not occurring in the watercourse. The evidence does suggest however that natural processes are operating within acceptable ranges for the native soil and vegetative conditions and there is certainly no need to lower thresholds for the sake of stormwater management targets. In fact, the stability threshold discharge for Telfer Creek appears to be higher than the active or 1.5-2yr flow as measured.

Telfer Creek cross-section 3 represents the location of lowest rooting density and thus the lowest level of vegetation control. This section appears to be the most sensitive to erosion potential under future conditions. This section also reflects the total catchment of the study area and is deemed to be the best location for subsequent analysis of stormwater management. From the modeling results it should also be noted that the D_{50} substrate size, sand, would be deemed to be unstable but the D_{84} size, cobble, is deemed stable at the modeled flows. There appears to be a balance between alluvial and semi-alluvial conditions based on the substrate types and as a result the stability criteria suggested in Table 2 are being met at a threshold condition under the active flow regime. Detailed threshold exceedance analysis should thus be based on the stability discharge of 1.03cms, representing the point at which channel instability might begin to occur with rising flow stage and rising discharge, or conversely when instability stops with falling flow stage and falling discharge.

Kenny Drain

Erosion threshold targets for the Kenny Drain differ between the east and west branches.

Natural channel vegetative control under existing channel geometry conditions is the appropriate target for the Kenny Drain east branch. The same criteria apply for the Kenny Drain east branch as Telfer Creek. Given the relatively consistent encroachment of vegetation in the east branch study area, the modeled erosion indicator results suggest that the stability discharge for this feature might in fact be higher than the determined active flow. For the sake of conservative assessment however the measured active flow regime target should be used for subsequent analysis of stormwater management. Detailed threshold exceedance analysis should thus be based on the stability discharge of 0.63cms, representing the point at which channel instability might begin to occur with rising flow stage and rising discharge, or conversely when instability stops with falling flow stage and falling discharge.

The most sensitive sections of the Kenny Drain west branch represent an entrenched channel that has eroded down to a relatively resistant dense till and bedrock layer. Softer materials exposed and eroding in steep channel banks characterize the more active lateral erosion process, currently working on the channel. The erosion process in this case is due not only to peak flow channel scour but is also a function of freeze-thaw, wetting-drying, and pore water pressure processes that act on the exposed un-vegetated banks. The channel is therefore in a widening phase as part of its long term evolution. Eventually the channel will carve a new nested floodplain, within the tableland corridor, that is wide enough to accommodate a balance of flow and sediment, and with bank angles shallow enough to support vegetation. Recognizing this channel evolution model is important for an entrenched channel because the preferred future condition is not the same as the current condition. Attempts to over-control the current erosion process will therefore do little but prolong the entrenchment and slow the preferred future stability regime. Conversely, uncontrolled flows will exacerbate erosion and aggradation cycles and the channel will evolve to an un-natural over widened corridor based on higher peak flows. Given this summary, the target flow regime should therefore be based on the stability discharge for the preferred future condition, meaning that current erosion processes for all sediment sizes can continue in the channel banks at all flows either under or over this threshold, but at some future point the channel will be in balance with the selected threshold. This threshold is thus deemed to be in the same vegetation control range as already noted for other locations. The vegetation control threshold is also deemed to be on average lower than the threshold for dense till and shale bedrock so these materials should by default be protected based on appropriate stormwater management that meets the lower target. The tractive force and velocity criteria for vegetation control also reflect suitable criteria for alluvial sediment in the medium to very coarse gravel size range, which in turn is reflected by the identified D_{84} to D_{100} sediment size range measured in each of the Kenny Drain west branch sections. These sediments therefore reflect a stable range for bed features, as noted in the Table 2 criteria.

The tractive force and velocity thresholds for vegetation control are noted to be met by the active flow for all sections in the Kenny Drain west branch, as shown in Table 1. The Kenny Drain west branch cross-section #2 has the highest erosion threshold indicators therefore this section represents the most sensitive location in the watercourse. Detailed threshold exceedance analysis should thus be based on the stability discharge of 0.71cms, representing the point at which channel instability might begin to occur with rising flow stage and rising discharge, or conversely when instability stops with falling flow stage and falling discharge based on a desired future condition of vegetation control. It must be kept in mind that this approach is conservative because as the channel process of widening continues slowly in the future, the respective depth of flow for any given event will decrease, assuming channel slope remains relatively the same, and the erosion thresholds will in fact gradually decrease.

Stormwater Analysis Alternatives

Based on the results of erosion threshold and stability discharge analysis, the options for stormwater management control treatments can be considered. The use of stability discharge targets can be used for three primary types of analysis.

The first analysis option is based on the Distributed Runoff Control (DRC) approach as discussed in the Provincial Stormwater Management Guidelines (MOE 2003). This approach uses 'continuous modeling' of historical runoff response to determine the exceedance hours of flows above the stability discharge flow. This analysis can be further detailed by an index of staged flow rates above the stability discharge times the relative time of exceedance at each stage. Runoff response can be adjusted by stormwater pond outlet controls at various levels based on the return event outlet configuration. The disadvantage to this approach is that only 30-40yrs of historical data is available for modeling and as a result lower frequency events with higher peak flows might not be addressed. By example, confined and entrenched systems will not be properly analyzed in terms of frequency flows that are partially or fully contained between channel banks and which are higher than the available continuous modeling results. This situation applies to the entrenched conditions seen in both of the study area watercourses.

The second analysis option is a simplified variation of the DRC approach based on relating the least resistant soil type in the receiving stream to an approximate percentage of bankfull depth where erosion is deemed to potentially start. Guidelines are then applied to establish an over-control level for the 2yr storm as related to the percent of depth (Aquafor Beech 2003). This approach is best used for a single or low number of ponds over a relatively small drainage area, where unconfined or non-entrenched watercourse systems are prevalent, due to the focus only on the 2yr storm. This approach can be enhanced by using specific cross-section modeling results that have determined the specific stability discharge rate and resultant percent of bankfull depth, in lieu of generalizations based on soil type (e.g. AquaLogic 2006a). Again, this method is not appropriate to this study given the entrenched conditions seen in the respective watercourses.

The third analysis option is a variation of the DRC approach that uses standard design storm modeling instead of continuous modeling. In this approach a Stability Discharge Index (SDI) is determined as a product of flow duration exceedance and flow peak exceedance above the erosion threshold discharge, applied to individual design storms (e.g. AquaLogic 2006b). The total index for all storms that apply to site specific conditions (based primarily on degree of confinement or entrenchment) determines the comparative SDI between existing and proposed conditions. The technique applies greater levels of over-control to more frequent storms as a balance against the volume requirements of less frequent events. The advantage to this approach is that a full spectrum of peak flow events is addressed compared to the lesser number of years reflected by continuous modeling. Nonetheless it must be recognized that the spectrum of events is based on synthetic storm distributions and the highest peak events are theoretical. Under some circumstances it may be warranted to enhance the SDI approach by also determining the total magnitude or flow volume of the hydrograph above the erosion threshold line.

Based on the summary of analysis options, the SDI approach offers the best overall methodology for addressing a full range of flow probabilities and for addressing specific locations of partial and full entrenchment. The SDI approach can therefore be used to confirm the depth of flow relative to return event storms and over-control flow iterations can be done to calculate the index of peak and duration exceedance. It is expected that all events up to and including the 100yr event are contained within the cross-sections identified as representative of each watercourse. The stormwater management flow model hydrographs for existing and proposed conditions for flow nodes closest to the representative cross-sections of each watercourse should be used for subsequent analysis. Individual index values will need to be done for each event contained within channel banks and the comparative total index can be determined as the sum of all return events under both existing and proposed conditions. The proposed conditions SDI must be equal to or less than the existing conditions SDI to maintain the target erosion threshold exceedance.

Summary

Erosion threshold analysis has been undertaken for Telfer Creek and the Kenny Drain regarding proposed urban expansion in the southeast area of the City of Owen Sound. Key points in each watercourse system were field surveyed for geomorphic channel relationships. Detailed measurements were undertaken and used in subsequent geomorphic modeling of erosion threshold indicators. The results of modeling have been used to establish channel stability flow regime thresholds. The resultant stability discharge levels are recommended for erosion potential treatment through the requisite stormwater management program. Stormwater analysis alternatives were considered with respect to maintaining exceedance levels at or below thresholds and the Stability

Discharge Index (SDI) approach is recommended as the preferred methodology for providing erosion potential control.

The proposed critical stability discharge targets are equal to:

Telfer Creek = 1.03cms at cross-section 3 location
Kenny Drain east branch = 0.63cms at cross-section 4
Kenny Drain west branch = 0.71cms at cross-section 2

Prepared by,

Bill de Geus

Bill de Geus, B.Sc., CET, CPESC, CCEP
AquaLogic Consulting

References

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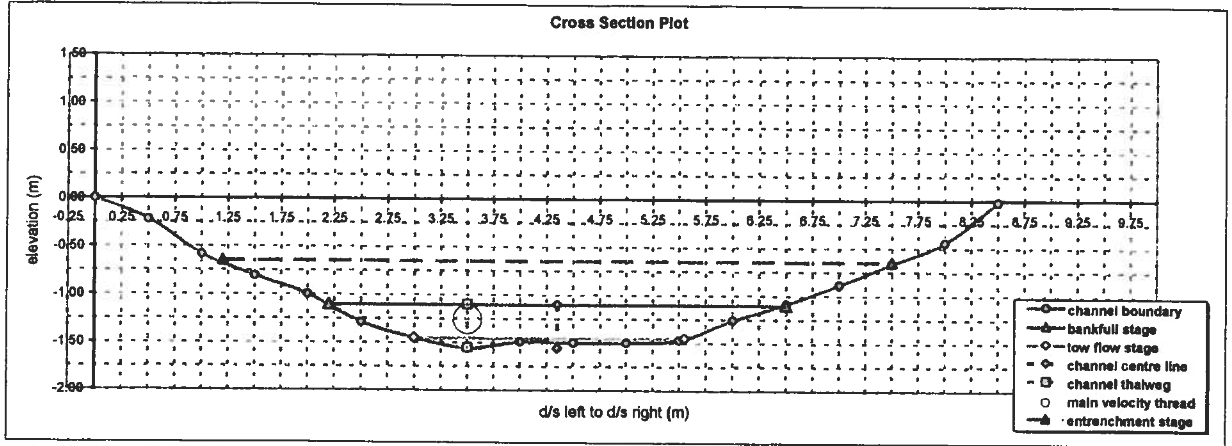
GEO-X v.4.4 Geomorphic Cross Section Analysis Model

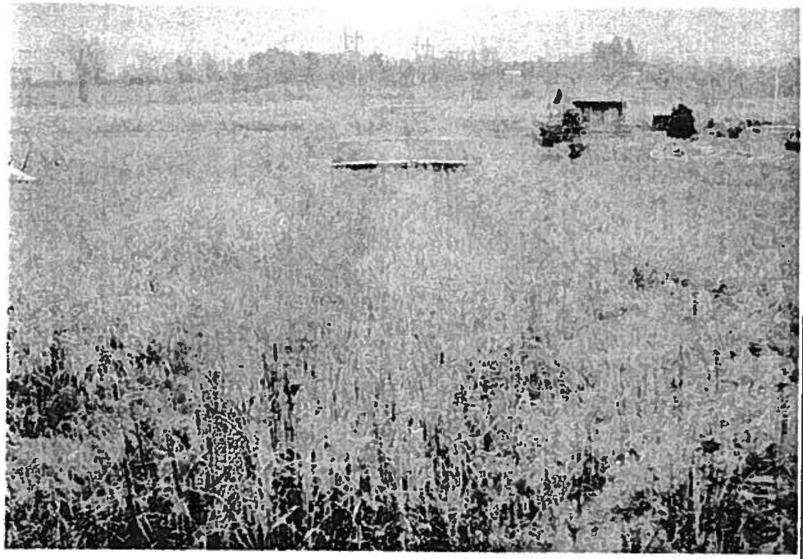
AquaLogic

Project: Erosion Thresholds

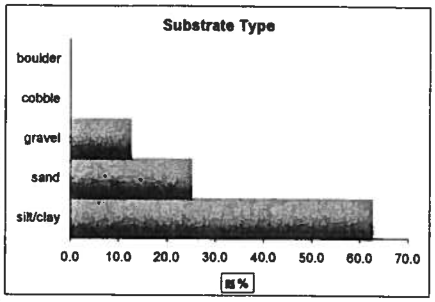
Telfer Creek section 1

B. de Geus 01/07





looking upstream over the cross-section location



Morphology Type

cascade	
step	
riffle	
run	X
glide	
pool	
thalweg out of phase	

Hydraulic Geometry

A (m^2)	1.13
R (m)	0.25
TW (m)	4.29
WP (m)	4.45
max d (m)	0.46
mean d (m)	0.26
$E_{s\ (Limerinos)}$ (m) [+]	
$E_{s\ (Strickler)}$ (m) [+]	

Hydraulic Roughness

rr *R*/D_{84}	507.68
ff V mean/V*	12.76
ff D_{84}	16.34
ff mean	15.55
	SMOOTH BED

Hydraulic Ratios

ER max d	1.47
r_c / TW	
TW / Lf_w	1.68
TW/max d	9.4
TW/mean d	16.3

Section Data

ER_e (m)	-0.64	ER stations L / R	1.20	7.50
Bf_e (m)	-1.100	Bf stations L / R	2.20	6.50
Lf_e (m)	-1.45	Lf stations L / R	3.00	5.55
W_{fp} (m)	6.30	E_s sta. $_{(Limerinos)}$ L / R		
r_c (m)		E_s sta. $_{(Strickler)}$ L / R		
z		T_e (m) $T_{o/s}$ (m)	-1.55	3.50
E_g (m m^{-1})	0.0026			

Bedload Transport

Rosgen type	Strickler Q method Q_{sb} (kg sec^{-1})	Strickler Q method Q_{sb} (kg hr^{-1})	Limerinos Q method Q_{sb} (kg sec^{-1})	Limerinos Q method Q_{sb} (kg hr^{-1})	Meyer-Peter-Muller # (Shields-Andrews) (q_b).
B3	0.0017	6.05	0.0022	7.93	4.60
C3	0.0001	0.48	0.0008	2.91	
C4	0.0053	19.19	0.0083	29.76	

Substrate Gradation (mm)

D_{15}	D_{30}	D_{50}	D_{84}	D_{100}
0.03	0.05	0.06	0.50	20.00

high turbulence - angular
high turbulence - rounded
low turbulence - angular
low turbulence - rounded

Flow Regime Strickler method

Q (cms)	0.657
V (m s^{-1})	0.58
n	0.035
Fr	0.36
D_c rectangular (m)	0.14
D_c trapezoidal (m)	0.26
D_c triangular (m)	0.40
D_c parabolic (m)	0.24
D_c mean (m)	0.26
flow type	SUBCRITICAL
Ω (watts m^{-1})	16.74
ω_s (watts m^{-2})	3.76
ω_s/TW (watts m^{-1})	0.88
*Re**	0.1
Re	129458
turbulence	LOW

Flow Regime Limerinos method

Q (cms)	
V (m s^{-1})	
n	
Fr	
D_c rectangular (m)	
D_c trapezoidal (m)	
D_c triangular (m)	
D_c parabolic (m)	
D_c mean (m)	
flow type	
Ω (watts m^{-1})	
ω_s (watts m^{-2})	
ω_s/TW (watts m^{-1})	
*Re**	
Re	
turbulence	

Erosion Thresholds

τ_{calc} (kg m^{-2})	0.66
τ_{calc} (N m^{-2})	6.47
τ D_{crit} (gr-co) (mm)	6.67
V_c (vcs +) (m s^{-1})	0.04

V_c / V_b Strickler	V_c / V_b Limerinos
0.09	
AT RISK	

Bank Data u/s L u/s R

	u/s L	u/s R
H_b (m)		
Bf_d (m)		
RDp (m)		
H_b/Bf_d		
RDp/H_b		
RDn (%)		
BA (°)		
BFP (%)		

Substrate Type (%)

silt/clay	sand	gravel	cobble	boulder
62.5	25.0	12.5	0.0	0.0

GEO-X v.4.4 Geomorphic Cross Section Analysis Model

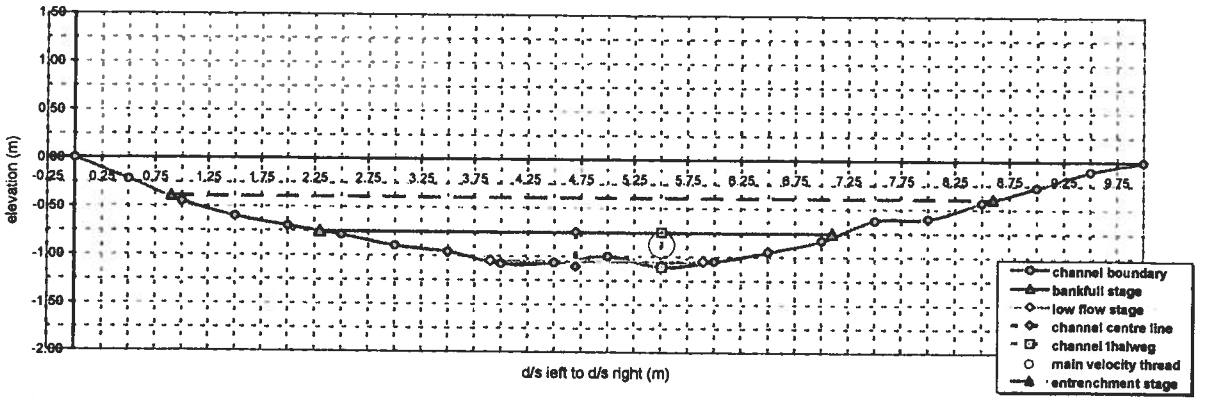
AquaLogic

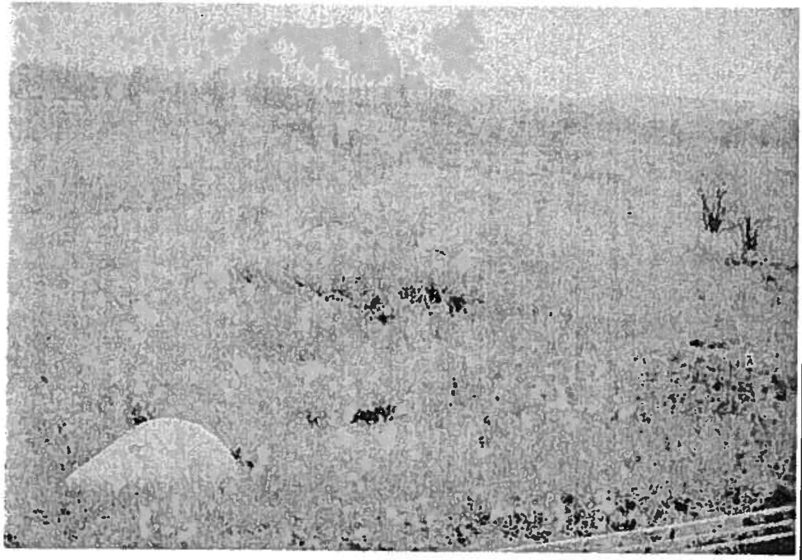
Project: Erosion Thresholds

Telfer Creek section 2

B. de Geus 01/07

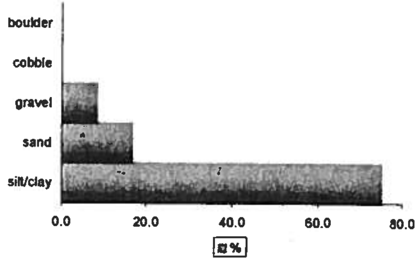
Cross Section Plot





looking downstream over the cross-section location

Substrate Type



Morphology Type

cascade	
step	
riffle	
run	X
glide	
pool	
thalweg out of phase	

Hydraulic Geometry

A (m^2)	1.01
R (m)	0.20
TW (m)	4.91
WP (m)	5.01
max d (m)	0.36
mean d (m)	0.21
$E_{s\ (Limerinos)}$ (m) [+]	
$E_{s\ (Strickler)}$ (m) [+]	

Hydraulic Roughness

rr *R*/D_{84}	202.58
ff V mean/V*	11.31
ff D_{84}	16.02
ff mean	13.67
	SMOOTH BED

Hydraulic Ratios

ER max d	1.57
r_c / TW	
TW / Lf_w	2.46
TW/max d	13.6
TW/mean d	23.8

Section Data

ER_e (m)	-0.39	ER stations L / R	0.90	8.60
Bf_e (m)	-0.750	Bf stations L / R	2.30	7.10
Lf_e (m)	-1.05	Lf stations L / R	3.90	5.90
W_{fp} (m)	7.70	E_s sta. $_{(Limerinos)}$ L / R		
r_c (m)		E_s sta. $_{(Strickler)}$ L / R		
z		T_e (m) $T_{o/s}$ (m)	-1.11	5.51
E_g ($m\ m^{-1}$)	0.0093			

Bedload Transport

Rosgen type	Strickler Q method Q_{sb} (kg sec^{-1})	Strickler Q method Q_{sb} (kg hr^{-1})	Limerinos Q method Q_{sb} (kg sec^{-1})	Limerinos Q method Q_{sb} (kg hr^{-1})	Meyer-Peter-Muller # (Shields-Andrews) (q_b)-
B3	0.0018	8.65	0.0024	8.82	
C3	0.0002	0.69	0.0014	5.07	16.61
C4	0.0062	22.35	0.0095	34.06	

Substrate Gradation (mm)

D_{15}	D_{30}	D_{50}	D_{84}	D_{100}
0.03	0.05	0.06	1.00	20.00

high turbulence - angular
high turbulence - rounded
low turbulence - angular
low turbulence - rounded

Flow Regime Strickler method

Q (cms)	0.907
V ($m\ s^{-1}$)	0.89
n	0.037
Fr	0.63
D_c rectangular (m)	0.15
D_c trapezoidal (m)	0.30
D_c triangular (m)	0.45
D_c parabolic (m)	0.30
D_c mean (m)	0.30
flow type	SUBCRITICAL
Ω (watts m^{-1})	82.67
ω_a (watts m^{-2})	16.51
ω_a/TW (watts m^{-1})	3.36
*Re**	0.1
Re	156915
turbulence	LOW

Flow Regime Limerinos method

Q (cms)	
V ($m\ s^{-1}$)	
n	
Fr	
D_c rectangular (m)	
D_c trapezoidal (m)	
D_c triangular (m)	
D_c parabolic (m)	
D_c mean (m)	
flow type	
Ω (watts m^{-1})	
ω_a (watts m^{-2})	
ω_a/TW (watts m^{-1})	
*Re**	
Re	
turbulence	

Erosion Thresholds

τ_{calc} (kg m^{-2})	1.88
τ_{calc} (N m^{-2})	18.46
τ D_{crit} (gr-co) (mm)	19.03
V_c (vcs +) ($m\ s^{-1}$)	0.04

V_c / V_b Strickler	V_c / V_b Limerinos
0.06	

Bank Data u/s L u/s R

H_b (m)		
Bf_d (m)		
RDp (m)		
H_b/Bf_d		
RDp/H_b		
RDn (%)		
BA (°)		
BFP (%)		

Substrate Type (%)

silt/clay	sand	gravel	cobble	boulder
75.0	18.7	6.3	0.0	0.0

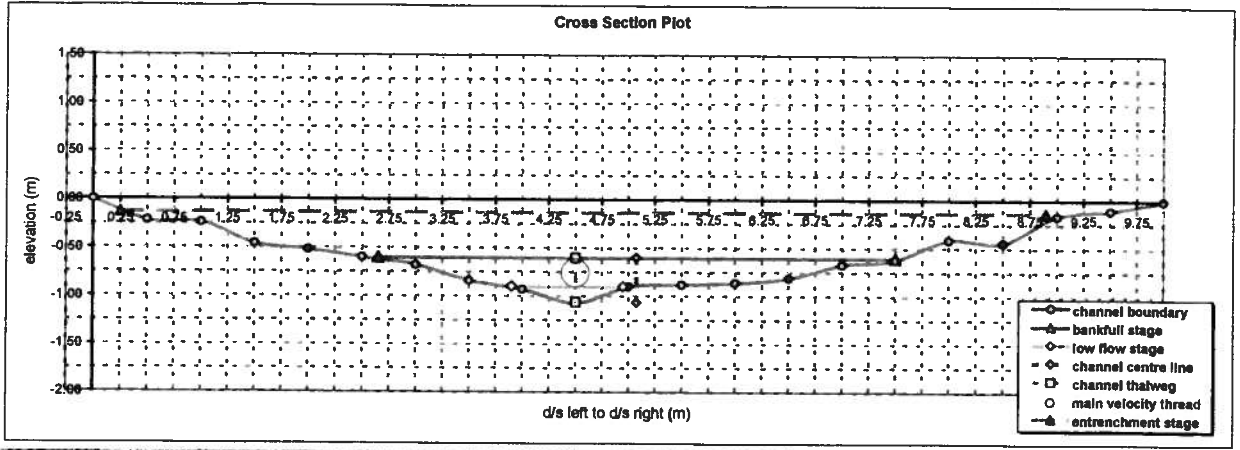
GEO-X v.4.4 Geomorphic Cross Section Analysis Model

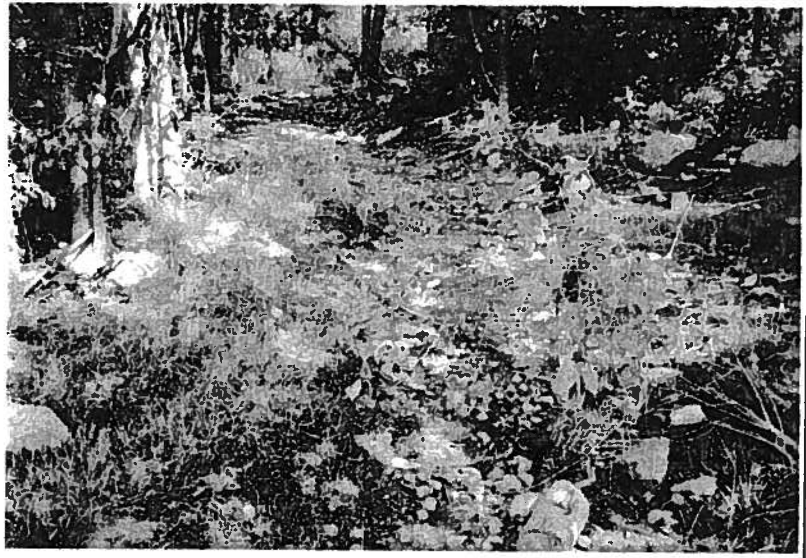
AquaLogic

Project: Erosion Thresholds

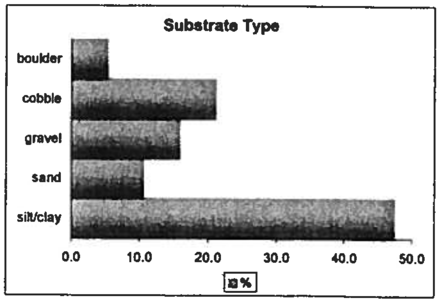
Telfer Creek section 3

B. de Geus 01/07





looking downstream over the cross-section location, Sept/06



Morphology Type	
cascade	
step	
riffle	
run	X
glide	
pool	
thalweg out of phase	

Hydraulic Geometry	
A (m^2)	1.13
R (m)	0.22
TW (m)	5.05
WP (m)	5.16
max d (m)	0.47
mean d (m)	0.22
$E_{s\ (Limerinos)}$ (m) [+]	
$E_{s\ (Strickler)}$ (m) [+]	

Hydraulic Roughness	
rr *R*/D_{84}	2.91
ff V mean/V*	6.25
ff D_{84}	5.53
ff mean	5.89
	ROUGH BED

Hydraulic Ratios	
ER max d	1.71
r_c / TW	
TW / Lf_w	4.81
TW/max d	10.7
TW/mean d	22.6

Section Data

ER_e (m)	-0.13	ER stations L / R	0.25	8.90
Bf_e (m)	-0.600	Bf stations L / R	2.65	7.50
Lf_e (m)	-0.9	Lf stations L / R	3.90	4.95
W_{fp} (m)	8.65	E_s sta. (Limerinos) L / R		
r_c (m)		E_s sta. (Strickler) L / R		
z		*T*$_e$ (m) *T*$_{o/s}$ (m)	-1.06	4.50
E_g (m m^{-1})	0.0089			

Bedload Transport

Rosgen type	Strickler Q method Q_{sb} (kg sec^{-1})	Strickler Q method Q_{sb} (kg hr^{-1})	Limerinos Q method Q_{sb} (kg sec^{-1})	Limerinos Q method Q_{sb} (kg hr^{-1})	Meyer-Peter-Muller # (Shields-Andrews) (q_b)*
B3	0.0019	6.91	0.0018	6.65	
C3	0.0003	1.15	0.0002	0.89	19.35
C4	0.0066	23.77	0.0062	22.34	

Substrate Gradation (mm)

	D_{15}	D_{30}	D_{50}	D_{84}	D_{100}
	0.03	0.05	1.00	75.00	300.00
high turbulence - angular					
high turbulence - rounded					
low turbulence - angular					
low turbulence - rounded					

Erosion Thresholds

		V_c / V_b Strickler	V_c / V_b Limerinos
τ_{calc} (kg m^{-2})	1.94		
τ_{calc} (N m^{-2})	19.01		
τ D_{crit} (gr-co) (mm)	19.60	0.24	
V_c (vcs +) (m s^{-1})	0.16	AT RISK	

Substrate Type (%)

silt/clay	sand	gravel	cobble	boulder
47.4	10.5	15.8	21.1	5.3

Bank Data u/s L u/s R

	u/s L	u/s R
H_b (m)		
Bf_d (m)		
RDp (m)		
H_b/Bf_d		
RDp/H_b		
RDn (%)		
BA (°)		
BFP (%)		

Flow Regime

Strickler method		Limerinos method	
Q (cms)	1.034	Q (cms)	
V (m s^{-1})	0.92	V (m s^{-1})	
n	0.037	n	
Fr	0.62	*Fr*	
D_c rectangular (m)	0.17	D_c rectangular (m)	
D_c trapezoidal (m)	0.32	D_c trapezoidal (m)	
D_c triangular (m)	0.48	D_c triangular (m)	
D_c parabolic (m)	0.32	D_c parabolic (m)	
D_c mean (m)	0.32	D_c mean (m)	
flow type	SUBCRITICAL	flow type	
Ω (watts m^{-1})	90.19	Ω (watts m^{-1})	
ω_a (watts m^{-2})	17.47	ω_e (watts m^{-2})	
ω_a/TW (watts m^{-1})	3.46	ω_a/TW (watts m^{-1})	
*Re**	1.5	*Re**	
Re	175679	*Re*	
turbulence	LOW	turbulence	

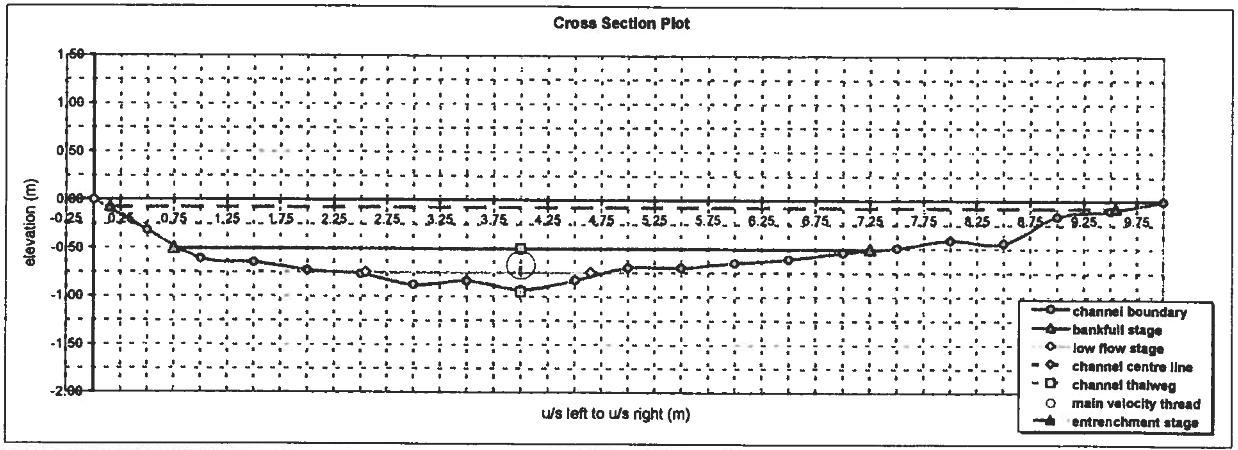
GEO-X v.4.4 Geomorphic Cross Section Analysis Model

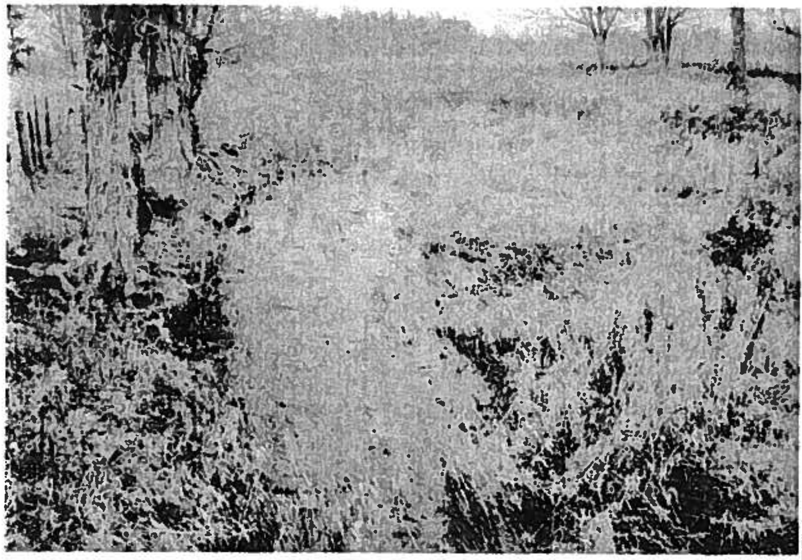
AquaLogic

B. de Geus 01/07

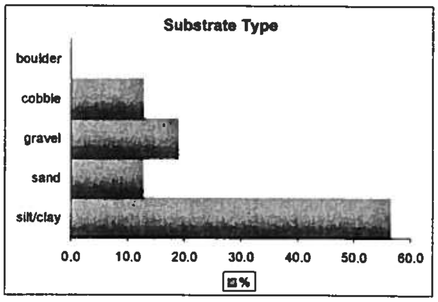
Project: Erosion Thresholds

Telfer Creek section 4





looking upstream over the cross-section location, Nov/06



Morphology Type

cascade	
step	
riffle	
run	X
glide	
pool	
thalweg out of phase	

Hydraulic Geometry

A (m^2)	1.39
R (m)	0.21
TW (m)	8.59
WP (m)	6.69
max d (m)	0.43
mean d (m)	0.21
$E_{s\ (Limerinos)}$ (m) [+]	
$E_{e\ (Strickler)}$ (m) [+]	

Hydraulic Roughness

π R/D_{84}	13.89
ff V mean/V*	8.10
ff D_{84}	9.38
ff mean	8.74
	SMOOTH BED

Hydraulic Ratios

ER max d	1.43
r_c / TW	
TW / Lf_w	3.14
TW/max d	15.3
TW/mean d	31.2

Section Data

ER_e (m)	-0.07	ER stations L / R	0.15	9.55
Bf_e (m)	-0.500	Bf stations L / R	0.75	7.25
Lf_e (m)	-0.75	Lf stations L / R	2.55	4.65
W_{fp} (m)	9.40	E_s sta. (Limerinos) L / R		
r_c (m)		E_e sta. (Strickler) L / R		
z		T_e (m) $T_{o/s}$ (m)	-0.95	4.00
E_g (m m^{-1})	0.0110			

Substrate Gradation (mm)

	D_{15}	D_{30}	D_{50}	D_{84}	D_{100}
	0.03	0.05	0.06	15.00	70.00
high turbulence - angular					
high turbulence - rounded					
low turbulence - angular					
low turbulence - rounded					

Erosion Thresholds

		V_c / V_b	
τ_{calc} (kg m^{-2})	2.29	Strickler	Limerinos
τ_{calc} (N m^{-2})	22.45	0.05	
τ D_{crit} (gr-co) (mm)	23.15	AT RISK	
V_c (vcs +) (m s^{-1})	0.04		

Substrate Type (%)

silt/clay	sand	gravel	cobble	boulder
56.3	12.5	18.8	12.5	0.0

Bank Data u/s L u/s R

H_b (m)		
Bf_d (m)		
RDp (m)		
H_b/Bf_d		
RDp/H_b		
RDn (%)		
BA (°)		
BFP (%)		

Bedload Transport

	Strickler Q method		Limerinos Q method		Meyer-Peter-Muller
Rosgen	Q_{sb}		Q_{sb}		#
type	(kg sec^{-1})	(kg hr^{-1})	(kg sec^{-1})	(kg hr^{-1})	(Shields-Andrews)
B3	0.0021	7.51	0.0023	8.38	$(q_b)_*$
C3	0.0006	2.02	0.0012	4.18	24.16
C4	0.0076	27.25	0.0090	32.50	

Flow Regime Strickler method

Q (cms)	1.380
V (m s^{-1})	0.99
n	0.037
Fr	0.69
D_c rectangular (m)	0.17
D_c trapezoidal (m)	0.36
D_c triangular (m)	0.53
D_c parabolic (m)	0.37
D_c meen (m)	0.36
flow type	SUBCRITICAL
Ω (watts m^{-1})	148.80
ω_a (watts m^{-2})	22.25
ω_a/TW (watts m^{-1})	3.38
Re^*	0.1
Re	181051
turbulence	LOW

Flow Regime Limerinos method

Q (cms)	
V (m s^{-1})	
n	
Fr	
D_c rectangular (m)	
D_c trapezoidal (m)	
D_c triangular (m)	
D_c parabolic (m)	
D_c mean (m)	
flow type	
Ω (watts m^{-1})	
ω_a (watts m^{-2})	
ω_a/TW (watts m^{-1})	
Re^*	
Re	
turbulence	

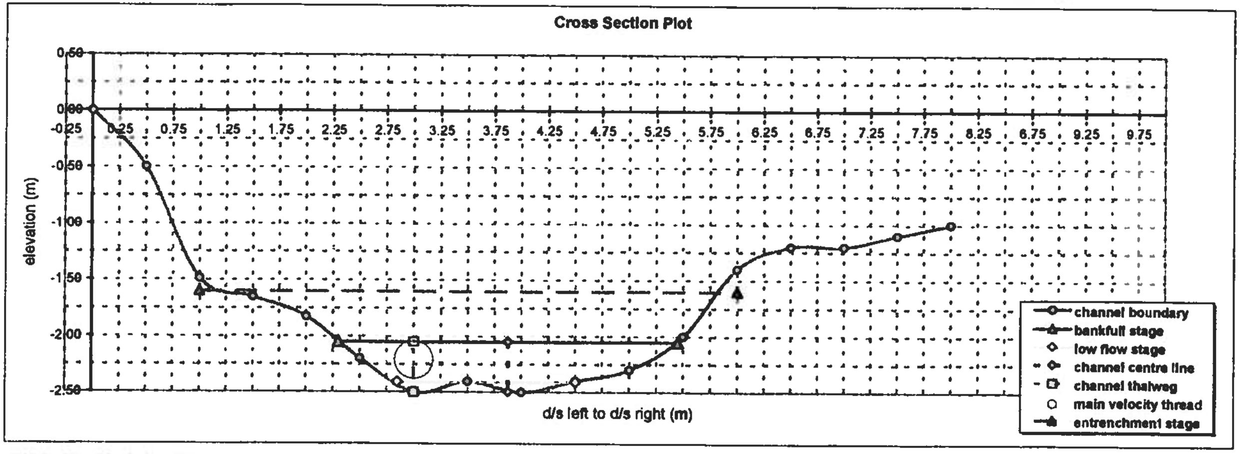
GEO-X v.4.4 Geomorphic Cross Section Analysis Model

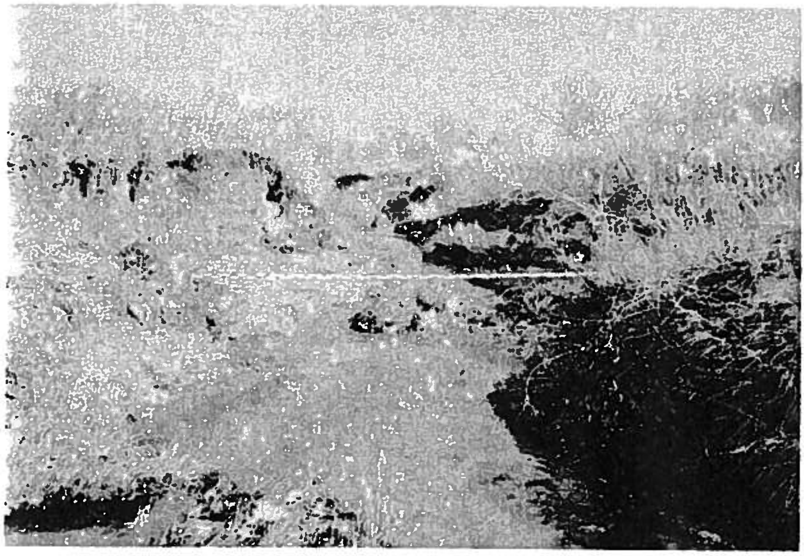
AquaLogic

Project: Erosion Thresholds

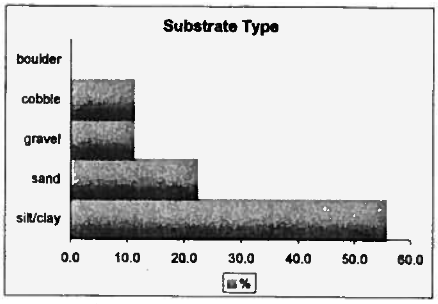
Kenny Drain west tributary section 1

B. de Geus 01/07





looking downstream over the cross-section location



Morphology Type

cascade	
step	
riffle	
run	X
glide	
pool	
thalweg out of phase	

Hydraulic Geometry

A (m^2)	0.75
R (m)	0.22
TW (m)	3.12
WP (m)	3.36
max d (m)	0.45
mean d (m)	0.24
$E_{s\ (Limerinos)}$ (m) [+]	
$E_{s\ (Strickler)}$ (m) [+]	

Hydraulic Roughness

rr *R*/D_{84}	22.26
ff V mean/V*	6.92
ff D_{84}	10.70
ff mean	9.81
	SMOOTH BED

Hydraulic Ratios

ER max d	1.60
r_c / TW	
TW / Lf_w	1.89
TW/max d	6.9
TW/mean d	13.0

Section Data

ER_e (m)	-1.60	ER stations L / R	1.00	6.00
Bf_e (m)	-2.050	Bf stations L / R	2.30	5.45
Lf_e (m)	-2.41	Lf stations L / R	2.85	4.50
W_{fp} (m)	5.00	E_s sta. $_{(Limerinos)}$ L / R		
r_c (m)		E_s sta. $_{(Strickler)}$ L / R		
z		*T*$_s$ (m) *T*$_{o/s}$ (m)	-2.50	3.00
E_g ($m\ m^{-1}$)	0.0077			

Bedload Transport

Rosgen type	Strickler Q method Q_{sb} (kg sec^{-1})	Strickler Q method Q_{sb} (kg hr^{-1})	Limerinos Q method Q_{sb} (kg sec^{-1})	Limerinos Q method Q_{sb} (kg hr^{-1})	Meyer-Peter-Muller # (Shields-Andrews) $(q_s)_*$
B3	0.0017	6.13	0.0019	6.93	16.42
C3	0.0001	0.52	0.0003	1.18	
C4	0.0054	19.58	0.0066	23.90	

Substrate Gradation (mm)

	D_{15}	D_{30}	D_{50}	D_{84}	D_{100}
	0.03	0.05	0.06	10.00	80.00
high turbulence - angular					
high turbulence - rounded					
low turbulence - angular					
low turbulence - rounded					

Flow Regime Strickler method

Q (cms)	0.686
V (m s^{-1})	0.92
n	0.035
Fr	0.60
D_c rectangular (m)	0.17
D_c trapezoidal (m)	0.28
D_c triangular (m)	0.40
D_c parabolic (m)	0.25
D_c mean (m)	0.26
flow type	SUBCRITICAL
Ω (watts m^{-1})	51.74
ω_a (watts m^{-2})	15.41
ω_a/TW (watts m^{-1})	4.94
*Re**	0.1
Re	179115
turbulence	LOW

Flow Regime Limerinos method

Q (cms)	
V (m s^{-1})	
n	
Fr	
D_c rectangular (m)	
D_c trapezoidal (m)	
D_c triangular (m)	
D_c parabolic (m)	
D_c mean (m)	
flow type	
Ω (watts m^{-1})	
ω_a (watts m^{-2})	
ω_a/TW (watts m^{-1})	
*Re**	
Re	
turbulence	

Erosion Thresholds

τ_{calc} (kg m^{-2})	1.72	V_c / V_b Strickler	V_c / V_b Limerinos
τ_{calc} (N m^{-2})	16.61	0.06	
τ D_{crit} (gr-co) (mm)	17.33	AT RISK	
V_c (vcs +) (m s^{-1})	0.04		

Bank Data u/s L u/s R

H_b (m)		
Bf_d (m)		
RDp (m)		
H_b/Bf_d		
RDp/H_b		
RDn (%)		
BA (°)		
BFP (%)		

Substrate Type (%)

silt/clay	sand	gravel	cobble	boulder
55.6	22.2	11.1	11.1	0.0

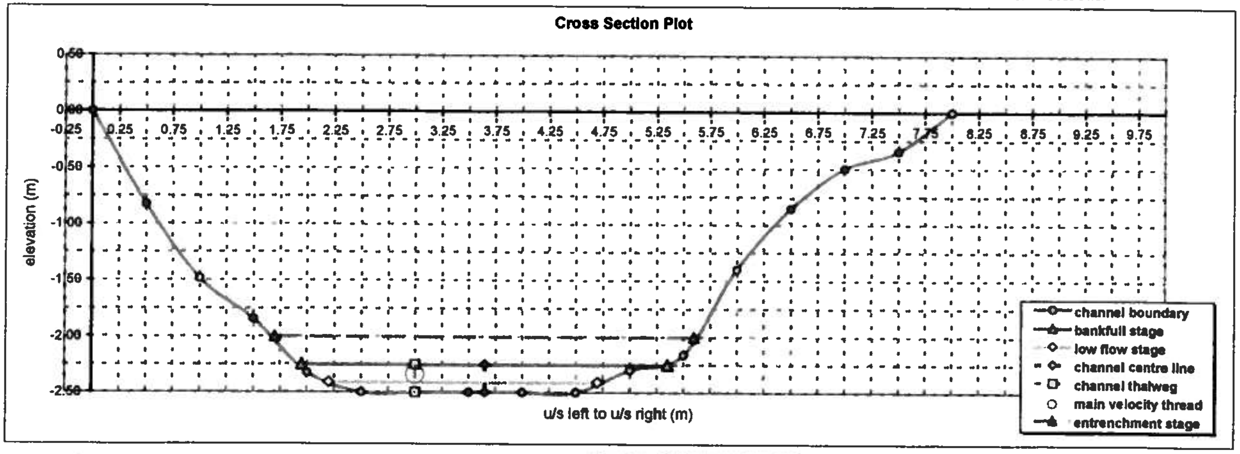
GEO-X v.4.4 Geomorphic Cross Section Analysis Model

AquaLogic

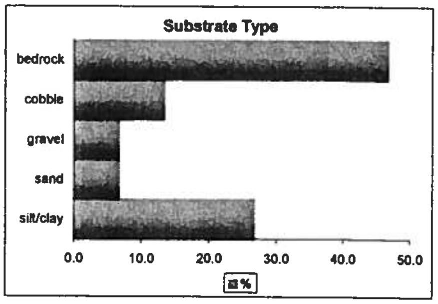
B. de Geus 01/07

Project: Erosion Thresholds

Kenny Drain west tributary section 2



looking upstream over the cross-section location



Morphology Type	
cascade	
step	X
riffle	
run	
glide	
pool	
thalweg out of phase	

Hydraulic Geometry	
A (m^2)	0.57
R (m)	0.17
TW (m)	3.26
WP (m)	3.37
max d (m)	0.25
mean d (m)	0.18
$E_{s\ (Limerinos)}$ (m) [+]	
$E_{s\ (Strickler)}$ (m) [+]	

Hydraulic Roughness	
ff *R*/D_{84}	2.83
ff V mean/V*	8.46
ff D_{84}	5.48
ff mean	5.97
	ROUGH BED

Hydraulic Ratios	
ER max d	1.20
r_c / TW	
TW / Lf_w	1.31
TW/max d	13.1
TW/mean d	18.8

Section Data

ER_e (m)	-2.00	ER stations L / R	1.70	5.60
Bf_e (m)	-2.250	Bf stations L / R	1.95	5.35
Lf_e (m)	-2.41	Lf stations L / R	2.20	4.70
W_{fp} (m)	3.90	E_s sta. (Limerinos) L / R		
r_c (m)		E_s sta. (Strickler) L / R		
z		*T*$_e$ (m) *T*$_{o/s}$ (m)	-2.50	3.00
E_g (m m^{-1})	0.0160			

Bedload Transport

Rosgen type	Strickler Q method Q_{sb} (kg sec^{-1})	(kg hr^{-1})	Limerinos Q method Q_{sb} (kg sec^{-1})	(kg hr^{-1})	Meyer-Peter-Muller # (Shields-Andrews) $(q_b)_*$
B3	0.0017	6.18	0.0016	5.81	35.42
C3	0.0002	0.55	0.0001	0.36	
C4	0.0055	19.87	0.0050	17.95	

Substrate Gradation (mm)

D_{15}	D_{30}	D_{50}	D_{84}	D_{100}
0.03	2.00	6.00	60.00	

high turbulence - angular
high turbulence - rounded
low turbulence - angular
low turbulence - rounded

Flow Regime

Strickler method		Limerinos method	
Q (cms)	0.707	Q (cms)	
V (m s^{-1})	1.24	V (m s^{-1})	
n	0.033	n	
Fr	0.95	*Fr*	
D_c rectangular (m)	0.17	D_c rectangular (m)	
D_c trapezoidal (m)	0.29	D_c trapezoidal (m)	
D_c triangular (m)	0.41	D_c triangular (m)	
D_c parabolic (m)	0.28	D_c parabolic (m)	
D_c mean (m)	0.29	D_c mean (m)	
flow type	~CRITICAL	flow type	
Ω (watts m^{-1})	124.80	Ω (watts m^{-1})	
ω_a (watts m^{-2})	37.08	ω_a (watts m^{-2})	
ω_a/TW (watts m^{-1})	11.36	ω_a/TW (watts m^{-1})	
*Re**	11.3	*Re**	
Re	184269	*Re*	
turbulence	HIGH	turbulence	

Erosion Thresholds

τ_{calc} (kg m^{-2})	3.05		
τ_{calc} (N m^{-2})	29.92	*V*$_c$ / *V*$_b$	
τ D_{crit} (gr-co) (mm)	30.85	Strickler	Limerinos
		0.51	
V$_c$ (vcs +) (m s^{-1})	0.44	AT RISK	

Substrate Type (%)

silt/clay	sand	gravel	cobble	bedrock
26.7	6.7	6.7	13.3	46.7

Bank Data u/s L u/s R

H_b (m)		
Bf_d (m)		
RDp (m)		
H_b/Bf_d		
RDp/H_b		
RDn (%)		
BA (°)		
BFP (%)		

GEO-X v.4.4 Geomorphic Cross Section Analysis Model

AquaLogic

Project: Erosion Thresholds

Kenny Drain west tributary section 3

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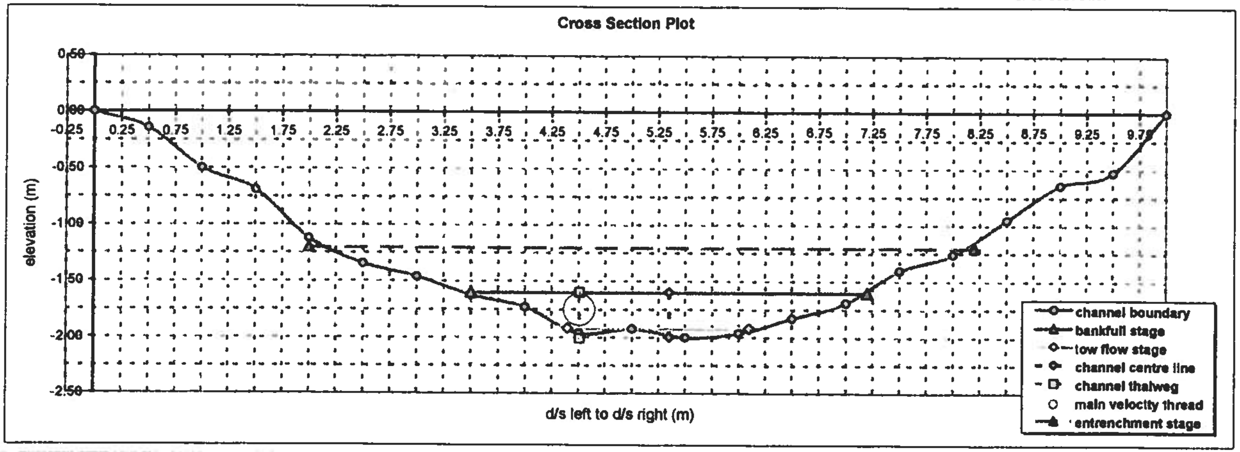
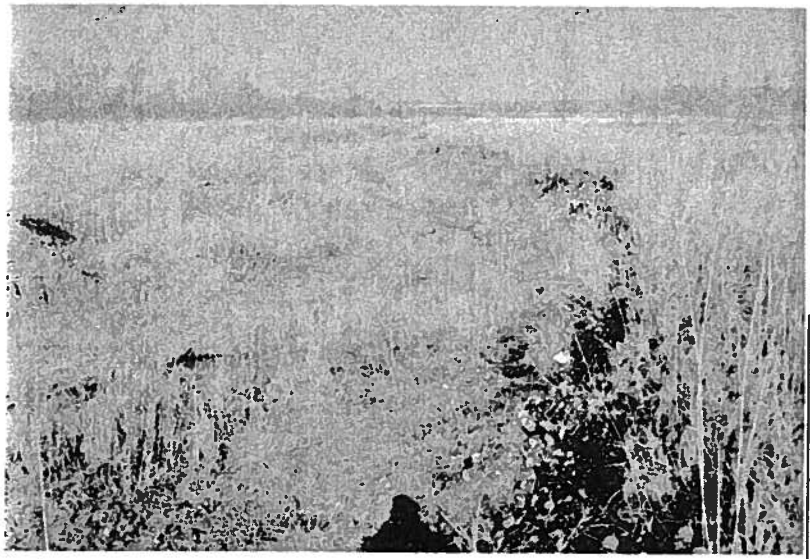
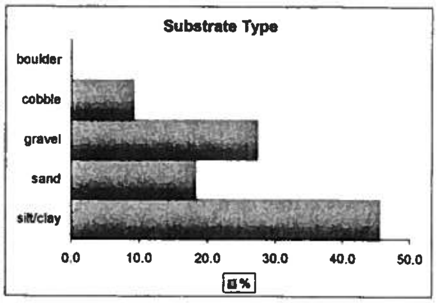




looking downstream over the cross-section location



Morphology Type

cascade	
step	
riffle	
run	X
glide	
pool	
thalweg out of phase	

Hydraulic Geometry

A (m^2)	0.88
R (m)	0.23
TW (m)	3.74
WP (m)	3.67
max d (m)	0.40
mean d (m)	0.23
$E_{s\ (Limerinos)}$ (m) [+]	
$E_{s\ (Strickler)}$ (m) [+]	

Hydraulic Roughness

rr *R*/D_{84}	15.11
ff V mean/V*	8.67
ff D_{84}	9.64
ff mean	9.16
	SMOOTH BED

Hydraulic Ratios

ER max d	1.66
r_c / TW	
TW / Lf_w	2.20
TW/max d	9.3
TW/mean d	15.9

Section Data

ER_e (m)	-1.20	ER stations L / R	2.00	8.20
Bf_e (m)	-1.600	Bf stations L / R	3.50	7.20
Lf_e (m)	-1.92	Lf stations L / R	4.40	8.10
W_{fp} (m)	6.20	E_s sta. (Limerinos) L / R		
r_c (m)		E_s sta. (Strickler) L / R		
z		T_e (m) $T_{o/s}$ (m)	-2.01	4.51
E_g ($m\ m^{-1}$)	0.0057			

Bedload Transport

Rosgen type	Strickler Q method Q_{sb} (kg sec^{-1})	Strickler Q method Q_{sb} (kg hr^{-1})	Limerinos Q method Q_{sb} (kg sec^{-1})	Limerinos Q method Q_{sb} (kg hr^{-1})	Meyer-Peter-Muller # (Shields-Andrews) $(q_b)_*$
B3	0.0017	6.27	0.0019	6.78	11.26
C3	0.0002	0.61	0.0003	1.02	
C4	0.0056	20.34	0.0064	23.08	

Substrate Gradation (mm)

D_{15}	D_{30}	D_{50}	D_{84}	D_{100}
0.03	0.05	1.00	15.00	70.00

high turbulence - angular
high turbulence - rounded
low turbulence - angular
low turbulence - rounded

Flow Regime

Strickler method		Limerinos method	
Q (cms)	0.743	Q (cms)	
V ($m\ s^{-1}$)	0.85	V ($m\ s^{-1}$)	
n	0.033	n	
Fr	0.56	*Fr*	
D_c rectangular (m)	0.16	D_c rectangular (m)	
D_c trapezoidal (m)	0.28	D_c trapezoidal (m)	
D_c triangular (m)	0.42	D_c triangular (m)	
D_c parabolic (m)	0.26	D_c parabolic (m)	
D_c mean (m)	0.28	D_c mean (m)	
flow type	SUBCRITICAL	flow type	
Ω (watts m^{-1})	41.50	Ω (watts m^{-1})	
ω_s (watts m^{-2})	10.72	ω_s (watts m^{-2})	
ω_s/TW (watts m^{-1})	2.87	ω_s/TW (watts m^{-1})	
*Re**	1.4	*Re**	
Re	168337	*Re*	
turbulence	LOW	turbulence	

Erosion Thresholds

τ_{calc} ($kg\ m^{-2}$)	1.29
τ_{calc} ($N\ m^{-2}$)	12.66
$\tau\ D_{crit}$ (gr-co) (mm)	13.06
V_c (vcs +) ($m\ s^{-1}$)	0.16

V_c / V_b Strickler	V_c / V_b Limerinos
0.26	

Bank Data u/s L u/s R

H_b (m)		
Bf_d (m)		
RDp (m)		
H_b/Bf_d		
RDp/H_b		
RDn (%)		
BA (°)		
BFP (%)		

Substrate Type (%)

silt/clay	sand	gravel	cobble	boulder
45.5	16.2	27.3	9.1	0.0

GEO-X v.4.4 Geomorphic Cross Section Analysis Model

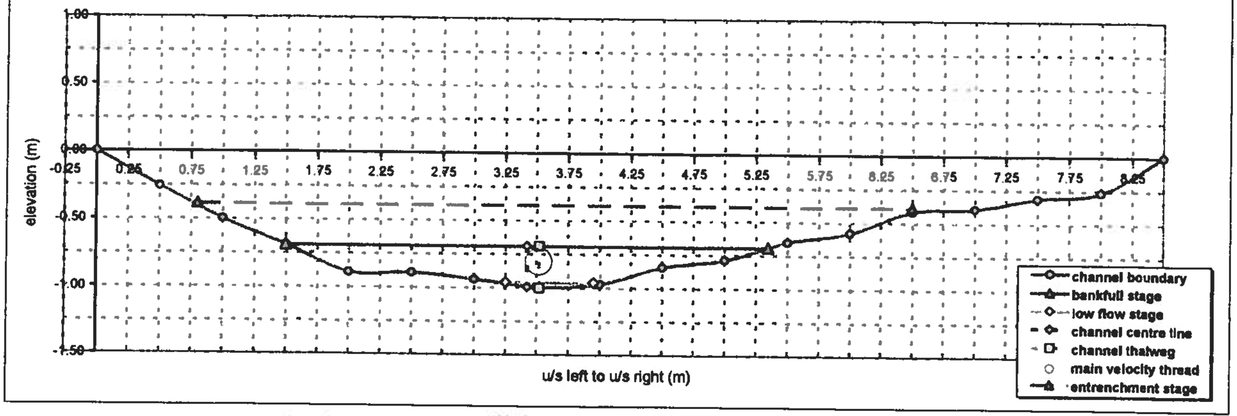
AquaLogic

Project: Erosion Thresholds

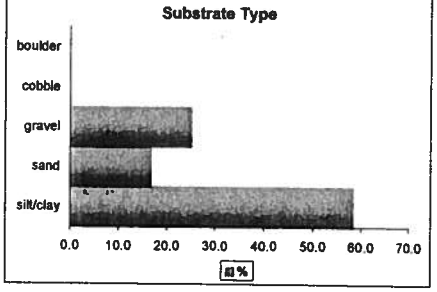
Kenny Drain east tributary section 4

B. de Geus 01/07

Cross Section Plot



looking upstream over the cross-section location



Morphology Type

cascade	
step	
riffle	
run	X
glide	
pool	
thalweg out of phase	

Hydraulic Geometry

A (m^2)	0.74
R (m)	0.19
TW (m)	3.86
WP (m)	3.94
max d (m)	0.31
mean d (m)	0.19
$E_{s\ (Limerinos)}$ (m) [+]	
$E_{s\ (Strickler)}$ (m) [+]	

Hydraulic Roughness

rr *R*/D_{84}	93.34
ff V mean/V*	10.33
ff D_{84}	14.11
ff mean	12.22
	SMOOTH BED

Hydraulic Ratios

ER max d	1.48
r_c / TW	
TW / Lf_w	-5.52
TW/max d	12.7
TW/mean d	20.3

Section Data

ER_e (m)	-0.39	ER stations L / R	0.80	6.50
Bf_e (m)	-0.690	Bf stations L / R	1.50	5.35
Lf_e (m)	-0.96	Lf stations L / R	3.95	3.25
W_{fp} (m)	5.70	E_s sta. $_{(Limerinos)}$ L / R		
r_c (m)		E_s sta. $_{(Strickler)}$ L / R		
z		T_e (m) $T_{o/s}$ (m)	-1.00	3.52
E_g (m m^{-1})	0.0096			

Bedload Transport

	Strickler Q method		Limerinos Q method		Meyer-Peter-Muller
Rosgen	Q_{sb}		Q_{sb}		#
type	(kg sec^{-1})	(kg hr^{-1})	(kg sec^{-1})	(kg hr^{-1})	(Shields-Andrews)
B3	0.0017	5.98	0.0021	7.52	$(q_b)_*$
C3	0.0001	0.44	0.0006	2.03	17.41
C4	0.0052	18.65	0.0076	27.26	

Substrate Gradation (mm)

D_{15}	D_{30}	D_{50}	D_{84}	D_{100}
0.03	0.05	0.06	2.00	25.00

high turbulence - angular
high turbulence - rounded
low turbulence - angular
low turbulence - rounded

Erosion Thresholds

τ_{calc} (kg m^{-2})	1.79		
τ_{calc} (N m^{-2})	17.56	V_c / V_b	
τ D_{crit} (gr-co) (mm)	18.11	Strickler	Limerinos
		0.06	
V_c (vcs +) (m s^{-1})	0.04	AT RISK	

Substrate Type (%)

silt/clay	sand	gravel	cobble	boulder
58.3	18.7	25.0	0.0	0.0

Bank Data u/s L u/s R

H_b (m)		
Bf_d (m)		
RDp (m)		
H_b/Bf_d		
RDp/H_b		
RDn (%)		
BA (°)		
BFP (%)		

Flow Regime Strickler method

Q (cms)	0.632
V (m s^{-1})	0.86
n	0.037
Fr	0.63
D_c rectangular (m)	0.14
D_c trapezoidal (m)	0.26
D_c triangular (m)	0.39
D_c parabolic (m)	0.26
D_c mean (m)	0.26
flow type	SUBCRITICAL
Ω (watts m^{-1})	59.50
ω_a (watts m^{-2})	15.11
ω_a/TW (watts m^{-1})	3.91
*Re**	0.1
Re	140852
turbulence	LOW

Flow Regime Limerinos method

Q (cms)	
V (m s^{-1})	
n	
Fr	
D_c rectangular (m)	
D_c trapezoidal (m)	
D_c triangular (m)	
D_c parabolic (m)	
D_c mean (m)	
flow type	
Ω (watts m^{-1})	
ω_a (watts m^{-2})	
ω_a/TW (watts m^{-1})	
*Re**	
Re	
turbulence	