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Technical Memorandum

Date: October 15, 2014

Subject: **Flood and Generic Regulation Limits Mapping for Cardinal Creek from Ottawa River to O'Toole Road, for the purposes of administering Ontario Regulation 174/06**

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Abstract

This report documents procedures that have been followed in producing 1:100 year flood lines and "regulation limits" for Cardinal Creek (see Figure 1) to support land use planning and development control in accordance with the provisions of the Natural Hazards policies of the Provincial Policy Statement under the Planning Act, and the administration and enforcement of RVCA regulations made under Section 28 of the Conservation Authorities Act (O.Reg 174/06). The flood line mapping has been completed in accordance with technical guidance for flood hazard delineation in Ontario as set out in the Ontario Ministry of Natural Resources Natural Hazards Technical Guides (MNR, 2002). The regulation limit mapping has been completed in accordance with Conservation Ontario (2005) guidelines and RVCA's (2005) reference manual.

This report supersedes its earlier version (RVCA, March 2, 2012).

1. Introduction

Until 2012, RVCA had not published regulatory (1:100 year) flood lines or regulation limits within the Cardinal Creek watershed, which became a part of the RVCA's area of jurisdiction in the early 1990's. Since 2004, when amendments to Section 28 of the Conservation Authorities Act were enacted and the so-called "Generic Regulation" (O.Reg. 97/04) was approved by the Provincial Government, the RVCA has been gradually working to expand and update its collection of flood hazard and regulation limits mapping, in order to achieve effective and consistent administration and enforcement of its local regulations – O.Reg 174/06.

The City of Ottawa's recently completed Cardinal Creek Subwatershed Study presented an opportunity to expedite the plotting of regulation limits mapping for the stream corridors and valleys of the Cardinal Creek watershed in two ways: (a) hydrologic, hydraulic and geomorphological studies completed during the "existing conditions" phase of the Subwatershed Study provide required background information related to flood and erosion hazards, and (b) a portion of funding allocated to the City's Subwatershed Study was made available to enable the regulation limits mapping for Cardinal Creek to be fast-tracked regardless of its status within RVCA-wide priorities for flood line and regulation limits mapping.

During 2011-12, RVCA did the first flood and regulation mapping based on the information available at that time (AECOM 2009), and summarized the work in a technical report (RVCA, 2012) which was approved by the RVCA Board of Directors on April 26th, 2012. Since then, the hydrologic analysis (AECOM 2012) and the subwatershed report (AECOM 2014) have been updated, and were approved by the City Council on May 14, 2014. This necessitated an update of the flood and regulation mapping by RVCA too. Also, a number of site-specific studies have also been conducted, which need to be accounted for in the regulation limit plotting.

Based on the topography and valley features, Cardinal Creek can be conveniently divided into two reaches for the purpose of delineating regulation limits.

The 6 km reach downstream of Innes Road is contained within an 'apparent' valley system, where slope stability is the dominant consideration for determining potential hazard areas and corresponding regulation limits. Upstream of Innes Road, the stream valleys are not well-defined, so the regulation limits are determined by the extent of the flood plain or erosion hazard (meander belt width), whichever is greater. There are some localized karst features near Watters Road. The regulation limits have been determined by considering all existing hazards, namely, flood, slope stability, karst and meander belt.

This report deals with these hazards sequentially, explaining how each of them was dealt with for the study area.

The work reported here conforms to the generic regulation guidelines of Conservation Ontario (2005), the natural hazards guidelines of MNR (2002) and the RVCA reference manual[1] (2005).

[1] RVCA reference manual entitled "RVCA Methods for Delineation of Regulation Limits in Accordance with Ontario Regulation 97/04" (November 16, 2005) approved at RVCA Board of Directors' meeting of November 24th, 2005 and based on the requirements set out in "Guidelines for Developing Schedules of Regulated Areas" approved by Conservation Ontario and Ontario Ministry of Natural Resources (October 2005).

2. Study Area

The upstream study limit was essentially determined by the areal extent of the available LiDAR data and the Digital Terrain Model (DTM) derived therefrom (see Figures 1 and 2). The downstream study limit is Cardinal Creek's confluence with the Ottawa River. The following streams were included in this study (Figure 3):

- Cardinal Creek – from Ottawa River to O'Toole Road
- Garvock Drain
- Antonio Farley Drain
- Un-named Drain

The entire area mapped is within the City of Ottawa. There is no major settlement upstream of Innes Road, only a few scattered rural residences. Downstream of Innes road and abutting the west bank of Cardinal Creek, there are several urban subdivisions. However, the entire area is expected to be urbanized in the near future. A community design plan and related master servicing study have been approved by the City of Ottawa for the proposed Cardinal Creek Village community on the east side of Cardinal Creek.

3. Flood Risk Mapping

3.1 Hydrological Analysis

The last RVCA study was based on the hydrologic analysis contained in an older report by AECOM (2009). Recently, AECOM (2012) conducted another thorough study of the Cardinal Creek basin, which forms part of the updated subwatershed study (AECOM 2014). A hydrological modeling exercise using the XPSWMM model was conducted for the following scenarios:

- 1:100 year snow plus rain event
- 1:100 year rain event
- 1:5 year rain event
- 1:2 year rain event
- July 1979 storm event

The most important hydrological updates incorporated by AECOM (2012) into their new model that had an impact on the results can be summarized as follows:

- Catchment areas were updated based on new topographic information.
- Time of concentration values were updated based on the Watt and Chow method.
- Some modification on the Storm Water facility's stage discharge relationship was based on survey data.
- An assessment of the use of longer duration design storms was made. These longer design storms seemed to produce higher flows than the previous snow and rain event in some cases.
- Finally, the model included the proposed conditions scenarios for the development of Cardinal Village.

The Regulatory Flood Standard in Eastern Ontario and the Rideau Valley is established in Provincial Policy as "the 100 Year Flood Event Standard" which "means rainfall or snowmelt, or a combination of rainfall and snowmelt producing at any location in a river, creek, stream or watercourse, a peak flow that has a probability of occurrence of one per cent during any given year" (ref: Schedule 1 to O.Reg. 174/06).

For the area upstream of Waters Road, the 1:100 year snow event as computed in the AECOM studies was found to produce higher flows than the 1:100 year rain event. The 1:100 year snow event flows listed in Table 1 have been used here for the purpose of flood plain delineation.

For the area downstream of Waters Road, the 24-hour Chicago storm events produced the highest flows (Table 1) and were used for floodplain modeling.

In using the flows estimated by AECOM (2012) for floodplain mapping, we note that the hydrologic analysis is more complicated and thus subject to the analyst's experience and judgment than hydraulic analysis. The FDRP Manual (MNR 1986) states that the "hydrological science falls far short of a universal model that can be generally recommended for all applications" and the manual "is not meant to be a list of mandatory instruction". Rather it serves to assist the experienced engineers in selection the most appropriate methods, and gives a wide degree of latitude to the 'professional engineer'.

The AECOM (2012) analysis was undertaken by a professional engineer, incorporated the urban stormwater management, was calibrated using available data, and was reviewed by the City of Ottawa staff. This analysis was well within the 'latitude' given to the engineer by FDRP Manual. We therefore concluded that the flows derived from AECOM (2012) study are the best available information at this time and can be used in hazard delineation by RVCA.

3.2 Data Used for Flood Hazard Mapping

Aerial photo: The DRAPE imagery was collected in May-July 2008 at a scale of 1:16667. This high quality coloured photo clearly shows the rivers, creeks, land use, houses, buildings, roads, infrastructure, vegetation and other details.

DTM: The City of Ottawa derived a DTM from the LIDAR data acquired in April 20-22, 2007 (Figure 2). Contour lines were drawn at 0.5 m intervals with 0.25 m interpolated lines. This DTM exceeds the FDRP (1986) specifications and is therefore suitable for flood mapping purposes.

Cross-Sections: River and flood plain cross-sections – the basic building blocks of hydraulic models – were generated from the high quality DTM using standard HEC-GeoRAS software (USACE, 2011). For the most part this procedure captured the floodplain as well as most of the low flow channel in sufficient detail to be used in floodplain mapping.

In some places along the Garvock Municipal Drain, the drain cross-sections as captured by the LIDAR data deviated substantially from the original design presented in the Engineer's Report (McNeely, Lecompte & Associates Ltd, 1970). Here, we have used the drain cross-section from the Engineer's Report and the floodplain from LIDAR data, in order to reflect the well-maintained size of the drain as originally intended.

Channel Roughness: Following standard procedures (Chow, 1959), the resistance of the channel under possible high water conditions was estimated from aerial photos and field inspections. In the upstream model, the Manning's n value for main channel was 0.08 in for Cardinal creek and 0.035 for Antonio Farley and Garvock drains. For the downstream model, a Manning's n value of 0.035 was used for Cardinal Creek. In both models, the floodplains were assigned a Manning's n value of 0.05.

Bridges/Culverts: Available road crossing data is presented in Table 2 and pictures of the structures are provided in Appendix C. Their physical dimensions and other pertinent data were collected from earlier studies (AECOM, 2009) and from a survey completed by City of Ottawa staff in October 2011. Additional structure information was obtained during surveys conducted by RVCA staff in October and November 2011 and in July 2014. Out of these, four culverts upstream of Watters Road were used in the hydraulic model. The coefficients of contraction and expansion associated with culverts were estimated from available information using standard procedures (USACE, 1990, 2010). Downstream of Watters Road, two culverts and one bridge-like structure (utility corridor crossing) were included in the hydraulic model.

There are three small farm crossings within the study area that were not included in the hydraulic model because the necessary structural information was not available.

The exclusion of these crossings is not expected to impact the location of the floodlines to a great extent because of their small size; however if and when the crossings are removed (due to new development or any other reason) the hydraulic modeling will have to be reviewed and adjusted if necessary.

3.3 Hydraulic Modeling

Two separate hydraulic models were built – one upstream of Watters Road and the other downstream. Because of the large drop in elevation at Watters Road (about 23 m), the two segments of the Cardinal Creek are hydraulically independent of each other and thus can be modeled separately.

Upstream HEC-RAS Model

(Cardinal Creek from Watters Road to O'Toole Road and tributaries)

Following standard procedures (MNR, 1986; USACE, 1990, 2010), a steady-state hydraulic model of Cardinal Creek and associated tributaries was built. The HEC-RAS model (version 4.1.0) developed by the US Army Corps of Engineers (USACE, 2010) was used. This has the same back water calculation procedure as HEC-2 (USACE, 1990) which has been the industry standard since the 1970s, but with improved data processing and graphical capabilities.

About 61 cross-sections were used in the model. Distances between sections along the stream centre and left and right overbanks were calculated using HEC-GeoRAS software (USACE, 2011). Bridges and culverts were inserted at appropriate locations. Figures 4a and 4b show the modeled stream reaches and cross-sections.

The design flows listed in Table 1 were used in the model at appropriate locations (Table 3). All five profiles – 100 year snow plus rain and the other four – were run in the model.

The assumed water level at the stormwater management (SWM) facility just upstream of Watters Road (cross-section 3759) is a boundary condition for the computation of the upstream water surface profile, and for the various simulated events.

The water levels were estimated by RVCA based on the Storm Water Facility Stage-discharge curve that was provided by AECOM (2012), as summarized in Table 5. Using the curve it was found that a 1:100 year rain and snowmelt flow value of 19.1 cms corresponds to a water level value of 80.48m, which was used as a boundary condition in the model.

All confluences were designated as internal junctions with matching water levels in accordance with accepted procedures (USACE, 1990, 2010).

Once the model was set up, the computed profiles and other parameters were scrutinized to assess the reasonableness of model outputs. Special attention was given to the computed water level and energy profiles near bridges and culverts. Adjustments of model parameters – mainly the channel resistance and contraction and expansion coefficients – were made as necessary.

The computed water surface elevations and other parameters corresponding to the 1:100 year snow plus rain event are shown in Table 7. A few typical water surface profiles and all cross-sections are included in Appendix A.

Computed water surface elevations for other flood events are presented in Table 9. It should be pointed out that the model has been built and tuned to simulate the 1:100 year flood levels; therefore the water surface elevations for other events – simulated using the same parameters, especially the Manning's n values – are only approximate. This is because the river roughness varies with flow magnitude, with higher resistance associated with lower flows.

Downstream HEC-RAS Model

(Cardinal Creek from Ottawa River to Watters Road)

A separate HEC-RAS model was built for the segment of the Cardinal Creek from Watters Road to its confluence with Ottawa River. No tributary was included in the model. The creek in this reach is entrenched in a deep valley.

About 43 cross-sections were used in the model. Distances between sections along the stream centre and left and right overbanks were calculated using HEC-GeoRAS software (USACE, 2011). Bridges and culverts were inserted at appropriate locations. Figure 4c shows the modeled stream reaches and cross-sections.

The design flows listed in Table 1 were used in the model at appropriate locations (Table 4). All five profiles – 100 year snow plus rain and the other four – were run in the model. It should be noted that the flows used in the downstream model correspond to 24-hour Chicago storm events.

The water level of the Ottawa River at the confluence was used as the downstream boundary condition for Cardinal Creek. Computed water levels of the Ottawa River were taken from a recent study (RVCA, 2014), which are shown in Table 6.

The computed water surface elevations and other parameters corresponding to the 1:100 year rain event are shown in Table 8. A few typical water surface profiles and all cross-sections are included in Appendix B. Computed water surface elevations for other flood events are presented in Table 10.

3.4 Regulatory Flood Levels

As per Section 3 of the Provincial Policy Statement under the Planning Act (MMAH, 2005, 2014), the regulatory flood in Zone 2, which includes the RVCA, is the 1:100 year flood, as noted previously. The HEC-RAS model output includes a computed "water surface elevation" and a computed "energy grade elevation" for each modeled cross-section. At most cross-sections the difference between computed water surface elevation and energy grade elevation is small (in the order of a few centimetres).

However, near bridges, culverts and other water control structures, where the simulated stream velocities are relatively high, the computed water surface elevation may be substantially lower than the energy grade. In addition, the downstream model includes some relatively steep slopes in some sections, the HEC-RAS manual indicates that there is an inherent error in the computation of the water level surface for river channels that have slope that is larger than 1:10 (USACE, 2010). For that reason and given the inherent margins of error in all computer simulations, it is common practice to adopt the energy grade elevation as the Regulatory Flood Level (RFL) at such locations. It is noted that none of the roads were overtopped during the 1:100 year event. The computed head losses at the road crossings are listed in Tables 11 and 12.

For this study, we have taken the energy grade as the RFL (Tables 7 and 8) at all cross-sections.

3.5 Flood Line Delineation

Once the RFLs are established, the plotting of 1:100 year flood lines or flood risk limits is a relatively straightforward matter. Given the topographical information in the form of LIDAR points and 0.25 m contour lines, the inundated area below the RFLs can be easily delineated manually or by using automated computer programs. In the present case, the process was mostly automated. A model was constructed in ArcGIS that applies the appropriate water levels at the cross sections and interpolates the water levels in between based on the DTM. The water levels were then manually edited in few sections where the automation output seemed to be inaccurate.

Traditional flood plain maps were not produced for this study. Instead flood lines are shown on standard regulation maps of RVCA. Four such maps (No. 4, 5, 11 and 12) cover the study area and are included with this report. Once finalized, floodlines are included as shapefiles within the RVCA's Geographical Information System.

4. Slope Stability

Downstream of Innes Road, Cardinal Creek is contained within a well-defined valley system with relatively steep slopes along the main stem of Cardinal Creek and its tributaries.

Surficial deposits of sensitive marine clays occur throughout the watershed, requiring that a conservative 5:1 (horizontal:vertical) slope inclination be applied to determine the stable slope allowance for regulation limit plotting. The RVCA (2005) reference manual was again followed to determine the regulation limits (see Figure 5 for the decision tree).

Where the distance from toe of slope to existing stream bank (water's edge) is presently less than 15 metres, it was conservatively assumed that the stream may be actively eroding and a 15 metre toe erosion allowance was applied at the bottom of the slope, as indicated in Figure 7. Where the distance from stream to toe of slope is greater than 15 metres, the stable slope allowance is applied from the present position of the toe of slope. Where the valley wall slope is less steep than 5:1 (horizontal:vertical) the regulation limits were positioned 15 metres upland from the existing crest of slope (RVCA, 2005). It should be emphasized that the regulation limits established by these criteria are a <u>conservative</u> approximation of the areas that may be vulnerable to erosion and slope failure risks. They will be used to define areas where RVCA permission under O.Reg, 174/06 is required for development and site alteration, and where permission may be granted provided that applications for permission are supported by site specific geotechnical investigations completed to established standards by qualified professional engineers.

Where they were available, detailed site specific information from previous geotechnical investigations supporting approved plans of subdivision or infrastructure projects has been used in lieu of the conservative criteria described above, to establish the areas that should be considered vulnerable to slope instability. In particular, the regulation lines were adjusted according to the findings of Slope Stability Evaluations and Geotechnical Investigations for two housing developments along Cardinal Creek and for proposed improvements to Watters Road (Golder, 2001, 2002, 2003, 2004) as well as the geotechnical investigation for the proposed Cardinal Creek Village north of Old Montreal Road, and the Boulet subdivision south of Old Montreal road (Paterson, 2011a, 2011b, 2013, 2014).

5. Karst Features

Near Watters Road (Figure 6), karst features have been identified by Speltech (1991) and Golder (1991). Karst features result when soluble bedrock dissolves when in contact with flowing water, gradually forming underground channels and cavities within the rock formation. At the Watters Road location, Cardinal Creek flows through such underground passageways, entering at the top and emerging at the base of a partially buried bedrock escarpment. Conservation Ontario (2005) guidelines refer to karsts (a particular form of unstable bedrock) within the hazard delineation framework. They are considered natural hazards in the sense that they present particular challenges in the design and construction of buildings and infrastructure, and should be recognized in land use planning and approval processes accordingly.

In the case of Cardinal Creek, the karstic area is localized, relatively small and consists of both surface and subsurface channels within the bedrock. As can be seen in Figure 6, the identified karstic area is within the slope stability limits. Therefore, the regulation limits are determined by the slope stability at this locale, and the karsts have not influenced the positioning of regulation limits in this case.

6. Meander Belt

Site-specific geomorphological assessment studies provide the best information for estimating meander belt criteria. In the absence of such studies, Conservation Ontario (2005) and the MNR Natural hazards Guides (MNR, 2002) recommend 20 times the bankfull width as a conservative value for the estimated meander belt width, in stream systems which exhibit a meandering behaviour driven by fluvial geomorphological processes. A detailed geomorphological study of Cardinal Creek was undertaken by Geomorphic Solutions (2007) as a component of the Cardinal Creek Subwatershed Study. Their study determined the meander belt width of Cardinal Creek and tributaries, based on direct measurements from aerial photographs and topographical mapping. These finding have been adopted for the purposes of RVCA's regulation mapping.

Typical meander belt widths varied from 34 to 59 m for the main stem of Cardinal Creek upstream of Innes Road.

7. Regulation Limit of Cardinal Creek

In keeping with the Generic Regulation (O.Reg. 97/04), regulation limits are to be delineated based on the natural hazard (flooding erosion, unstable soil or bedrock) or feature (wetland, lakeshore or valley) with the largest upland extent, including applicable allowances. Using the limits of various hazards as described above, the regulation limits have been plotted along the Cardinal Creek corridor (see RVCA Regulation Map No. 4, 5, 11 and 12). These maps show the regulation limits as well as other pertinent hazard limits.

Upstream of Innes Road, flood risk and meander belt lines govern the location of regulation limits. Downstream, the slope stability line dominates. The karst features were always within the slope stability lines, and therefore did not influence the positioning of the regulation limit.

8. Project Deliverables

The end products of this project are:

1. The Flood/Regulation Mapping Report (the current memo)
2. The flood risk limit lines in GIS format
3. The regulation limit lines in GIS format
4. The RVCA Regulation Limit Map Sheets, No. 4, 5, 11 and 12

These will be shared with the City of Ottawa with project completion.

The report will also be published by RVCA and will be available on the RVCA website. RVCA regulation limit maps are always available upon request. The HEC-RAS model files will be preserved by RVCA and will be given to any party upon singing a standard data sharing agreement.

9. Closure

This report supersedes its earlier version (RVCA, March 2, 2012).

The engineering and cartographic procedures used in this study conform to present day standards of hazard delineation for identifying areas that are subject to the requirements of Regulations made under section 28 of the Conservation Authorities Act, as per the MNR's Natural Hazards Technical Guide (MNR, 2002) and Conservation Ontario (2005) guidelines. The resulting 1:100 year flood risk lines and regulation limit lines are suitable for use in the RVCA's regulation administration and in municipal land use planning and development approval processes under the Planning Act.

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Table 1 Estimated flood flows

Flow Point	Stream/Reach	Drainage Area (ha)	Chicago Distribution 24hr Flow (cms)			SCS Type II Distribution 24hr Flow (cms)			Flow (cms)	Flow (cms)	Source
			2-year rain	5-year rain	100-year rain	2-year rain	5-year rain	100-year rain	Snow 100-year event	July 1979 event	
O	Cardinal Creek/Reach 1	3458	9.60	15.50	30.90	9.60	15.40	30.60	24.70	32.70	AECOM 2012 [1]
H	Cardinal Creek/Reach 1	3280	8.80	13.70	26.50	8.70	13.60	26.00	22.10	27.90	AECOM 2012 [1]
G	Cardinal Creek/Reach 1	3051	7.60	11.70	21.50	7.50	11.50	21.40	19.10	22.00	AECOM 2012 [1]
F	Cardinal Creek/Reach 1	3031	7.50	11.60	21.40	7.50	11.40	21.40	19.10	21.80	AECOM 2012 [1]
D	Cardinal Creek/Reach 2	2356	3.90	6.90	16.60	4.00	7.10	16.50	17.20	17.70	AECOM 2012 [1]
C	Cardinal Creek/Reach 2	1973	2.30	4.20	11.10	2.50	4.50	11.70	14.20	12.10	AECOM 2012 [1]
B	Cardinal Creek/Reach 2	1526	1.40	2.40	6.10	1.50	2.60	6.50	7.60	5.30	AECOM 2012 [1]
A	Cardinal Creek/Reach 3	756	0.60	1.00	2.60	0.60	1.10	2.80	4.00	2.20	AECOM 2012 [1]
A1	Cardinal Creek/Reach 3	869	0.92	1.57	4.00	0.98	1.71	4.26	4.98	3.48	Area Pro-rated [2]
B1	Un-named branch/Reach 1	656	0.74	1.27	3.24	0.80	1.38	3.45	4.04	2.82	Area Pro-rated [2]
B2	Antonio Farley drain/Reach 1	300	0.41	0.71	1.80	0.44	0.77	1.92	2.24	1.56	Area Pro-rated [2]
B3	Garvock municipal drain/Reach 1	256	0.37	0.63	1.60	0.39	0.68	1.71	1.99	1.39	Area Pro-rated [2]

1) Taken from Tables 2.2 and 2.3 "Greater Cardinal Creek Subwatershed Plan Hydrology Update" (AECOM, November 2012)
2) Estimated by RVCA based on Figure 1 of "Greater Cardinal Creek Subwatershed Plan Hydrology Update" (AECOM, November 2012)
3) The governing 100 year flows are highlighted in Yellow and were used in the HEC-RAS model.
4) The governing 5 year flows are highlighted in Orange and were used in the HEC-RAS model.
5) The governing 2 year flows are highlighted in Green and were used in the HEC-RAS model.

Table 2 Bridges and culverts

Stream/Reach	Location	Bridge/ Culvert	Chainage (m)	Bounding Cross Sections	Upstream Invert (m)	Downstream Invert (m)	Upstream Obvert [1] (m)	Downstream Obvert [1] (m)	Width [3] (m)	Height [2] (m)	Length [3] (m)
Cardinal/Reach 1	Regional Road. 174	C	1035	1 & 48	39.66	39.44	42.70	42.48	6	3.04	46
Cardinal/Reach 1	Utility corridor	C	2140	1164 & 1131	42.10	41.32	47.10 [2]	46.32 [2]	5 [2]	5.00	30 [5]
Cardinal/Reach 1	Old Montreal Road	C	3350	2379 & 2336	49.80	49.86	54.80	54.86	5 [4]	4.60 [4]	25
Cardinal/Reach 1	Watters Road	C	4580	3594 & 3578	78.61	78.60	81.55	81.54	4	2.94	7
Cardinal/Reach 2	Innes Road	C	7290	7307 & 7273	80.06	80.06	83.01	83.01	4	2.95	25
Cardinal/Reach 2	Frank Kenny Road	C	7570	7587 & 7555	80.34	80.34	82.54	82.54	6	2.20	18
Cardinal/Reach 3	O'Toole Road	C	9600	9648 & 9582	83.94	83.96	86.49	86.51	5	2.55	17
Gravock/Reach 1	O'Toole Road	C	390	408 & 340	84.35	84.35	85.35	85.35	1 diameter	-	12

1) City of Ottawa survey October 2011
2) RVCA Survey on October 14th 2011 and November 4th 2011
3) Taken from Table 2.2 page 27 "Greater Cardinal Creek Subwatershed Study Existing conditions report" (AECOM, August 2009)
4) City of Ottawa drawing "Old Montreal road (SN897220) Culvert renewal". Issued for circulation November 2013
5) Estimated from aerial photography

Table 3 Design flows in HEC-RAS model

Cardinal Creek from Watters Road to O'Toole Road (SCS type II distribution)

River/Creek	Reach	River Station	Flows (cms)				
			100 year Snow	1979 event	100 year rain	5 year rain	2 year rain
Cardinal Creek	Reach 2	8636	14.20	12.10	11.70	4.50	2.50
Cardinal Creek	Reach 2	8368	14.20	12.10	11.70	4.50	2.50
Cardinal Creek	Reach 2	7273	17.20	17.70	16.50	7.10	4.00
Cardinal Creek	Reach 2	6192	19.10	21.80	21.40	11.40	7.50
Cardinal Creek	Reach 3	9778	4.98	3.48	4.26	1.71	0.98
Un-named	Reach 1	672	4.04	2.82	3.45	1.38	0.80
Garvock	Reach 1	494	1.99	1.39	1.71	0.68	0.39
Antonio Farley	Reach 1	657	2.24	1.56	1.92	0.77	0.44

Table 4 Design flows in HEC-RAS model

Cardinal Creek from Ottawa River to Watters Road (Chicago Distribution)

River/Creek	Reach	River Station	Flows (cms)				
			100 year Snow	1979 event	100 year rain	5 year rain	2 year rain
Cardinal Creek	Reach 1	4578	19.10	22.00	21.50	11.70	7.60
Cardinal Creek	Reach 1	3931	22.10	27.90	26.50	13.70	8.80
Cardinal Creek	Reach 1	3379	24.70	32.70	30.90	15.50	9.60

Table 5 Downstream boundary condition at Waters Road Stormwater Pond

Event	Flow of Cardinal Creek at point "F" (cms)	Water Surface Elevations at the Pond (m) [1]
100 year S+R	19.10	80.48
1979 event	21.80	80.75
100 year rain	21.40	70.70
5 year rain	11.40	79.75
2 year rain	7.50	79.36

1) Estimated by RVCA from the CCOM On-Line Facility Stage-Discharge curve (August 2012)

Table 6 Downstream boundary condition at Ottawa River

Event	Flow at Ottawa River (cross-section 1015) (cms)	Corresponding Water Levels (m)	Source
100 year Snow	9240	44.92	RVCA[1]
1979 event	1730	42.82	Estimated
100 year rain	9240	44.92	RVCA[1]
5 year rain	6280	43.44	RVCA[1]
2 year rain	5160	42.82	RVCA[1]

1) RVCA (2014). Ottawa River Flood Risk Mapping from Shirley's Bay to Cumberland (draft)

Table 7 Regulatory Flood Levels for 100 Year Rain and Snow Event (Cardinal Creek from Watters Road to O'Toole Road)

Stream	Reach	River Station (m)	Q (total) (cms)	Computed WSEL (m)	EGL (m)	RFL (m)
Cardinal Creek	Reach 2	3759	19.10	81.00	81.00	81.00
	Reach 2	3995	19.10	81.00	81.01	81.01
	Reach 2	4247	19.10	81.01	81.01	81.01
	Reach 2	4476	19.10	81.02	81.02	81.02
	Reach 2	4781	19.10	81.03	81.03	81.03
	Reach 2	4995	19.10	81.04	81.04	81.04
	Reach 2	5278	19.10	81.05	81.06	81.06
	Reach 2	5620	19.10	81.08	81.09	81.09
	Reach 2	5945	19.10	81.14	81.14	81.14
	Reach 2	6192	19.10	81.26	81.27	81.27
	Reach 2	6546	17.20	81.52	81.53	81.53
	Reach 2	6847	17.20	81.80	81.82	81.82
	Reach 2	7068	17.20	82.10	82.12	82.12
	Reach 2	7217	17.20	82.27	82.28	82.28
	Reach 2	7273	17.20	82.27	82.49	82.49
	Reach 2	7290	Innes Road			
	Reach 2	7307	14.20	82.39	82.56	82.56
	Reach 2	7379	14.20	82.64	82.64	82.64
	Reach 2	7490	14.20	82.69	82.71	82.71
	Reach 2	7513	14.20	82.73	82.75	82.75
	Reach 2	7555	14.20	82.80	82.86	82.86
	Reach 2	7570	Frank Kenny Road			
	Reach 2	7587	14.20	82.84	82.90	82.90
	Reach 2	7647	14.20	82.96	82.97	82.97
	Reach 2	7739	14.20	83.03	83.04	83.04
	Reach 2	7920	14.20	83.14	83.14	83.14
	Reach 2	8230	14.20	83.33	83.35	83.35
	Reach 2	8368	14.20	83.54	83.58	83.58
	Reach 2	8491	14.20	83.70	83.71	83.71
	Reach 2	8636	14.20	83.84	83.88	83.88
	Reach 3	8721	4.98	84.07	84.07	84.07
	Reach 3	8791	4.98	84.16	84.17	84.17
	Reach 3	8881	4.98	84.28	84.29	84.29
	Reach 3	9042	4.98	84.47	84.48	84.48
	Reach 3	9109	4.98	84.61	84.63	84.63
	Reach 3	9127	4.98	84.73	84.79	84.79
	Reach 3	9258	4.98	85.43	85.45	85.45
	Reach 3	9438	4.98	85.72	85.73	85.73
	Reach 3	9582	4.98	85.88	85.90	85.90
	Reach 3	9600	O'Toole Road			
	Reach 3	9648	4.98	85.89	85.91	85.91

	Reach 3	9778	4.98	86.11	86.12	86.12
Un-named	Reach1	25	4.04	83.93	83.94	83.94
	Reach1	82	4.04	84.02	84.04	84.04
	Reach1	201	4.04	84.41	84.43	84.43
	Reach1	354	4.04	84.74	84.76	84.76
	Reach1	448	4.04	84.90	84.91	84.91
	Reach1	477	4.04	84.95	84.95	84.95
	Reach1	588	4.04	85.24	85.27	85.27
	Reach1	672	4.04	85.54	85.55	85.55
Garvock	Reach 1	22	1.99	85.56	85.57	85.57
	Reach 1	124	1.99	85.60	85.62	85.62
	Reach 1	249	1.99	85.74	85.76	85.76
	Reach 1	340	1.99	85.82	85.89	85.89
	Reach 1	390	O'Toole Road			
	Reach 1	408	1.99	86.61	86.66	86.66
	Reach 1	494	1.99	86.67	86.67	86.67
Antonio Farley	Reach 1	12	2.24	85.55	85.57	85.57
	Reach 1	96	2.24	85.63	85.66	85.66
	Reach 1	138	2.24	85.71	85.74	85.74
	Reach 1	217	2.24	85.90	85.93	85.93
	Reach 1	241	2.24	85.95	86.02	86.02
	Reach 1	332	2.24	86.32	86.35	86.35
	Reach 1	499	2.24	86.74	86.78	86.78
	Reach 1	657	2.24	87.10	87.13	87.13

Table 8 Regulatory Flood Levels for 100 Year Rain Event
(Cardinal Creek from Ottawa River to Watters Road)

Stream	Reach	River Station (m)	Q (total) (cms)	Computed WSEL (m)	EGL (m)	RFL (m)
Cardinal Creek	Reach 1	600	30.90	44.92	44.92	44.92
	Reach 1	800	30.90	44.92	44.92	44.92
	Reach 1	1000	30.90	44.92	44.92	44.92
	Reach 1	1035	Regional Road. 174			
	Reach 1	1048	30.90	45.05	45.10	45.10
	Reach 1	1121	30.90	45.10	45.10	45.10
	Reach 1	1211	30.90	45.10	45.10	45.10
	Reach 1	1334	30.90	45.10	45.10	45.10
	Reach 1	1442	30.90	45.10	45.10	45.10
	Reach 1	1599	30.90	45.10	45.11	45.11
	Reach 1	1701	30.90	45.10	45.11	45.11
	Reach 1	1843	30.90	45.11	45.11	45.11
	Reach 1	1970	30.90	45.11	45.12	45.12
	Reach 1	2070	30.90	45.12	45.12	45.12
	Reach 1	2131	30.90	45.06	45.18	45.18
	Reach 1	2140	Utility Corridor			
	Reach 1	2164	30.90	45.21	45.33	45.33
	Reach 1	2226	30.90	45.34	45.35	45.35
	Reach 1	2281	30.90	45.34	45.35	45.35
	Reach 1	2369	30.90	45.35	45.36	45.36
	Reach 1	2511	30.90	45.36	45.36	45.36
	Reach 1	2672	30.90	45.36	45.38	45.38
	Reach 1	2751	30.90	45.37	45.48	45.48
	Reach 1	2876	30.90	45.71	45.85	45.85
	Reach 1	2940	30.90	48.36	48.69	48.69
	Reach 1	3011	30.90	52.22	52.64	52.64
	Reach 1	3105	30.90	52.97	53.14	53.14
	Reach 1	3194	30.90	53.25	53.36	53.36
	Reach 1	3293	30.90	53.46	53.50	53.50
	Reach 1	3336	30.90	53.44	53.59	53.59
	Reach 1	3350	Old Montreal Road			
	Reach 1	3379	30.90	53.54	53.67	53.67
	Reach 1	3460	26.50	53.71	53.73	53.73
	Reach 1	3535	26.50	53.76	53.79	53.79
	Reach 1	3604	26.50	53.96	54.24	54.24

	Reach 1	3713	26.50	55.14	55.34	55.34
	Reach 1	3795	26.50	55.58	55.67	55.67
	Reach 1	3931	26.50	55.96	56.06	56.06
	Reach 1	4133	21.50	56.53	56.62	56.62
	Reach 1	4230	21.50	56.79	56.87	56.87
	Reach 1	4281	21.50	66.26	66.66	66.66
	Reach 1	4329	21.50	66.90	67.03	67.03
	Reach 1	4399	21.50	67.20	67.25	67.25
	Reach 1	4465	21.50	69.85	70.27	70.27
	Reach 1	4533	21.50	78.01	78.42	78.42
	Reach 1	4578	21.50	79.31	79.66	79.66

Table 9 Computed Water Surface Elevations for Different Flood Events
(Cardinal Creek from Watters Road to O'Toole Road)

Stream	Reach	River Station (m)	Flow (cms) and Computed WSEL (m) for Different Flood Events									
			Q100 R+S	WL100 R+S	Q1979 event	WL1979 event	Q100 R	WL100 R	Q5 R	WL5 R	Q2 R	WL2 R
Cardinal Creek	Reach 2	3759	19.10	81.00	21.80	80.70	21.40	80.00	11.40	78.50	7.50	78.01
	Reach 2	3995	19.10	81.00	21.80	80.71	21.40	80.03	11.40	78.81	7.50	78.65
	Reach 2	4247	19.10	81.01	21.80	80.72	21.40	80.06	11.40	78.98	7.50	78.80
	Reach 2	4476	19.10	81.02	21.80	80.74	21.40	80.11	11.40	79.11	7.50	78.90
	Reach 2	4781	19.10	81.03	21.80	80.76	21.40	80.16	11.40	79.31	7.50	79.10
	Reach 2	4995	19.10	81.04	21.80	80.78	21.40	80.21	11.40	79.49	7.50	79.31
	Reach 2	5278	19.10	81.05	21.80	80.81	21.40	80.32	11.40	79.76	7.50	79.58
	Reach 2	5620	19.10	81.08	21.80	80.87	21.40	80.51	11.40	80.11	7.50	79.95
	Reach 2	5945	19.10	81.14	21.80	80.99	21.40	80.80	11.40	80.49	7.50	80.33
	Reach 2	6192	19.10	81.26	21.80	81.22	21.40	81.15	11.40	80.83	7.50	80.66
	Reach 2	6546	17.20	81.52	17.70	81.54	16.50	81.50	7.10	81.14	4.00	80.94
	Reach 2	6847	17.20	81.80	17.70	81.82	16.50	81.78	7.10	81.39	4.00	81.17
	Reach 2	7068	17.20	82.10	17.70	82.12	16.50	82.08	7.10	81.64	4.00	81.38
	Reach 2	7217	17.20	82.27	17.70	82.29	16.50	82.24	7.10	81.80	4.00	81.54
	Reach 2	7273	17.20	82.27	17.70	82.29	16.50	82.25	7.10	81.87	4.00	81.62
	Reach 2	7290	Innes Road									
	Reach 2	7307	14.20	82.39	12.10	82.45	11.70	82.39	4.50	81.91	2.50	81.63
	Reach 2	7379	14.20	82.64	12.10	82.62	11.70	82.56	4.50	81.98	2.50	81.69
	Reach 2	7490	14.20	82.69	12.10	82.66	11.70	82.61	4.50	82.03	2.50	81.74
	Reach 2	7513	14.20	82.73	12.10	82.69	11.70	82.64	4.50	82.05	2.50	81.75
	Reach 2	7555	14.20	82.80	12.10	82.75	11.70	82.70	4.50	82.09	2.50	81.79
	Reach 2	7570	Frank Kenny Road									
	Reach 2	7587	14.20	82.84	12.10	82.78	11.70	82.73	4.50	82.10	2.50	81.79
	Reach 2	7647	14.20	82.96	12.10	82.88	11.70	82.83	4.50	82.16	2.50	81.83
	Reach 2	7739	14.20	83.03	12.10	82.94	11.70	82.90	4.50	82.25	2.50	81.91
	Reach 2	7920	14.20	83.14	12.10	83.05	11.70	83.01	4.50	82.43	2.50	82.12
	Reach 2	8230	14.20	83.33	12.10	83.24	11.70	83.21	4.50	82.74	2.50	82.50
	Reach 2	8368	14.20	83.54	12.10	83.44	11.70	83.41	4.50	82.91	2.50	82.68
	Reach 2	8491	14.20	83.70	12.10	83.59	11.70	83.56	4.50	83.02	2.50	82.75
	Reach 2	8636	14.20	83.84	12.10	83.72	11.70	83.70	4.50	83.16	2.50	82.88

	Reach 3	8721	4.98	84.07	3.48	83.95	4.26	83.94	1.71	83.48	0.98	83.31
	Reach 3	8791	4.98	84.16	3.48	84.02	4.26	84.05	1.71	83.63	0.98	83.43
	Reach 3	8881	4.98	84.28	3.48	84.13	4.26	84.18	1.71	83.76	0.98	83.56
	Reach 3	9042	4.98	84.47	3.48	84.29	4.26	84.38	1.71	83.97	0.98	83.79
	Reach 3	9109	4.98	84.61	3.48	84.43	4.26	84.52	1.71	84.13	0.98	83.98
	Reach 3	9127	4.98	84.73	3.48	84.57	4.26	84.66	1.71	84.36	0.98	84.26
	Reach 3	9258	4.98	85.43	3.48	85.23	4.26	85.34	1.71	84.93	0.98	84.75
	Reach 3	9438	4.98	85.72	3.48	85.48	4.26	85.61	1.71	85.13	0.98	84.91
	Reach 3	9582	4.98	85.88	3.48	85.63	4.26	85.77	1.71	85.23	0.98	85.00
	Reach 3	9600	O'Toole Road									
	Reach 3	9648	4.98	85.89	3.48	85.63	4.26	85.77	1.71	85.23	0.98	85.00
	Reach 3	9778	4.98	86.11	3.48	85.84	4.26	85.98	1.71	85.43	0.98	85.20
Un-named	Reach1	25	4.04	83.93	2.82	83.81	3.45	83.79	1.38	83.25	0.80	83.03
	Reach1	82	4.04	84.02	2.82	83.88	3.45	83.89	1.38	83.42	0.80	83.26
	Reach1	201	4.04	84.41	2.82	84.22	3.45	84.32	1.38	83.90	0.80	83.70
	Reach1	354	4.04	84.74	2.82	84.52	3.45	84.64	1.38	84.14	0.80	83.92
	Reach1	448	4.04	84.90	2.82	84.66	3.45	84.79	1.38	84.28	0.80	84.06
	Reach1	477	4.04	84.95	2.82	84.71	3.45	84.84	1.38	84.35	0.80	84.14
	Reach1	588	4.04	85.24	2.82	85.04	3.45	85.15	1.38	84.75	0.80	84.60
	Reach1	672	4.04	85.54	2.82	85.31	3.45	85.44	1.38	84.96	0.80	84.77
Garvock	Reach 1	22	1.99	85.56	1.39	85.34	1.71	85.46	0.68	84.99	0.39	84.79
	Reach 1	124	1.99	85.60	1.39	85.39	1.71	85.51	0.68	85.06	0.39	84.87
	Reach 1	249	1.99	85.74	1.39	85.56	1.71	85.66	0.68	85.31	0.39	85.18
	Reach 1	340	1.99	85.82	1.39	85.65	1.71	85.75	0.68	85.40	0.39	85.25
	Reach 1	390	O'Toole Road									
	Reach 1	408	1.99	86.61	1.39	86.00	1.71	86.31	0.68	85.40	0.39	85.23
	Reach 1	494	1.99	86.67	1.39	86.12	1.71	86.39	0.68	85.70	0.39	85.56
Antonio Farley	Reach 1	12	2.24	85.55	1.56	85.33	1.92	85.45	0.77	84.98	0.44	84.78
	Reach 1	96	2.24	85.63	1.56	85.43	1.92	85.54	0.77	85.14	0.44	85.01
	Reach 1	138	2.24	85.71	1.56	85.53	1.92	85.62	0.77	85.31	0.44	85.21
	Reach 1	217	2.24	85.90	1.56	85.78	1.92	85.85	0.77	85.63	0.44	85.55
	Reach 1	241	2.24	85.95	1.56	85.85	1.92	85.90	0.77	85.70	0.44	85.61
	Reach 1	332	2.24	86.32	1.56	86.22	1.92	86.28	0.77	86.06	0.44	85.96
	Reach 1	499	2.24	86.74	1.56	86.63	1.92	86.69	0.77	86.45	0.44	86.35
	Reach 1	657	2.24	87.10	1.56	86.97	1.92	87.04	0.77	86.78	0.44	86.66

Table 10 Computed Water Surface Elevations for Different Flood Events
(Cardinal Creek from Ottawa River to Watters Road)

Stream	Reach	River Station (m)	Flow (cms) and Computed WSEL (m) for Different Flood Events									
			Q100 R+S	WL100 R+S	Q1979 event	WL1979 event	Q100 R	WL100 R	Q5 R	WL5 R	Q2 R	WL2 R
Cardinal Creek	Reach 1	600	24.70	44.92	32.70	42.82	30.90	44.92	15.50	43.44	9.60	42.82
	Reach 1	800	24.70	44.92	32.70	42.82	30.90	44.92	15.50	43.44	9.60	42.82
	Reach 1	1000	24.70	44.92	32.70	42.82	30.90	44.92	15.50	43.44	9.60	42.82
	Reach 1	1035	Cardinal on regional road. 174									
	Reach 1	1048	24.70	45.01	32.70	42.89	30.90	45.05	15.50	43.46	9.60	42.83
	Reach 1	1121	24.70	45.04	32.70	43.04	30.90	45.10	15.50	43.49	9.60	42.84
	Reach 1	1211	24.70	45.04	32.70	43.05	30.90	45.10	15.50	43.49	9.60	42.84
	Reach 1	1334	24.70	45.04	32.70	43.07	30.90	45.10	15.50	43.49	9.60	42.85
	Reach 1	1442	24.70	45.04	32.70	43.12	30.90	45.10	15.50	43.49	9.60	42.85
	Reach 1	1599	24.70	45.04	32.70	43.22	30.90	45.10	15.50	43.50	9.60	42.88
	Reach 1	1701	24.70	45.04	32.70	43.28	30.90	45.10	15.50	43.51	9.60	42.90
	Reach 1	1843	24.70	45.04	32.70	43.39	30.90	45.11	15.50	43.52	9.60	42.93
	Reach 1	1970	24.70	45.04	32.70	43.44	30.90	45.11	15.50	43.53	9.60	42.95
	Reach 1	2070	24.70	45.05	32.70	43.49	30.90	45.12	15.50	43.54	9.60	42.97
	Reach 1	2131	24.70	45.01	32.70	43.23	30.90	45.06	15.50	43.50	9.60	42.97
	Reach 1	2140	Utility Corridor on Cardinal creek									
	Reach 1	2164	24.70	45.10	32.70	44.77	30.90	45.21	15.50	43.71	9.60	43.30
	Reach 1	2226	24.70	45.20	32.70	44.98	30.90	45.34	15.50	43.83	9.60	43.38
	Reach 1	2281	24.70	45.19	32.70	44.97	30.90	45.34	15.50	43.83	9.60	43.39
	Reach 1	2369	24.70	45.20	32.70	45.00	30.90	45.35	15.50	43.87	9.60	43.44
	Reach 1	2511	24.70	45.21	32.70	45.01	30.90	45.36	15.50	43.92	9.60	43.60
	Reach 1	2672	24.70	45.21	32.70	45.02	30.90	45.36	15.50	44.27	9.60	44.30
	Reach 1	2751	24.70	45.22	32.70	45.07	30.90	45.37	15.50	44.88	9.60	44.66
	Reach 1	2876	24.70	45.58	32.7	45.79	30.90	45.71	15.50	45.39	9.60	45.24
	Reach 1	2940	24.70	48.27	32.70	48.39	30.90	48.36	15.50	48.12	9.60	48.00
	Reach 1	3011	24.70	52.09	32.70	52.24	30.90	52.22	15.50	51.83	9.60	51.62
	Reach 1	3105	24.70	52.81	32.70	53.01	30.90	52.97	15.50	52.55	9.60	52.32
	Reach 1	3194	24.70	53.07	32.70	53.30	30.90	53.25	15.50	52.78	9.60	52.54
	Reach 1	3293	24.70	53.31	32.70	53.50	30.90	53.46	15.50	53.02	9.60	52.77
	Reach 1	3336	24.70	53.31	32.70	53.48	30.90	53.44	15.50	53.05	9.60	52.82
	Reach 1	3350	Cardinal on Old Montreal road									

	Reach 1	3379	24.70	53.38	32.70	53.59	30.90	53.54	15.50	53.08	9.60	52.83
	Reach 1	3460	22.10	53.49	27.90	53.77	26.50	53.71	13.70	53.10	8.80	52.81
	Reach 1	3535	22.10	53.57	27.90	53.81	26.50	53.76	13.70	53.27	8.80	53.07
	Reach 1	3604	22.10	53.89	27.90	53.98	26.50	53.96	13.70	53.71	8.80	53.60
	Reach 1	3713	22.10	55.06	27.90	55.16	26.50	55.14	13.70	54.86	8.80	54.71
	Reach 1	3795	22.10	55.48	27.90	55.61	26.50	55.58	13.70	55.25	8.80	55.09
	Reach 1	3931	22.10	55.86	27.90	55.99	26.50	55.96	13.70	55.64	8.80	55.48
	Reach 1	4133	19.10	56.43	22.00	56.55	21.50	56.53	11.70	56.18	7.60	55.98
	Reach 1	4230	19.10	56.71	22.00	56.81	21.50	56.79	11.70	56.45	7.60	56.27
	Reach 1	4281	19.10	66.20	22.00	66.27	21.50	66.26	11.70	65.99	7.60	65.85
	Reach 1	4329	19.10	66.83	22.00	66.91	21.50	66.90	11.70	66.59	7.60	66.44
	Reach 1	4399	19.10	67.14	22.00	67.21	21.50	67.20	11.70	66.93	7.60	66.78
	Reach 1	4465	19.10	69.79	22.00	69.87	21.50	69.85	11.70	69.55	7.60	69.39
	Reach 1	4533	19.10	77.95	22.00	78.03	21.50	78.01	11.70	77.72	7.60	77.56
	Reach 1	4578	19.10	79.25	22.00	79.32	21.50	79.31	11.70	79.06	7.60	78.93

Table 11 Headloss at culverts along Cardinal Creek from Watters Road to O'Toole Road (1:100 year Snow plus Rain Event)

Stream/Reach	Location	Chainage (m)	Upstream Invert (m)	Downstream Invert (m)	Upstream Obvert [1] (m)	Downstream Obvert [1] (m)	E.G. Elev. u/s of Culvert[3] (m)	E.G. Elev. d/s of Culvert[3] (m)	Headloss (m)
Cardinal/Reach 2	Innes Road	7290	80.06	80.06	83.01	83.01	82.56	82.49	0.07
Cardinal/Reach 2	Frank Kenny Road	7570	80.34	80.34	82.54	82.54	82.90	82.86	0.04
Cardinal/Reach 3	O'Toole Road	9600	83.94	83.96	86.49	86.51	85.91	85.90	0.01
Garvock/Reach 1	O'Toole Road	390	84.35	84.35	85.35	85.35	86.66	85.89	0.77

Table 12 Headloss at culverts along Cardinal Creek from Ottawa River to Watters Road (1:100 year Rain Event)

Stream/Reach	Location	Chainage (m)	Upstream Invert (m)	Downstream Invert (m)	Upstream Obvert [1] (m)	Downstream Obvert [1] (m)	E.G. Elev. u/s of Culvert[3] (m)	E.G. Elev. d/s of Culvert[3] (m)	Headloss (m)
Cardinal/Reach 1	Regional Road. 174	1035	39.66	39.44	42.70	42.48	45.10	44.92	0.18
Cardinal/Reach 1	Utility corridor	2140	42.10	41.32	47.10 [2]	46.32 [2]	45.33	45.18	0.15
Cardinal/Reach 1	Old Montreal Road	3350	49.80	49.86	54.80	54.86	53.67	53.59	0.08

E.G. Elev. - Energy Grade Elevation

1) City of Ottawa survey October 2011
2) RVCA Survey on October 14th 2011 and November 4th 2011
3) Output from HEC-RAS Model, RVCA 2014

Figure 1: Study Area

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Projection note: U.T.M. Zone 18 - NAD 83 Datum

File name: Cardinal Figure 2: Extent of hill shade.

Date Modified: 7/11/2011

Created by: AAHMED

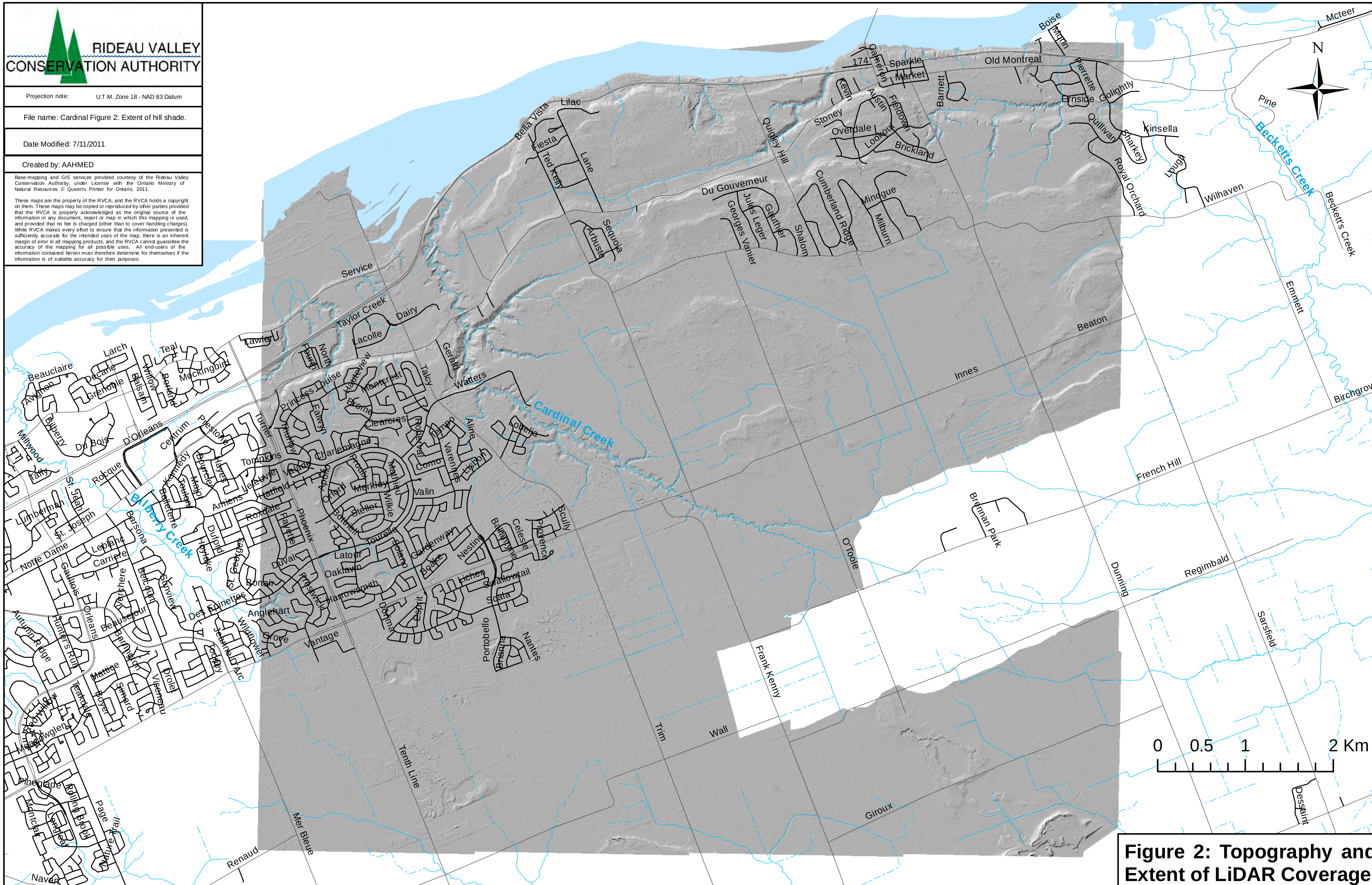


Figure 2: Topography and Extent of LiDAR Coverage

Flow Point	Stream/Reach	Drainage Area (ha)	Chicago Distribution 24hr Flow (cms)			SCS Type II Distribution 24hr Flow (cms)			Flow (cms)	Flow (cms)
			2-year rain	5-year rain	100-year rain	2-year rain	5-year rain	100-year rain	Snow 100-year event	July 1979 event
O	Cardinal Creek/Reach 1	3458	9.60	15.50	30.90	9.60	15.40	30.60	24.70	32.70
H	Cardinal Creek/Reach 1	3280	8.80	13.70	26.50	8.70	13.60	26.00	22.10	27.90
G	Cardinal Creek/Reach 1	3051	7.60	11.70	21.50	7.50	11.50	21.40	19.10	22.00
F	Cardinal Creek/Reach 1	3031	7.50	11.60	21.40	7.50	11.40	21.40	19.10	21.80
D	Cardinal Creek/Reach 2	2356	3.90	6.90	16.60	4.00	7.10	16.50	17.20	17.70
C	Cardinal Creek/Reach 2	1973	2.30	4.20	11.10	2.50	4.50	11.70	14.20	12.10
B	Cardinal Creek/Reach 2	1526	1.40	2.40	6.10	1.50	2.60	6.50	7.60	5.30
A	Cardinal Creek/Reach 3	756	0.60	1.00	2.60	0.60	1.10	2.80	4.00	2.20
A1	Cardinal Creek/Reach 3	869	0.92	1.57	4.00	0.98	1.71	4.26	4.98	3.48
B1	Un-named branch/Reach 1	656	0.74	1.27	3.24	0.80	1.38	3.45	4.04	2.82
B2	Antonio Farley drain/Reach 1	300	0.41	0.71	1.80	0.44	0.77	1.92	2.24	1.56
B3	Garvock municipal drain/Reach 1	256	0.37	0.63	1.60	0.39	0.68	1.71	1.99	1.39

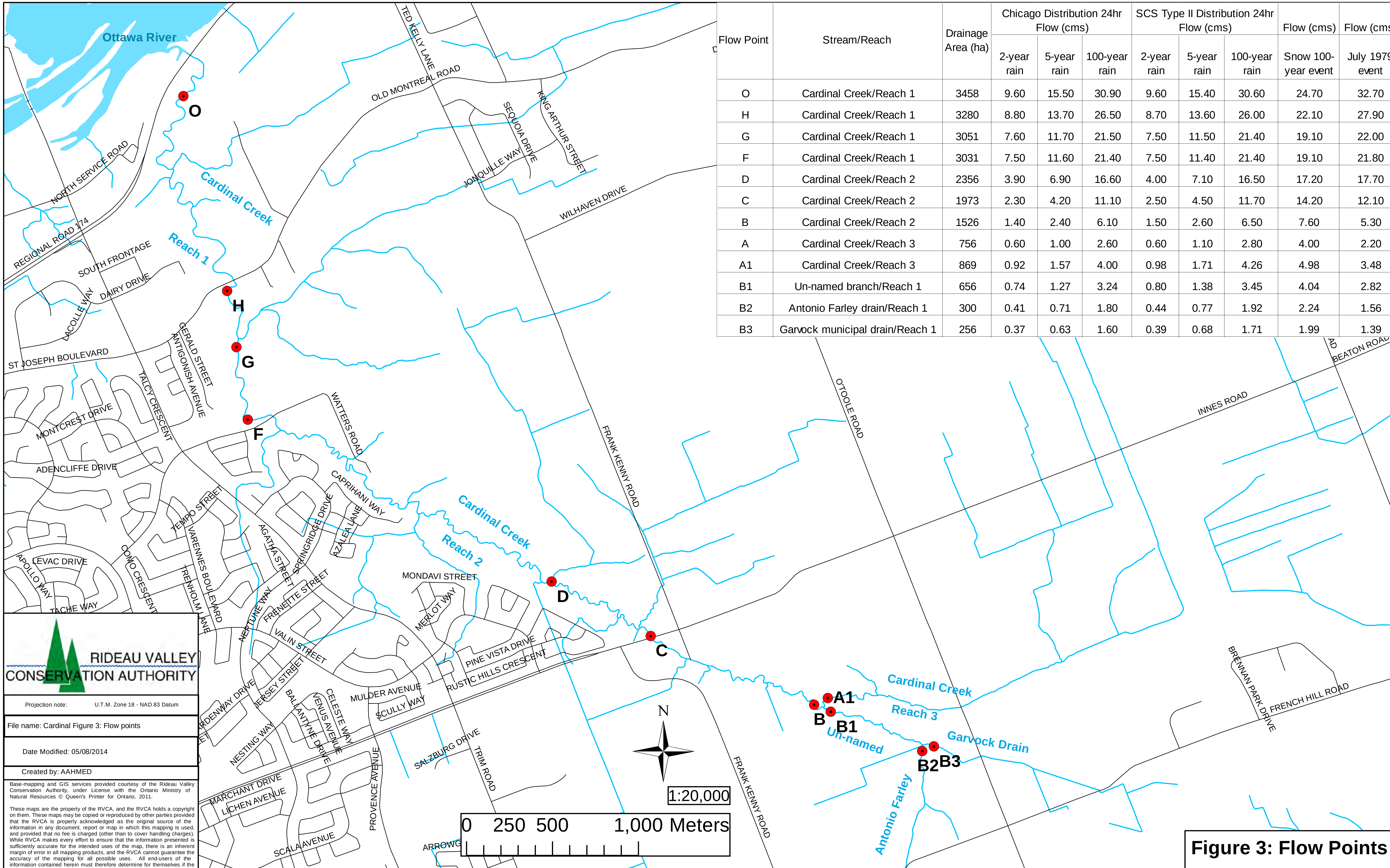
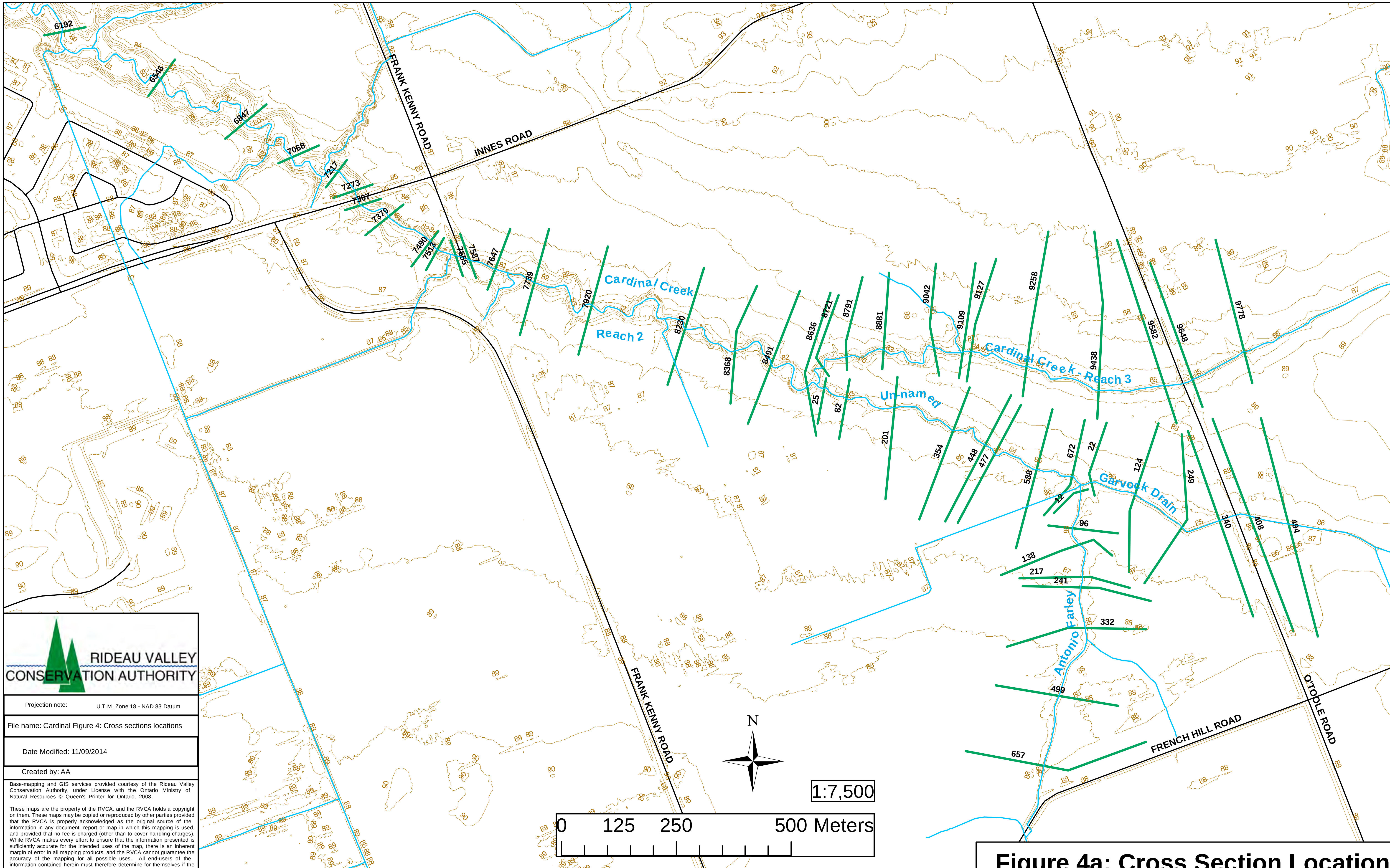


Figure 3: Flow Points



RIDEAU VALLEY CONSERVATION AUTHORITY

Projection note: U.T.M. Zone 18 - NAD 83 Datum

File name: Cardinal Figure 4: Cross sections locations

Date Modified: 11/09/2014

Created by: AA

Figure 4a: Cross Section Locations

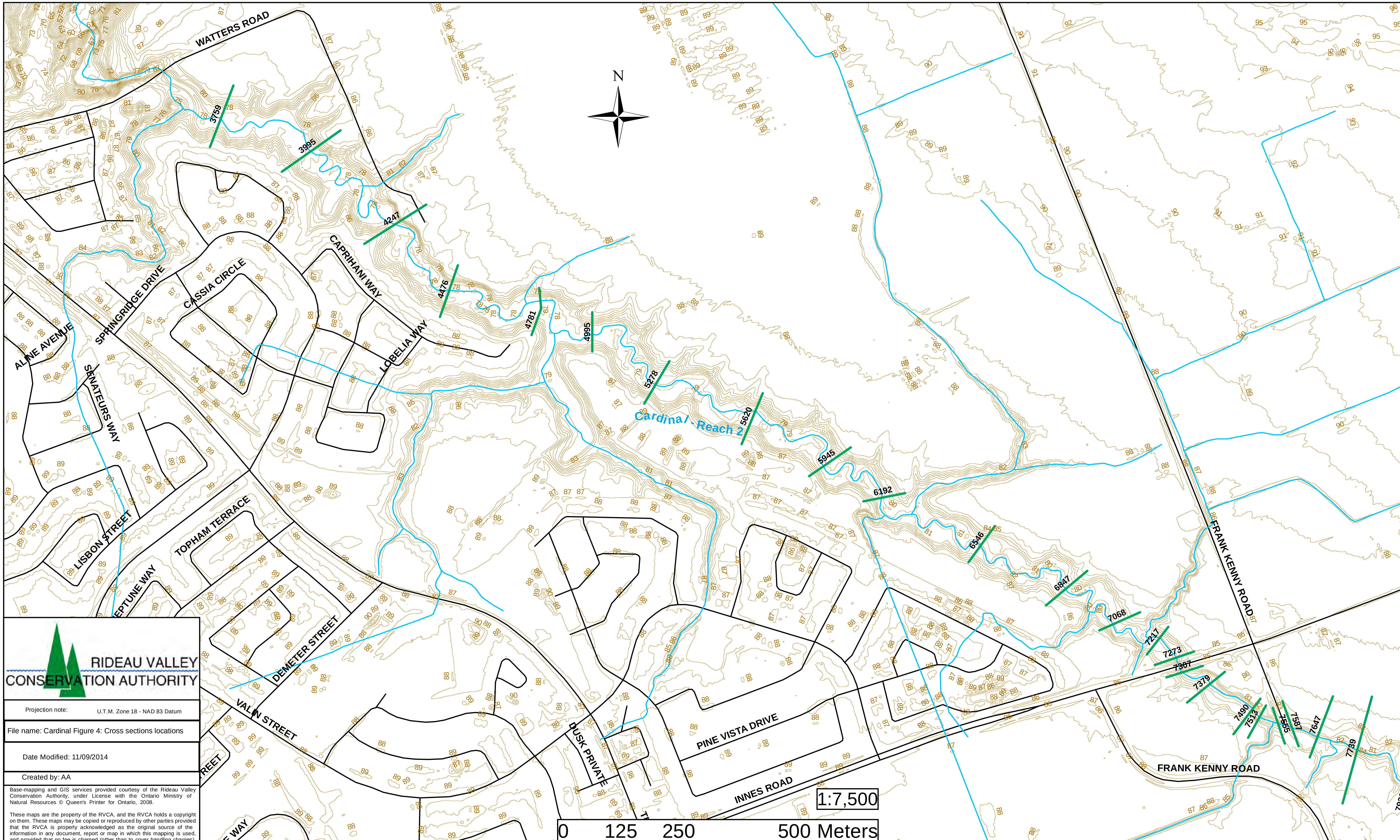


Figure 4b: Cross Section Locations

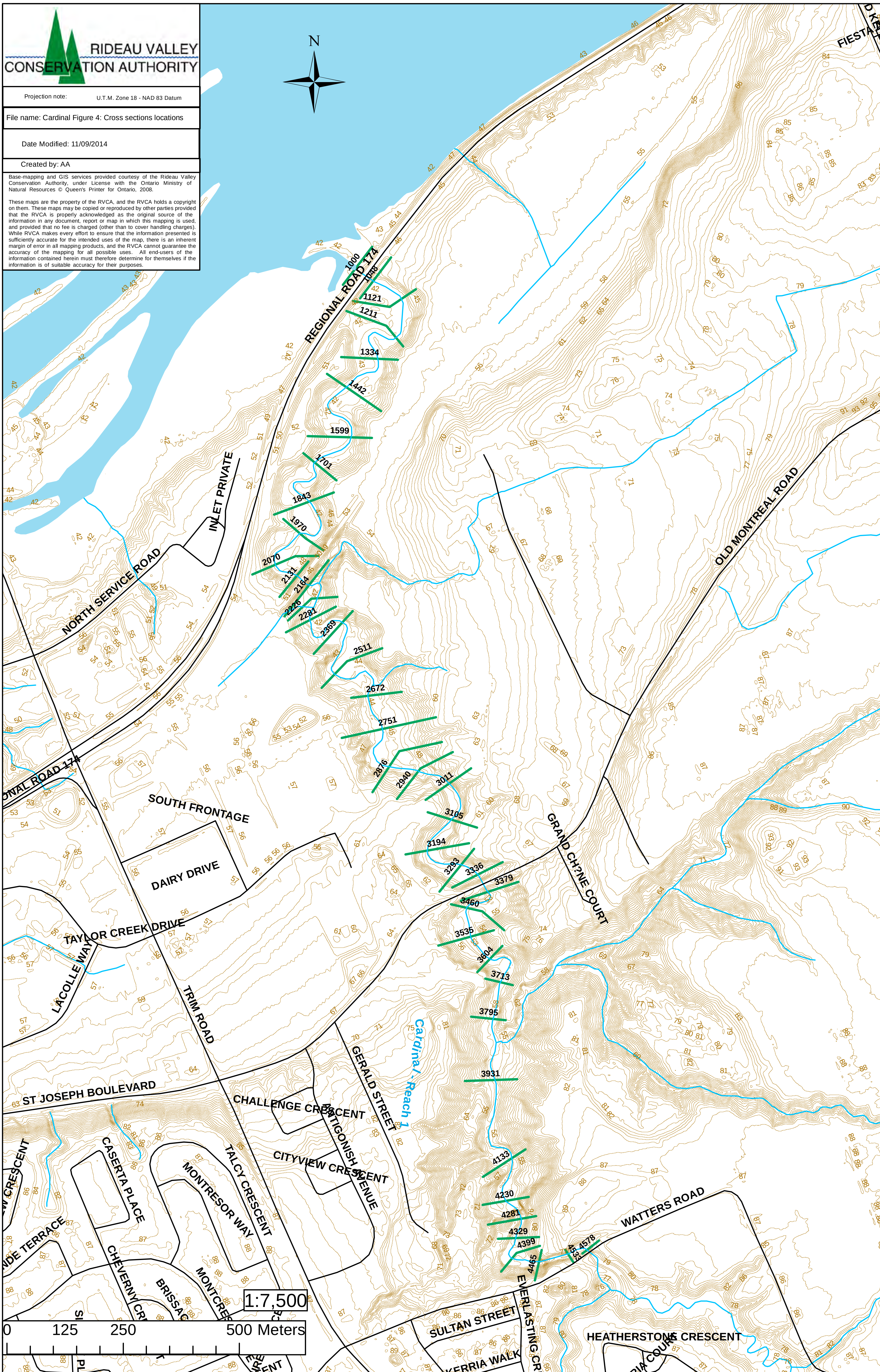
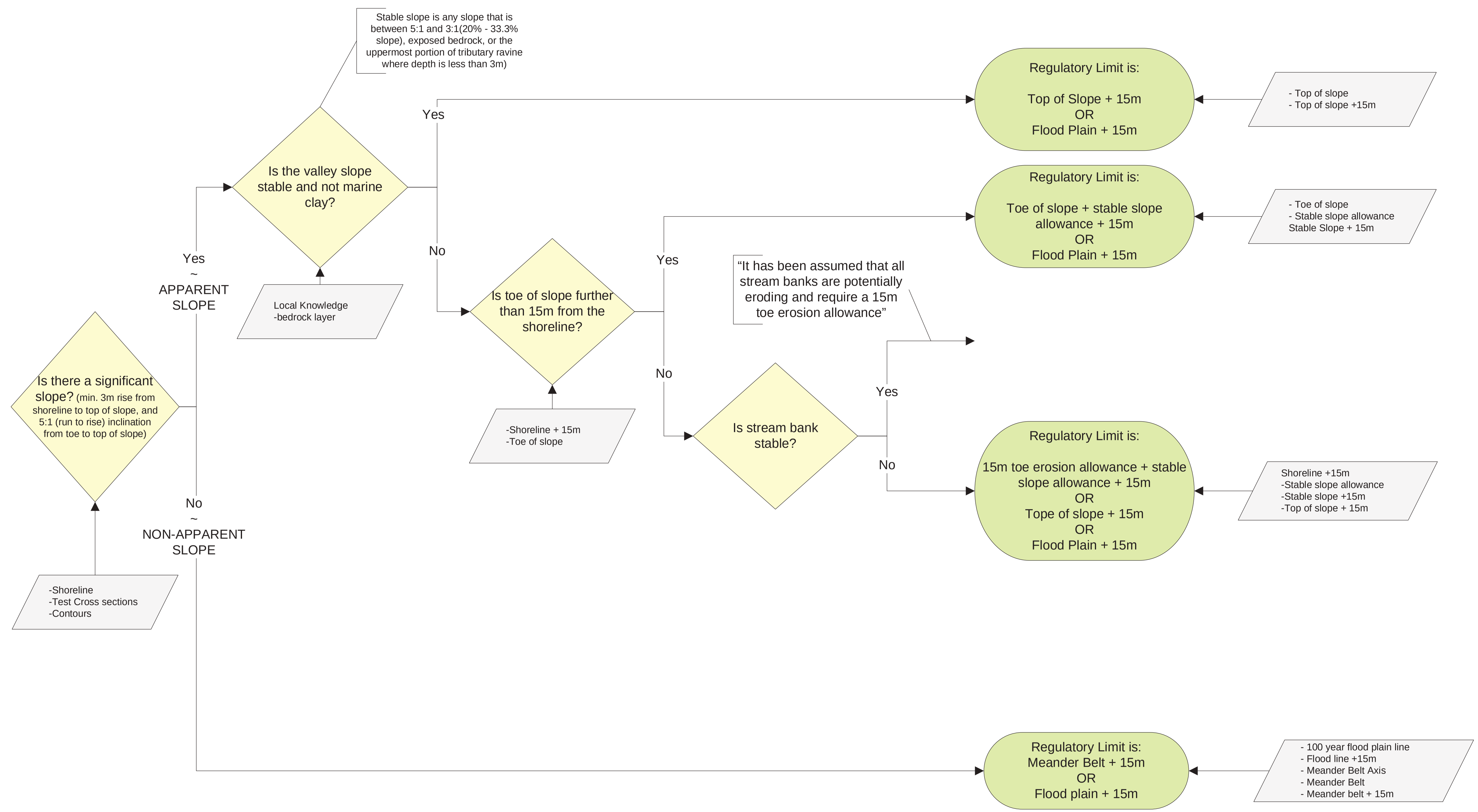


Figure 4c: Cross Section Locations

Figure 5:
Generic Regulation Limit Delineation:
Decision Tree



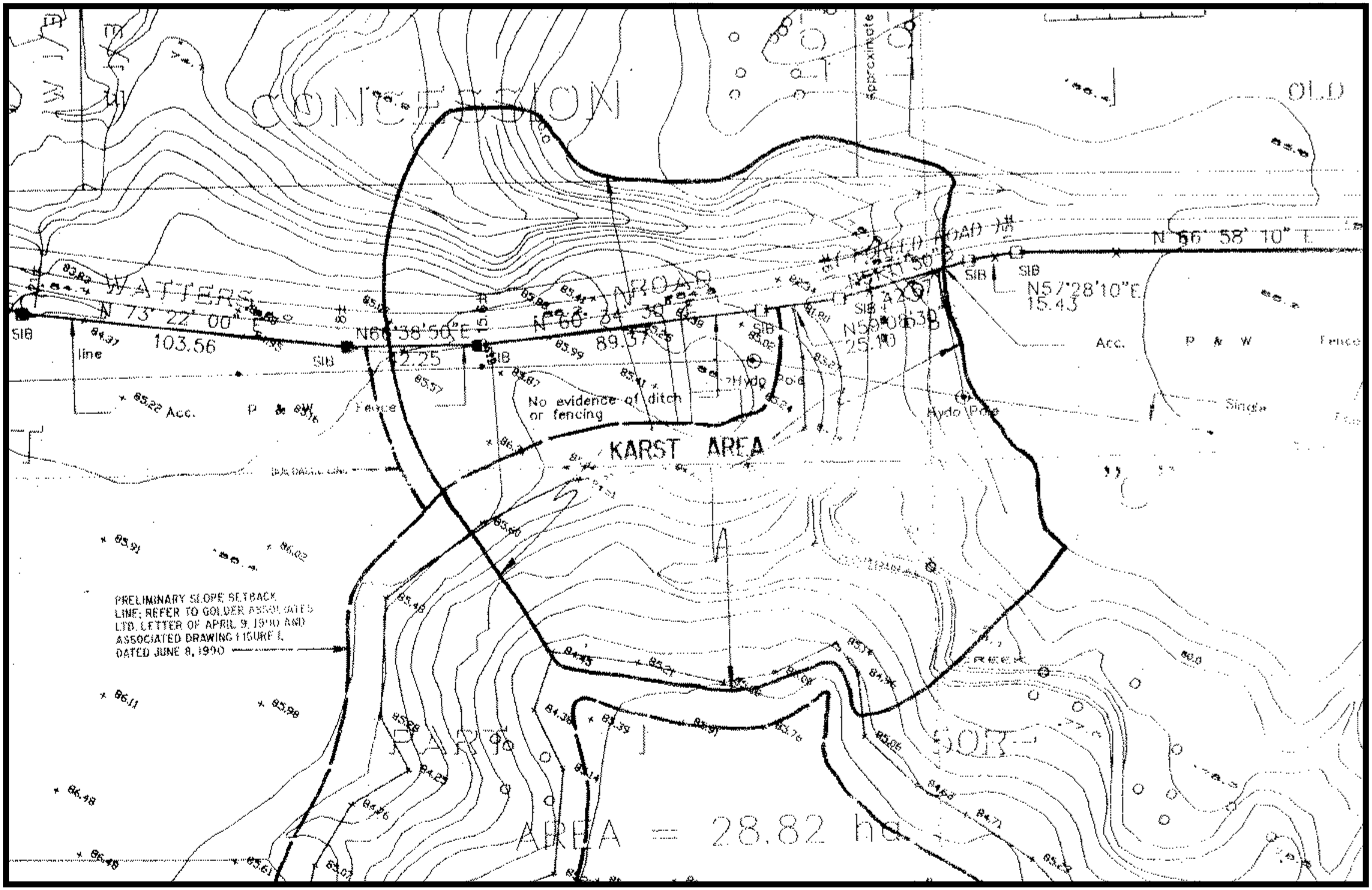


Figure 6: Cardinal Creek Karst Feature (Golder, 1991)

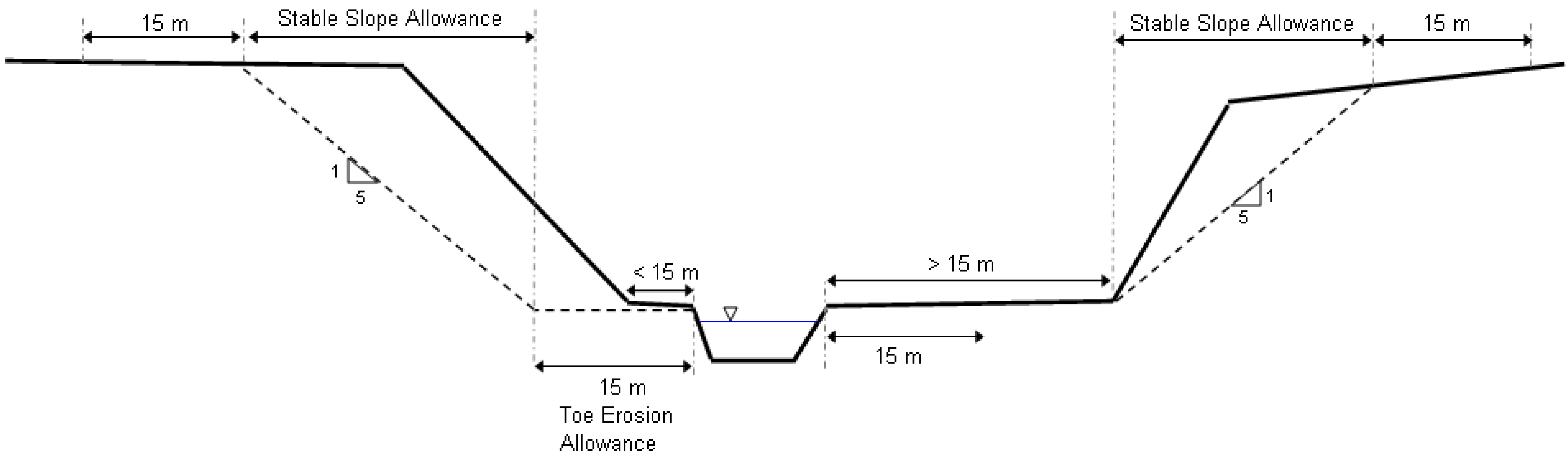
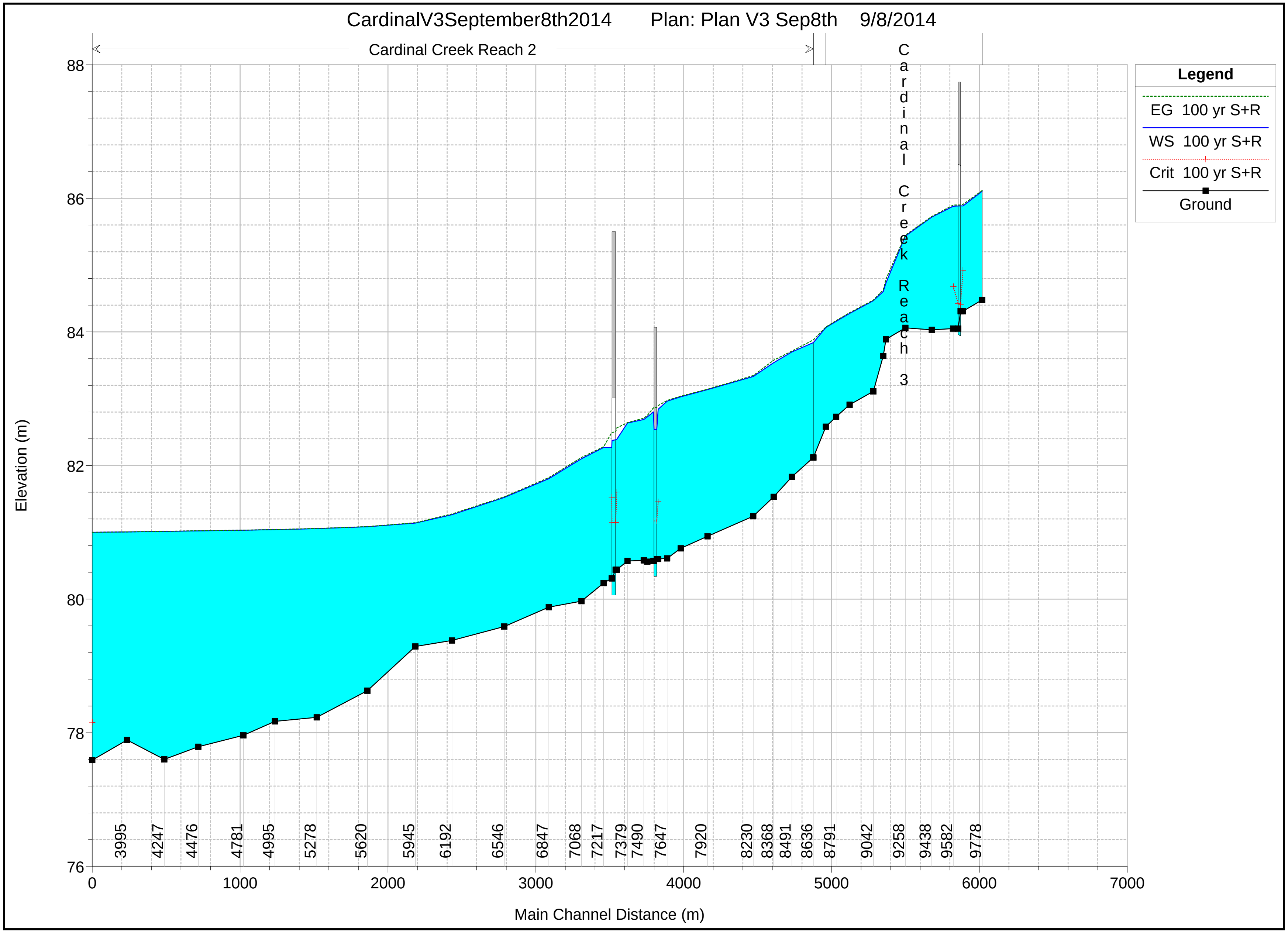


Figure 7: Erosion and Stable Slope Allowances (RVCA, 2005)

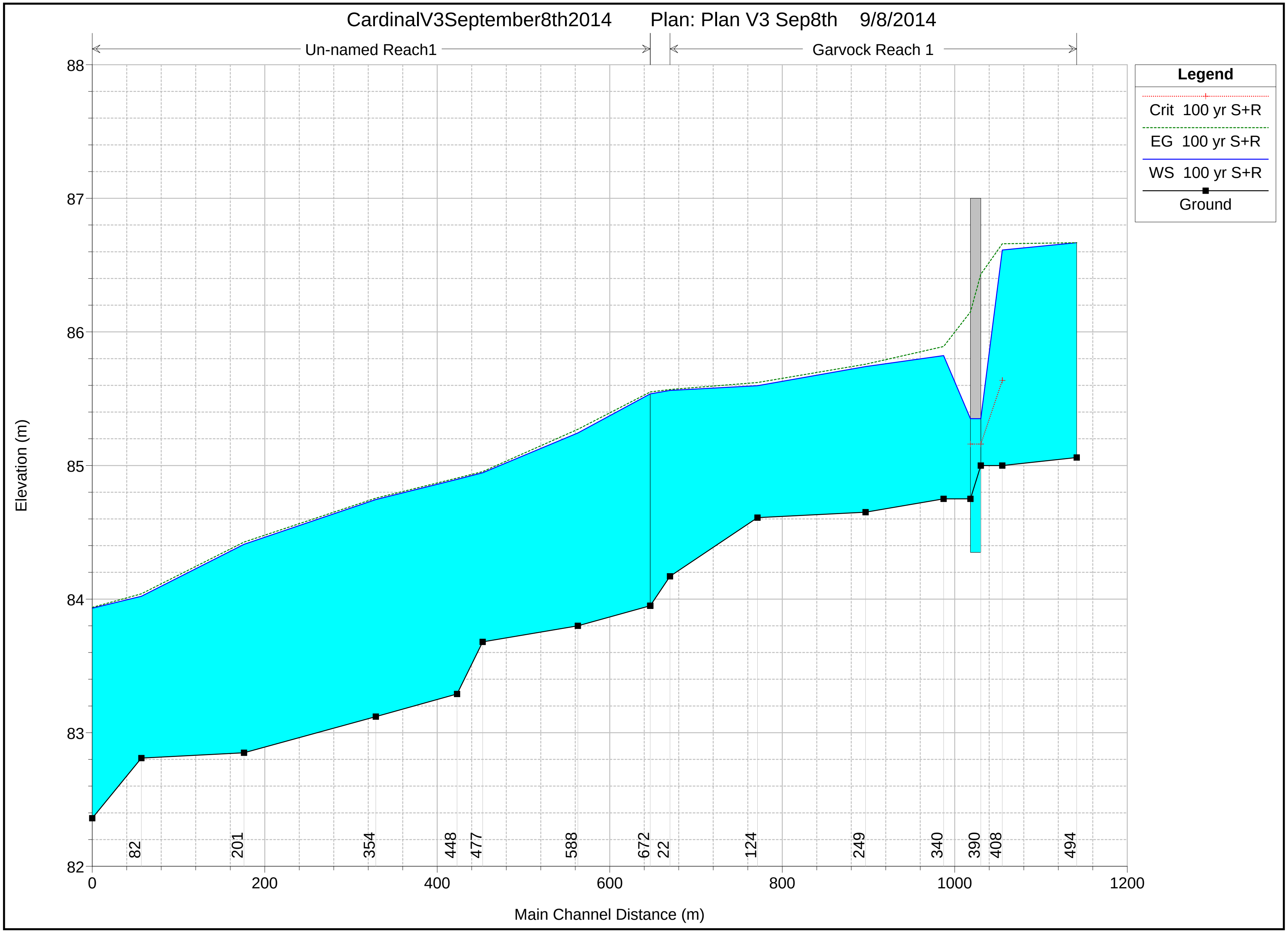
Appendix A
HEC-RAS Model Output
Upstream Model
(Cardinal Creek from Watters Road to O’Toole Road)

Longitudinal Profiles

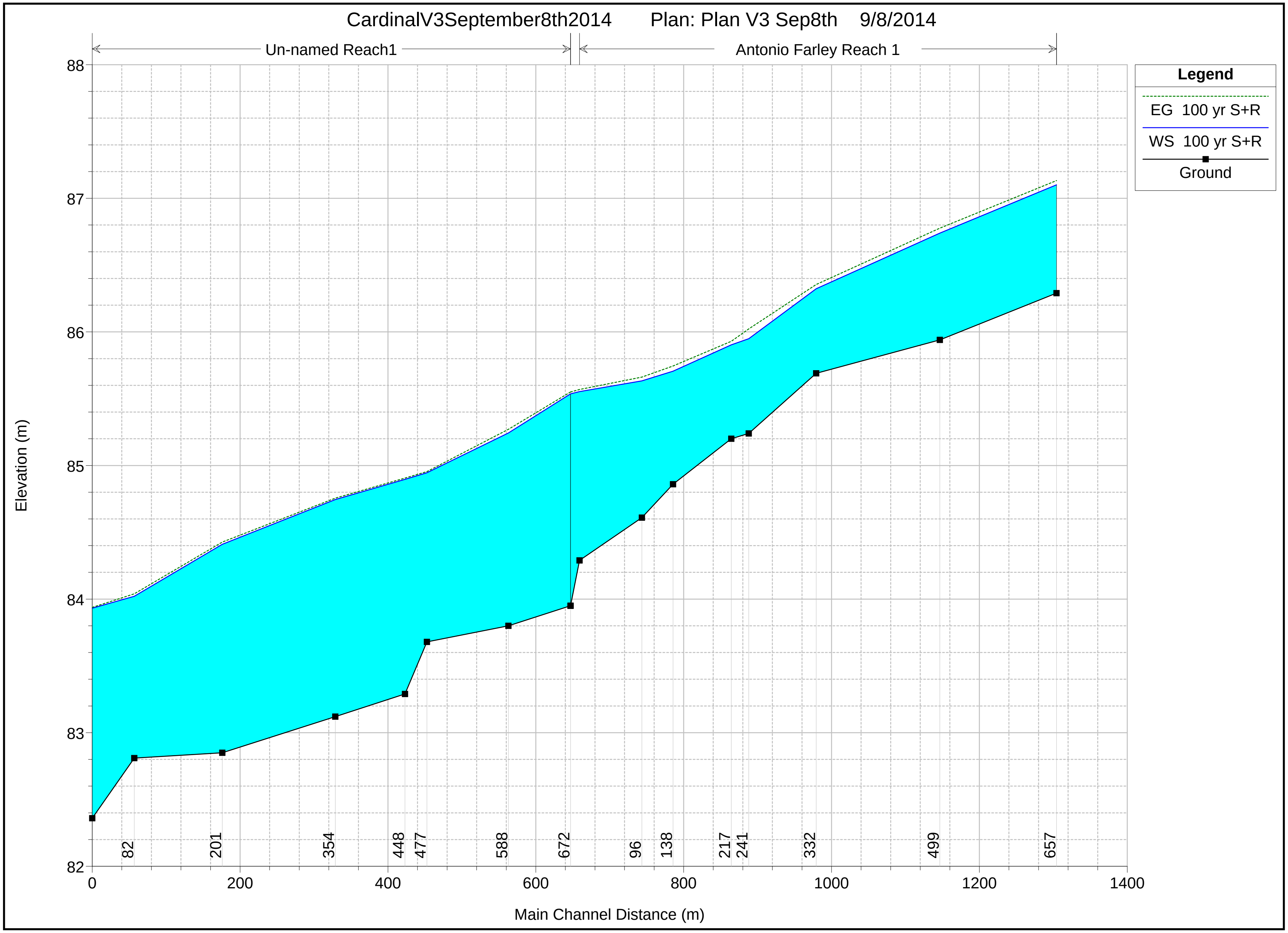
Cross-Sections



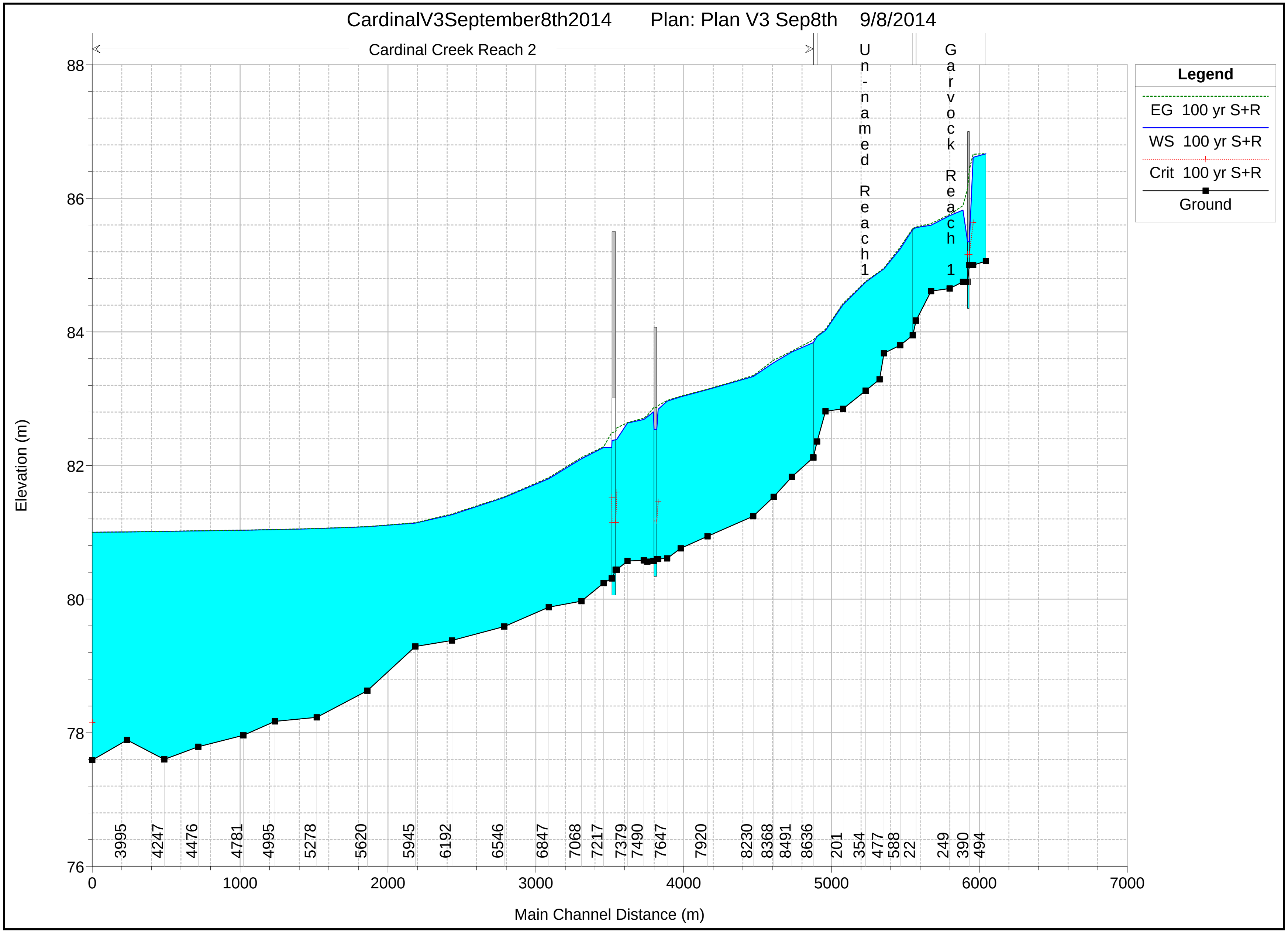
CardinalV3September8th2014 Plan: Plan V3 Sep8th 9/8/2014
Cardinal Creek Reach 2
Cardinal Creek Reach 3
Legend
EG 100 yr S+R
WS 100 yr S+R
Crit 100 yr S+R
Ground
Elevation (m)
Main Channel Distance (m)
88
86
84
82
80
78
76
0
1000
2000
3000
4000
5000
6000
7000
3995
4247
4476
4781
4995
5278
5620
5945
6192
6546
6847
7068
7217
7379
7490
7647
7920
8230
8368
8491
8636
8791
9042
9258
9438
9582
9778



CardinalV3September8th2014 Plan: Plan V3 Sep8th 9/8/2014
Un-named Reach1
Garvock Reach 1
Legend
Crit 100 yr S+R
EG 100 yr S+R
WS 100 yr S+R
Ground
Elevation (m)
Main Channel Distance (m)
88
87
86
85
84
83
82
0
200
400
600
800
1000
1200
82
201
354
448
477
588
672
22
124
249
340
390
408
494



CardinalV3September8th2014 Plan: Plan V3 Sep8th 9/8/2014
Un-named Reach1
Antonio Farley Reach 1
Legend
EG 100 yr S+R
WS 100 yr S+R
Ground
Elevation (m)
Main Channel Distance (m)
88
87
86
85
84
83
82
0
200
400
600
800
1000
1200
1400
82
201
354
448
477
588
672
96
138
217
241
332
499
657



CardinalV3September8th2014 Plan: Plan V3 Sep8th 9/8/2014
Cardinal Creek Reach 2
Un-named Reach 1
Garvock Reach 1
Legend
EG 100 yr S+R
WS 100 yr S+R
Crit 100 yr S+R
Ground
Elevation (m)
Main Channel Distance (m)
88
86
84
82
80
78
76
0
1000
2000
3000
4000
5000
6000
7000
3995
4247
4476
4781
4995
5278
5620
5945
6192
6546
6847
7068
7217
7379
7490
7647
7920
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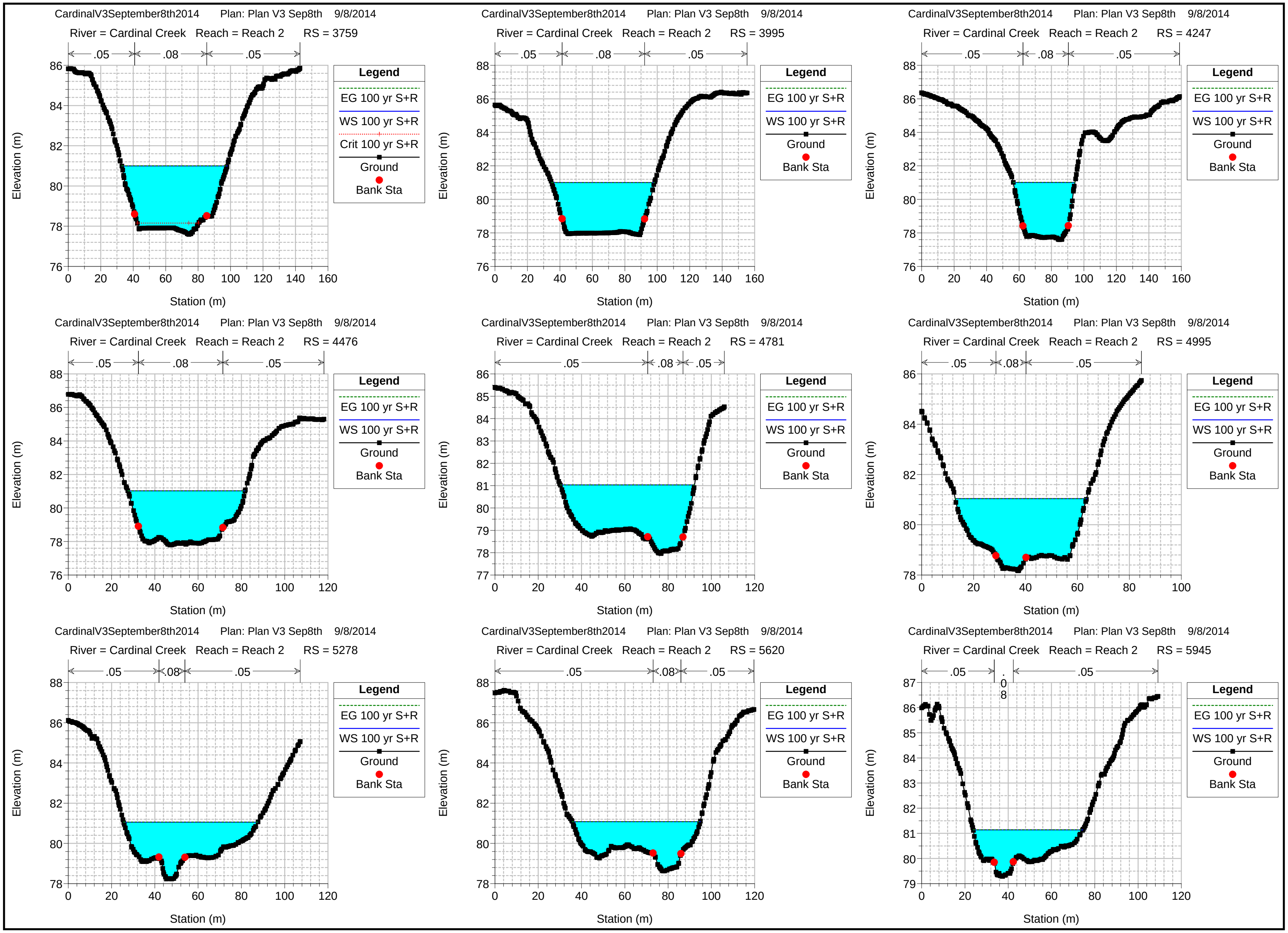
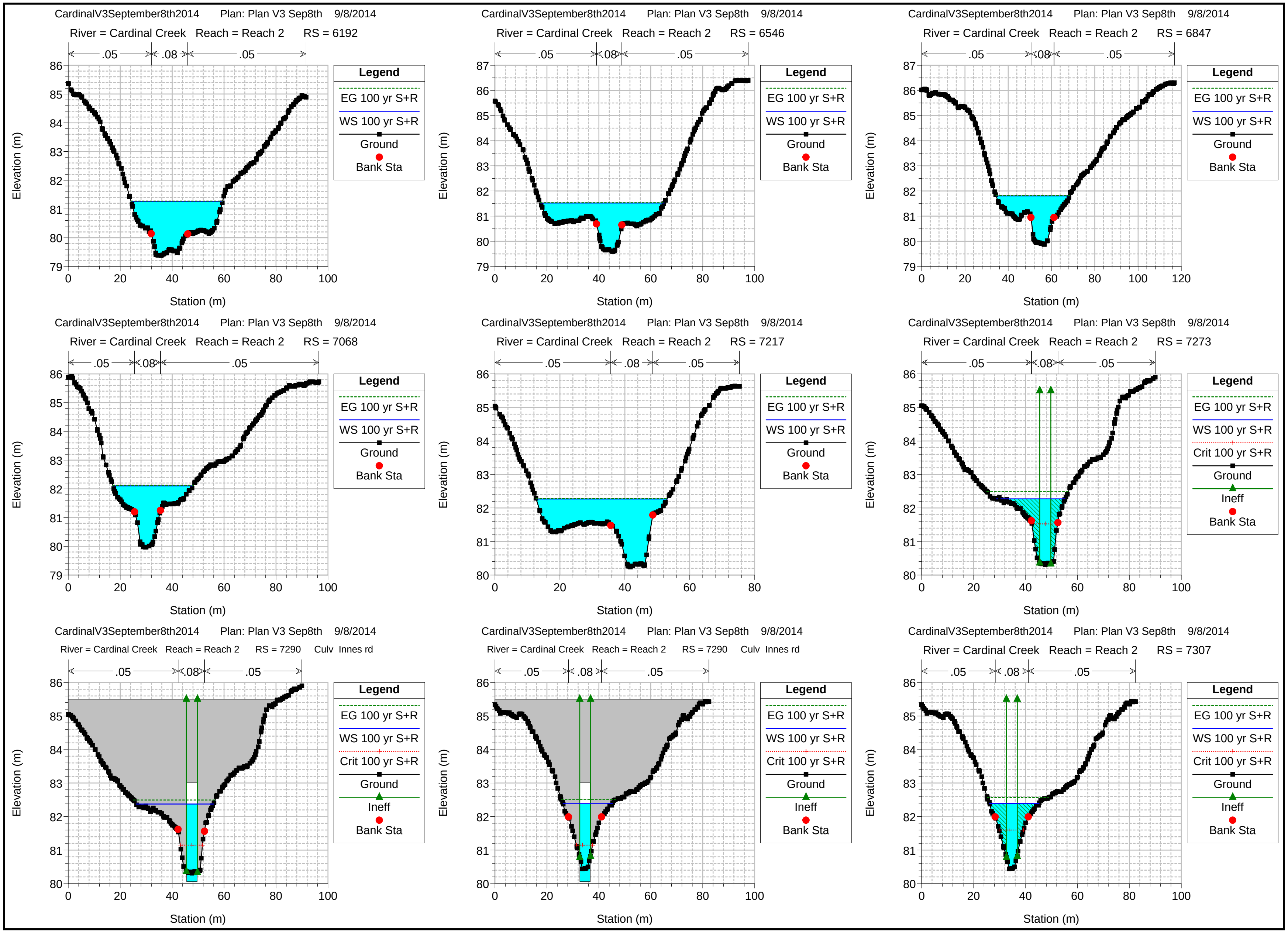
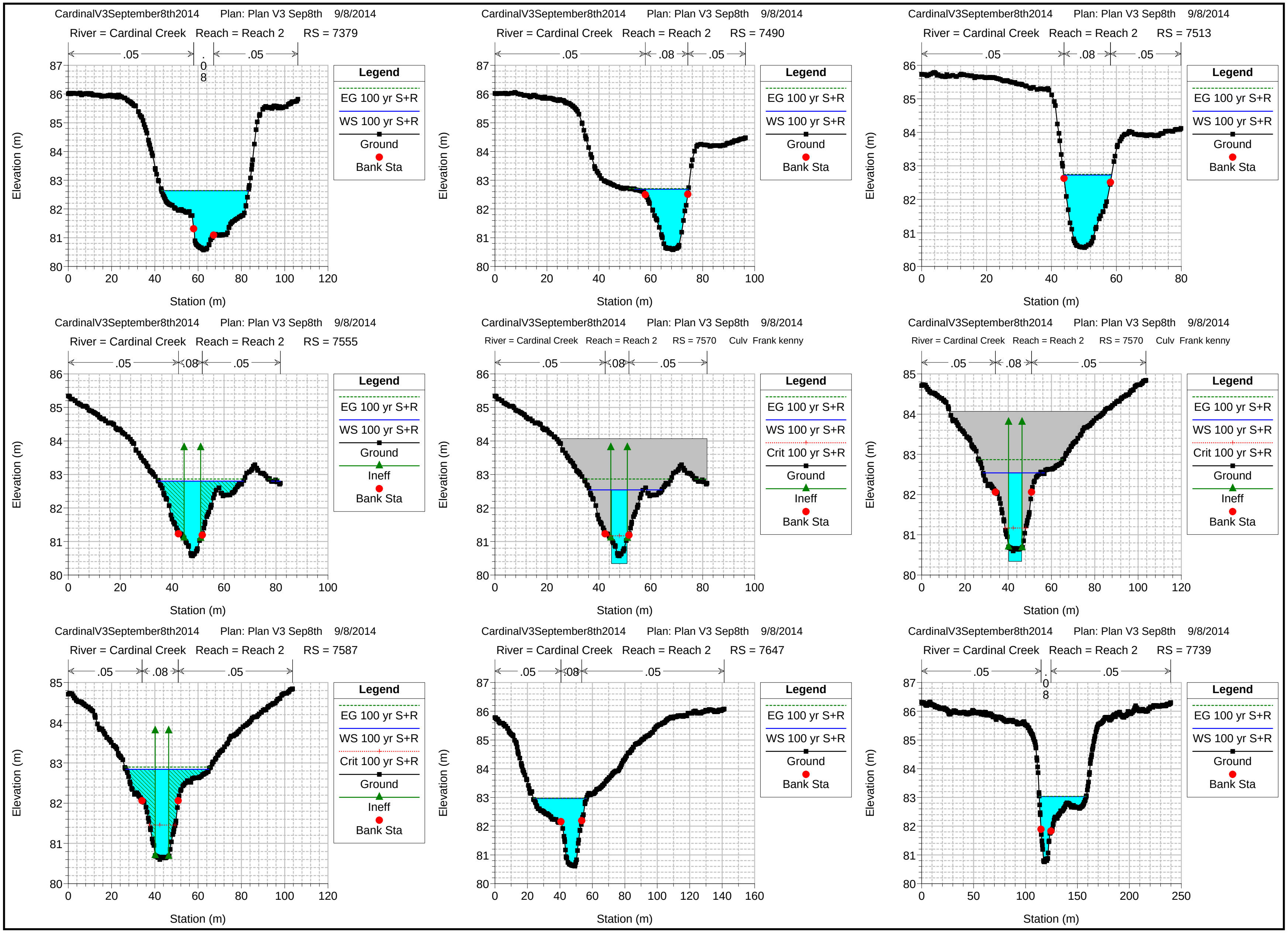
201
354
477
588
22
249
390
494

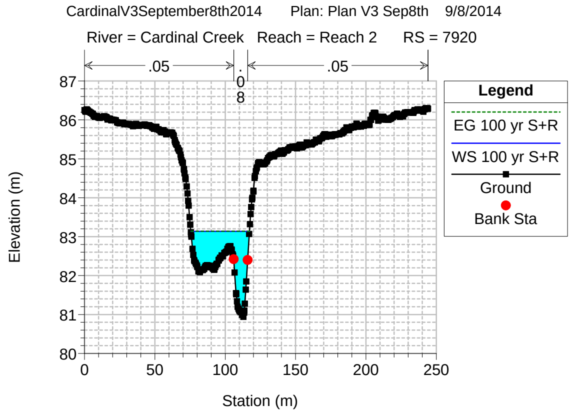


CardinalV3September8th2014 Plan: Plan V3 Sep8th 9/8/2014
River = Cardinal Creek Reach = Reach 2 RS = 3759
.05 .08 .05
Legend
EG 100 yr S+R
WS 100 yr S+R
Crit 100 yr S+R
Ground
Bank Sta
Elevation (m)
Station (m)
CardinalV3September8th2014 Plan: Plan V3 Sep8th 9/8/2014
River = Cardinal Creek Reach = Reach 2 RS = 3995
.05 .08 .05
Legend
EG 100 yr S+R
WS 100 yr S+R
Ground
Bank Sta
Elevation (m)
Station (m)
CardinalV3September8th2014 Plan: Plan V3 Sep8th 9/8/2014
River = Cardinal Creek Reach = Reach 2 RS = 4247
.05 .08 .05
Legend
EG 100 yr S+R
WS 100 yr S+R
Ground
Bank Sta
Elevation (m)
Station (m)
CardinalV3September8th2014 Plan: Plan V3 Sep8th 9/8/2014
River = Cardinal Creek Reach = Reach 2 RS = 4476
.05 .08 .05
Legend
EG 100 yr S+R
WS 100 yr S+R
Ground
Bank Sta
Elevation (m)
Station (m)
CardinalV3September8th2014 Plan: Plan V3 Sep8th 9/8/2014
River = Cardinal Creek Reach = Reach 2 RS = 4781
.05 .08 .05
Legend
EG 100 yr S+R
WS 100 yr S+R
Ground
Bank Sta
Elevation (m)
Station (m)
CardinalV3September8th2014 Plan: Plan V3 Sep8th 9/8/2014
River = Cardinal Creek Reach = Reach 2 RS = 4995
.05 .08 .05
Legend
EG 100 yr S+R
WS 100 yr S+R
Ground
Bank Sta
Elevation (m)
Station (m)
CardinalV3September8th2014 Plan: Plan V3 Sep8th 9/8/2014
River = Cardinal Creek Reach = Reach 2 RS = 5278
.05 .08 .05
Legend
EG 100 yr S+R
WS 100 yr S+R
Ground
Bank Sta
Elevation (m)
Station (m)
CardinalV3September8th2014 Plan: Plan V3 Sep8th 9/8/2014
River = Cardinal Creek Reach = Reach 2 RS = 5620
.05 .08 .05
Legend
EG 100 yr S+R
WS 100 yr S+R
Ground
Bank Sta
Elevation (m)
Station (m)
CardinalV3September8th2014 Plan: Plan V3 Sep8th 9/8/2014
River = Cardinal Creek Reach = Reach 2 RS = 5945
.05 0 8 .05
Legend
EG 100 yr S+R
WS 100 yr S+R
Ground
Bank Sta
Elevation (m)
Station (m)



CardinalV3September8th2014 Plan: Plan V3 Sep8th 9/8/2014
River = Cardinal Creek Reach = Reach 2 RS = 6192
CardinalV3September8th2014 Plan: Plan V3 Sep8th 9/8/2014
River = Cardinal Creek Reach = Reach 2 RS = 6546
CardinalV3September8th2014 Plan: Plan V3 Sep8th 9/8/2014
River = Cardinal Creek Reach = Reach 2 RS = 6847
CardinalV3September8th2014 Plan: Plan V3 Sep8th 9/8/2014
River = Cardinal Creek Reach = Reach 2 RS = 7068
CardinalV3September8th2014 Plan: Plan V3 Sep8th 9/8/2014
River = Cardinal Creek Reach = Reach 2 RS = 7217
CardinalV3September8th2014 Plan: Plan V3 Sep8th 9/8/2014
River = Cardinal Creek Reach = Reach 2 RS = 7273
CardinalV3September8th2014 Plan: Plan V3 Sep8th 9/8/2014
River = Cardinal Creek Reach = Reach 2 RS = 7290 Culv Innes rd
CardinalV3September8th2014 Plan: Plan V3 Sep8th 9/8/2014
River = Cardinal Creek Reach = Reach 2 RS = 7290 Culv Innes rd
CardinalV3September8th2014 Plan: Plan V3 Sep8th 9/8/2014
River = Cardinal Creek Reach = Reach 2 RS = 7307
.05
.08
Legend
EG 100 yr S+R
WS 100 yr S+R
Crit 100 yr S+R
Ground
Ineff
Bank Sta
Elevation (m)
Station (m)


CardinalV3September8th2014 Plan: Plan V3 Sep8th 9/8/2014
River = Cardinal Creek Reach = Reach 2 RS = 7379
Legend
EG 100 yr S+R
WS 100 yr S+R
Ground
Bank Sta
Elevation (m)
Station (m)
CardinalV3September8th2014 Plan: Plan V3 Sep8th 9/8/2014
River = Cardinal Creek Reach = Reach 2 RS = 7490
Legend
EG 100 yr S+R
WS 100 yr S+R
Ground
Bank Sta
Elevation (m)
Station (m)
CardinalV3September8th2014 Plan: Plan V3 Sep8th 9/8/2014
River = Cardinal Creek Reach = Reach 2 RS = 7513
Legend
EG 100 yr S+R
WS 100 yr S+R
Ground
Bank Sta
Elevation (m)
Station (m)
CardinalV3September8th2014 Plan: Plan V3 Sep8th 9/8/2014
River = Cardinal Creek Reach = Reach 2 RS = 7555
Legend
EG 100 yr S+R
WS 100 yr S+R
Ground
Ineff
Bank Sta
Elevation (m)
Station (m)
CardinalV3September8th2014 Plan: Plan V3 Sep8th 9/8/2014
River = Cardinal Creek Reach = Reach 2 RS = 7570 Culv Frank kenny
Legend
EG 100 yr S+R
WS 100 yr S+R
Crit 100 yr S+R
Ground
Ineff
Bank Sta
Elevation (m)
Station (m)
CardinalV3September8th2014 Plan: Plan V3 Sep8th 9/8/2014
River = Cardinal Creek Reach = Reach 2 RS = 7570 Culv Frank kenny
Legend
EG 100 yr S+R
WS 100 yr S+R
Crit 100 yr S+R
Ground
Ineff
Bank Sta
Elevation (m)
Station (m)
CardinalV3September8th2014 Plan: Plan V3 Sep8th 9/8/2014
River = Cardinal Creek Reach = Reach 2 RS = 7587
Legend
EG 100 yr S+R
WS 100 yr S+R
Crit 100 yr S+R
Ground
Ineff
Bank Sta
Elevation (m)
Station (m)
CardinalV3September8th2014 Plan: Plan V3 Sep8th 9/8/2014
River = Cardinal Creek Reach = Reach 2 RS = 7647
Legend
EG 100 yr S+R
WS 100 yr S+R
Ground
Bank Sta
Elevation (m)
Station (m)
CardinalV3September8th2014 Plan: Plan V3 Sep8th 9/8/2014
River = Cardinal Creek Reach = Reach 2 RS = 7739
Legend
EG 100 yr S+R
WS 100 yr S+R
Ground
Bank Sta
Elevation (m)
Station (m)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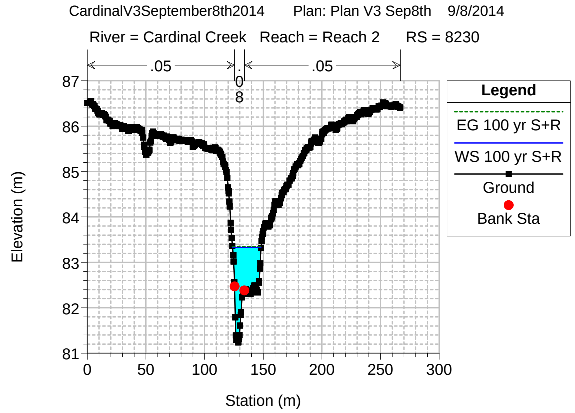
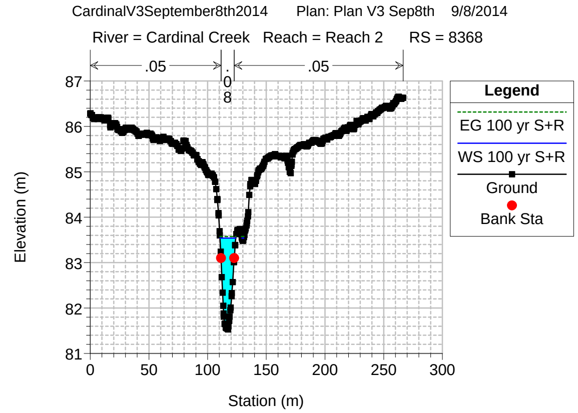
River = Cardinal Creek Reach = Reach 2 RS = 7920
.05
.08
.05
Legend
EG 100 yr S+R
WS 100 yr S+R
Ground
Bank Sta
Elevation (m)
Station (m)


CardinalV3September8th2014 Plan: Plan V3 Sep8th 9/8/2014
River = Cardinal Creek Reach = Reach 2 RS = 8230
.05
.08
.05
Legend
EG 100 yr S+R
WS 100 yr S+R
Ground
Bank Sta
Elevation (m)
Station (m)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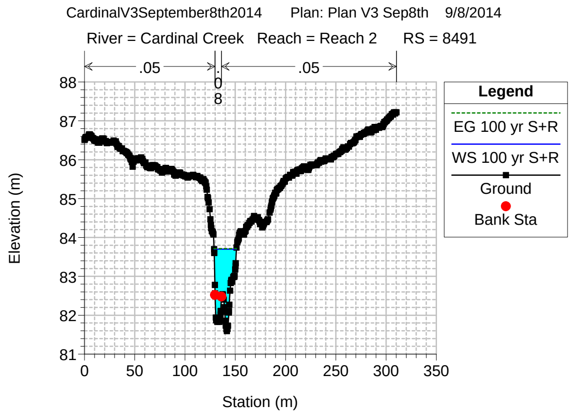
River = Cardinal Creek Reach = Reach 2 RS = 8368
.05
.08
.05
Legend
EG 100 yr S+R
WS 100 yr S+R
Ground
Bank Sta
Elevation (m)
Station (m)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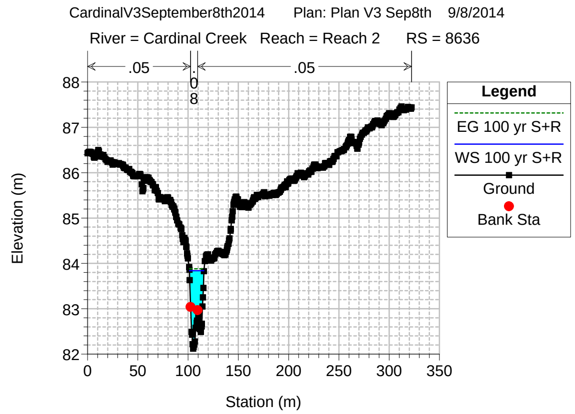
River = Cardinal Creek Reach = Reach 2 RS = 8491
.05
.08
.05
Legend
EG 100 yr S+R
WS 100 yr S+R
Ground
Bank Sta
Elevation (m)
Station (m)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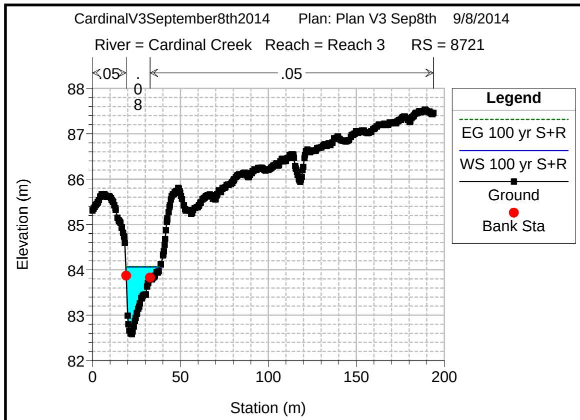
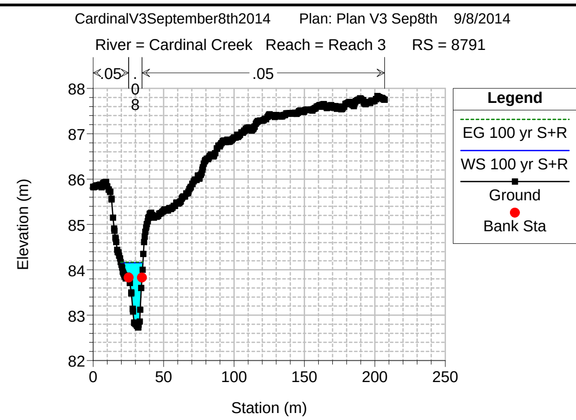
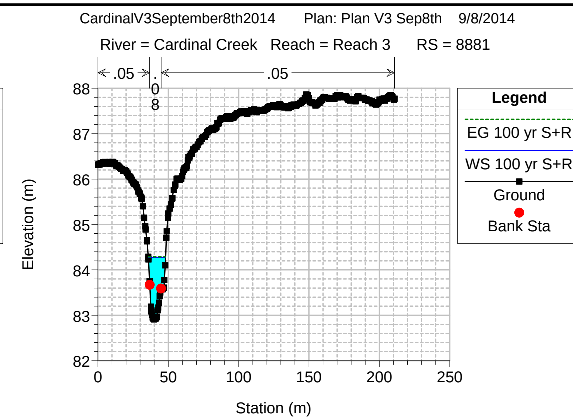
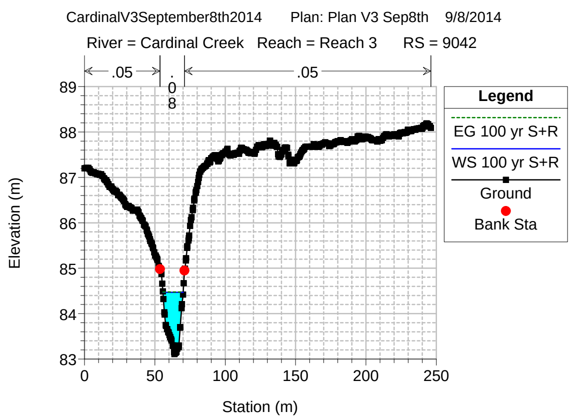
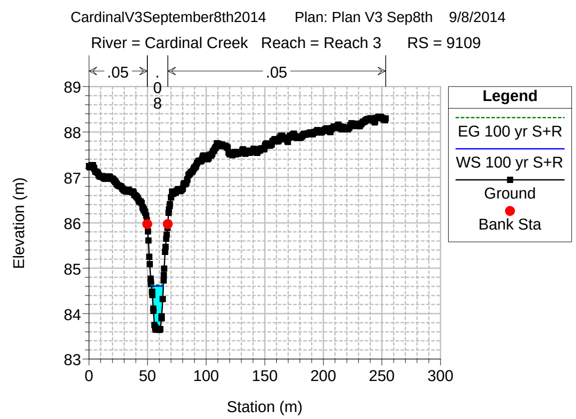
River = Cardinal Creek Reach = Reach 2 RS = 8636
.05
.08
.05
Legend
EG 100 yr S+R
WS 100 yr S+R
Ground
Bank Sta
Elevation (m)
Station (m)

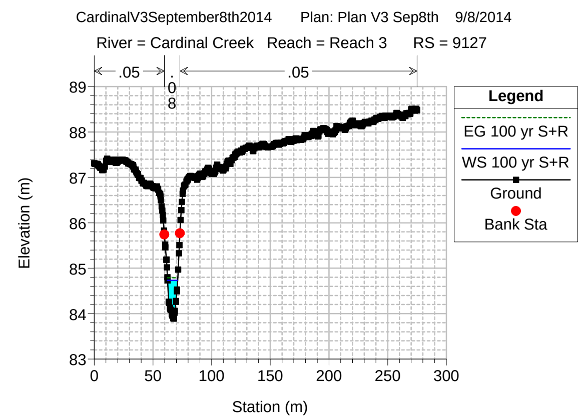

CardinalV3September8th2014 Plan: Plan V3 Sep8th 9/8/2014
River = Cardinal Creek Reach = Reach 3 RS = 8721
Legend
EG 100 yr S+R
WS 100 yr S+R
Ground
Bank Sta
Elevation (m)
Station (m)

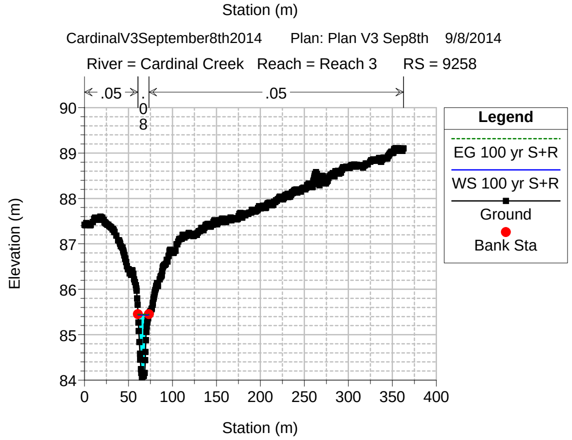

CardinalV3September8th2014 Plan: Plan V3 Sep8th 9/8/2014
River = Cardinal Creek Reach = Reach 3 RS = 8791
Legend
EG 100 yr S+R
WS 100 yr S+R
Ground
Bank Sta
Elevation (m)
Station (m)

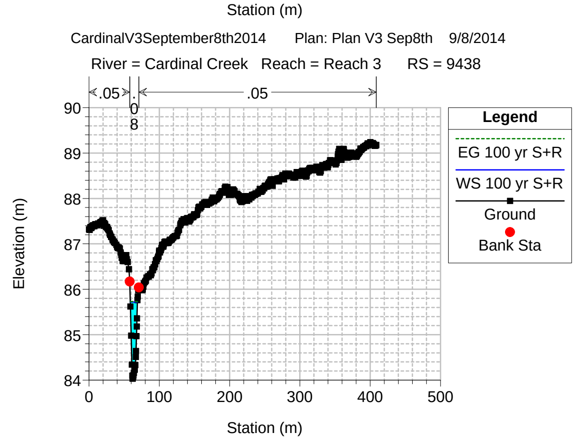

CardinalV3September8th2014 Plan: Plan V3 Sep8th 9/8/2014
River = Cardinal Creek Reach = Reach 3 RS = 8881
Legend
EG 100 yr S+R
WS 100 yr S+R
Ground
Bank Sta
Elevation (m)
Station (m)

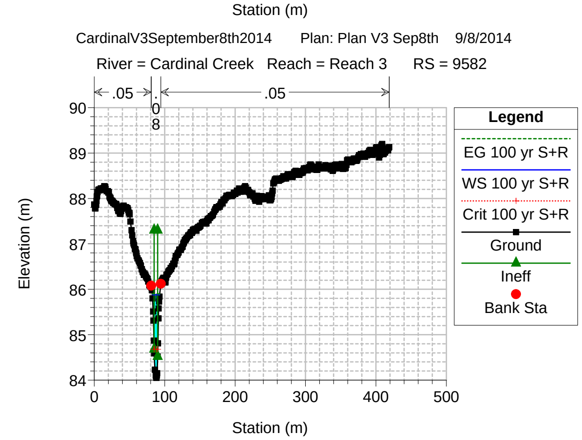

CardinalV3September8th2014 Plan: Plan V3 Sep8th 9/8/2014
River = Cardinal Creek Reach = Reach 3 RS = 9042
Legend
EG 100 yr S+R
WS 100 yr S+R
Ground
Bank Sta
Elevation (m)
Station (m)

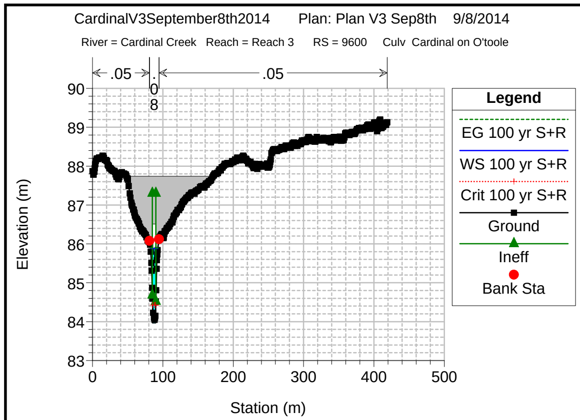

CardinalV3September8th2014 Plan: Plan V3 Sep8th 9/8/2014
River = Cardinal Creek Reach = Reach 3 RS = 9109
Legend
EG 100 yr S+R
WS 100 yr S+R
Ground
Bank Sta
Elevation (m)
Station (m)

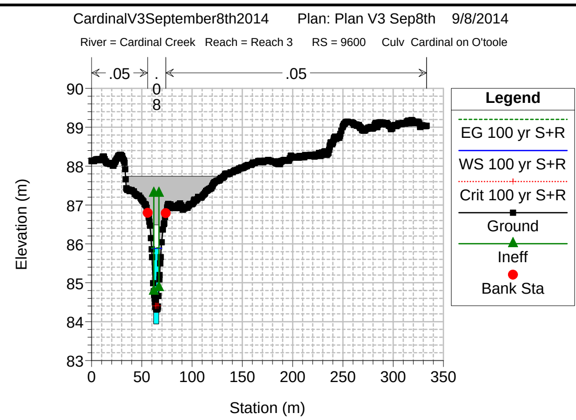

CardinalV3September8th2014 Plan: Plan V3 Sep8th 9/8/2014
River = Cardinal Creek Reach = Reach 3 RS = 9127
Legend
EG 100 yr S+R
WS 100 yr S+R
Ground
Bank Sta
Elevation (m)
Station (m)

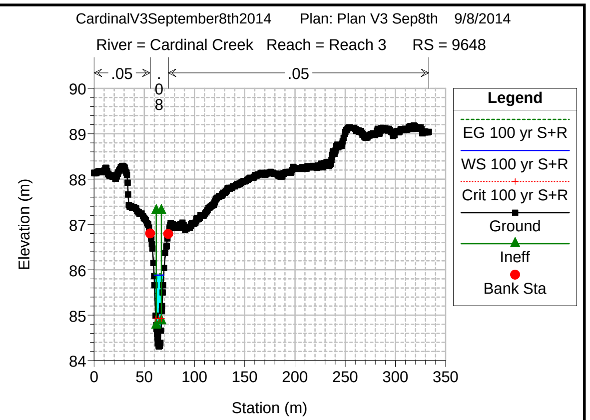

CardinalV3September8th2014 Plan: Plan V3 Sep8th 9/8/2014
River = Cardinal Creek Reach = Reach 3 RS = 9258
Legend
EG 100 yr S+R
WS 100 yr S+R
Ground
Bank Sta
Elevation (m)
Station (m)

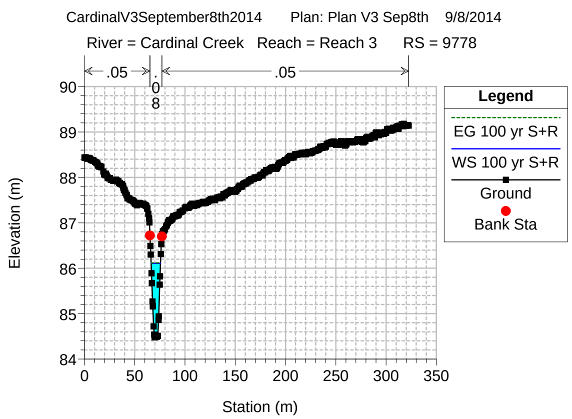

CardinalV3September8th2014 Plan: Plan V3 Sep8th 9/8/2014
River = Cardinal Creek Reach = Reach 3 RS = 9438
Legend
EG 100 yr S+R
WS 100 yr S+R
Ground
Bank Sta
Elevation (m)
Station (m)

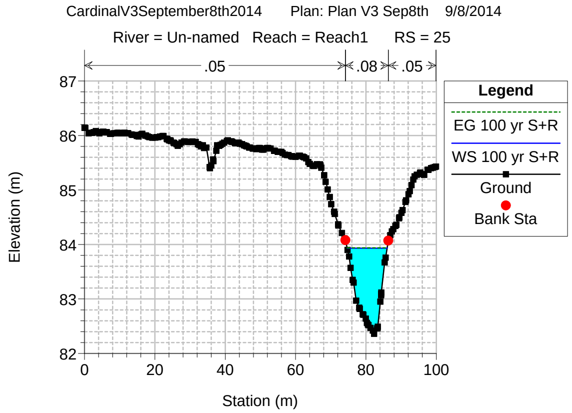

CardinalV3September8th2014 Plan: Plan V3 Sep8th 9/8/2014
River = Cardinal Creek Reach = Reach 3 RS = 9582
Legend
EG 100 yr S+R
WS 100 yr S+R
Crit 100 yr S+R
Ground
Ineff
Bank Sta
Elevation (m)
Station (m)


CardinalV3September8th2014 Plan: Plan V3 Sep8th 9/8/2014
River = Cardinal Creek Reach = Reach 3 RS = 9600 Culv Cardinal on O'toole
.05
.08
.05
Elevation (m)
Station (m)
Legend
EG 100 yr S+R
WS 100 yr S+R
Crit 100 yr S+R
Ground
Ineff
Bank Sta

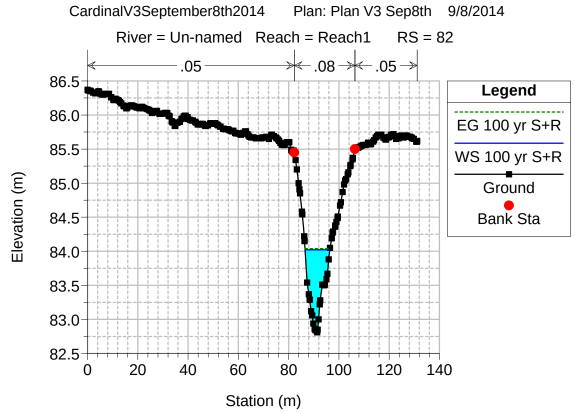

CardinalV3September8th2014 Plan: Plan V3 Sep8th 9/8/2014
River = Cardinal Creek Reach = Reach 3 RS = 9600 Culv Cardinal on O'toole
.05
.08
.05
Elevation (m)
Station (m)
Legend
EG 100 yr S+R
WS 100 yr S+R
Crit 100 yr S+R
Ground
Ineff
Bank Sta


CardinalV3September8th2014 Plan: Plan V3 Sep8th 9/8/2014
River = Cardinal Creek Reach = Reach 3 RS = 9648
.05
.08
.05
Elevation (m)
Station (m)
Legend
EG 100 yr S+R
WS 100 yr S+R
Crit 100 yr S+R
Ground
Ineff
Bank Sta

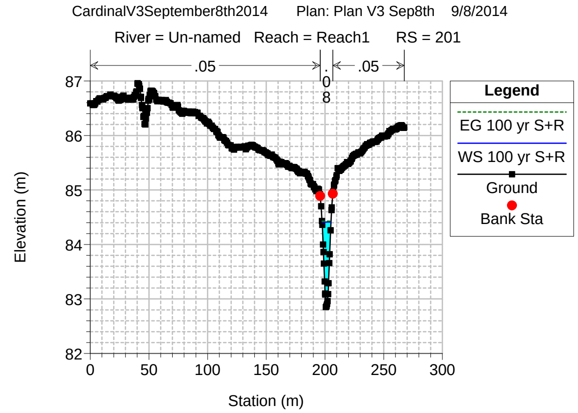

CardinalV3September8th2014 Plan: Plan V3 Sep8th 9/8/2014
River = Cardinal Creek Reach = Reach 3 RS = 9778
.05
.08
.05
Elevation (m)
Station (m)
Legend
EG 100 yr S+R
WS 100 yr S+R
Ground
Bank Sta



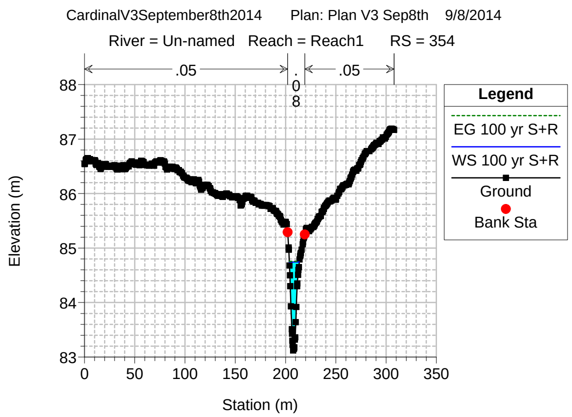
CardinalV3September8th2014 Plan: Plan V3 Sep8th 9/8/2014
River = Un-named Reach = Reach1 RS = 25
.05 .08 .05
Elevation (m)
Station (m)
Legend
EG 100 yr S+R
WS 100 yr S+R
Ground
Bank Sta



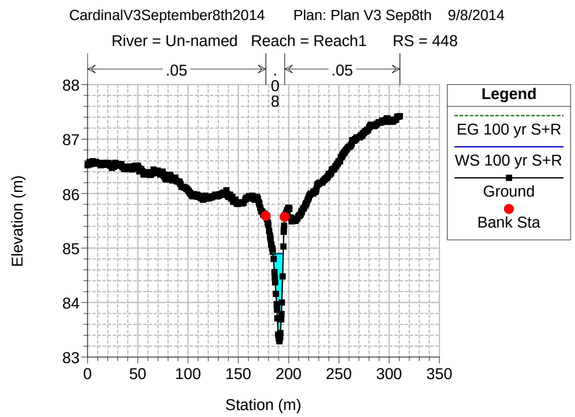
CardinalV3September8th2014 Plan: Plan V3 Sep8th 9/8/2014
River = Un-named Reach = Reach1 RS = 82
.05 .08 .05
Elevation (m)
Station (m)
Legend
EG 100 yr S+R
WS 100 yr S+R
Ground
Bank Sta



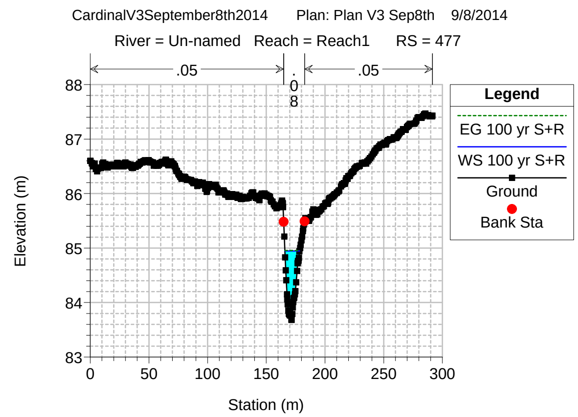
CardinalV3September8th2014 Plan: Plan V3 Sep8th 9/8/2014
River = Un-named Reach = Reach1 RS = 201
.05 .08 .05
Elevation (m)
Station (m)
Legend
EG 100 yr S+R
WS 100 yr S+R
Ground
Bank Sta



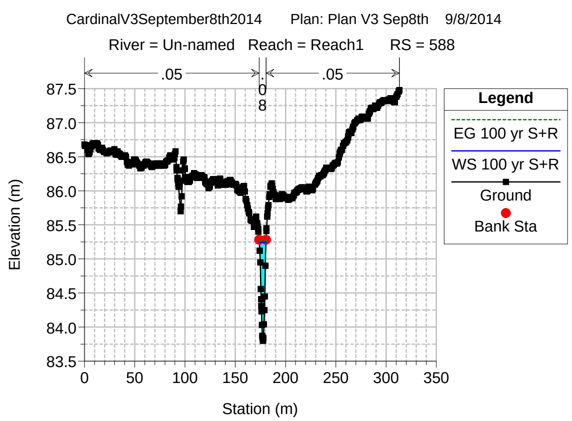
CardinalV3September8th2014 Plan: Plan V3 Sep8th 9/8/2014
River = Un-named Reach = Reach1 RS = 354
.05 .08 .05
Elevation (m)
Station (m)
Legend
EG 100 yr S+R
WS 100 yr S+R
Ground
Bank Sta



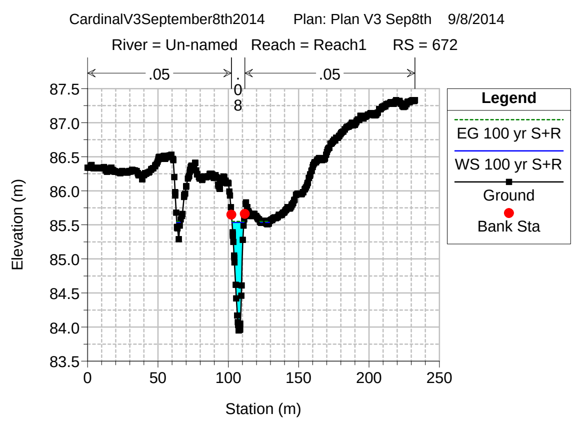
CardinalV3September8th2014 Plan: Plan V3 Sep8th 9/8/2014
River = Un-named Reach = Reach1 RS = 448
.05 .08 .05
Elevation (m)
Station (m)
Legend
EG 100 yr S+R
WS 100 yr S+R
Ground
Bank Sta



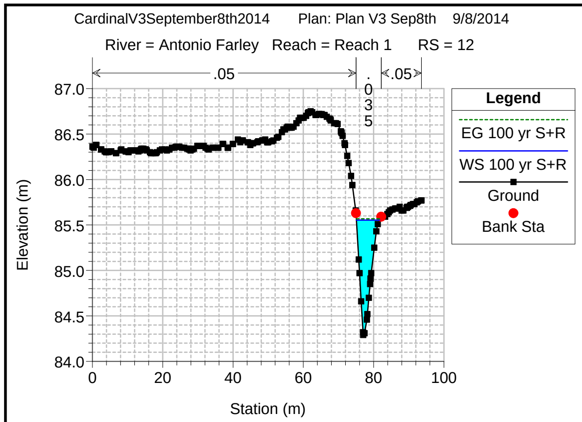
CardinalV3September8th2014 Plan: Plan V3 Sep8th 9/8/2014
River = Un-named Reach = Reach1 RS = 477
.05 .08 .05
Elevation (m)
Station (m)
Legend
EG 100 yr S+R
WS 100 yr S+R
Ground
Bank Sta

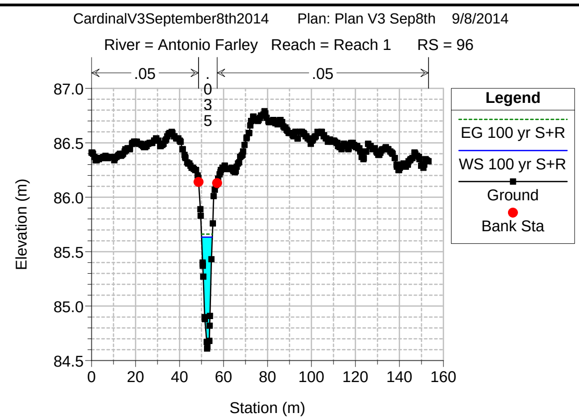


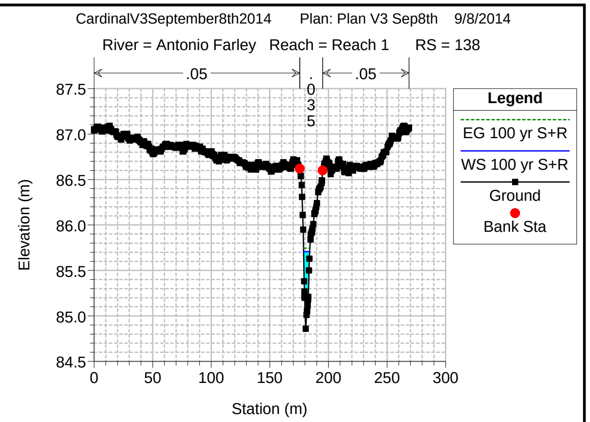
CardinalV3September8th2014 Plan: Plan V3 Sep8th 9/8/2014
River = Un-named Reach = Reach1 RS = 588
.05 .08 .05
Elevation (m)
Station (m)
Legend
EG 100 yr S+R
WS 100 yr S+R
Ground
Bank Sta

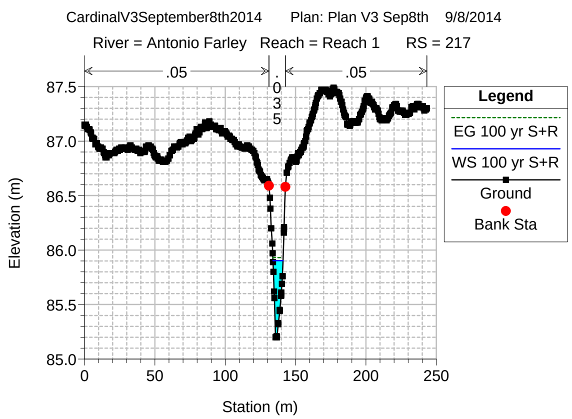


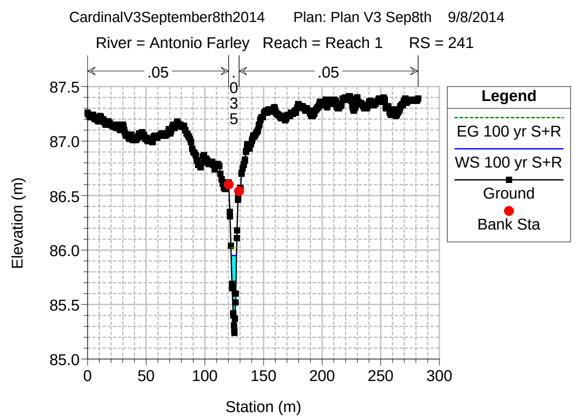
CardinalV3September8th2014 Plan: Plan V3 Sep8th 9/8/2014
River = Un-named Reach = Reach1 RS = 672
.05 .08 .05
Elevation (m)
Station (m)
Legend
EG 100 yr S+R
WS 100 yr S+R
Ground
Bank Sta

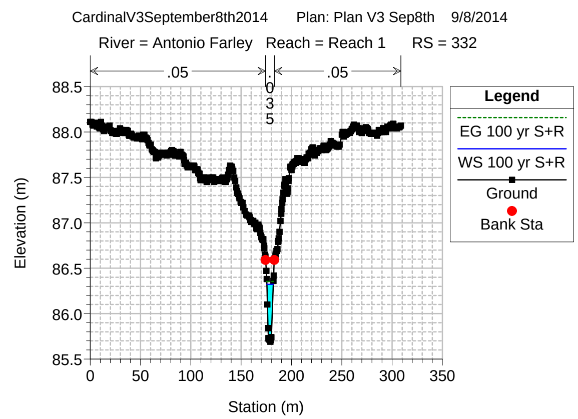

CardinalV3September8th2014 Plan: Plan V3 Sep8th 9/8/2014
River = Antonio Farley Reach = Reach 1 RS = 12
.05
.035
.05
Elevation (m)
Station (m)
Legend
EG 100 yr S+R
WS 100 yr S+R
Ground
Bank Sta

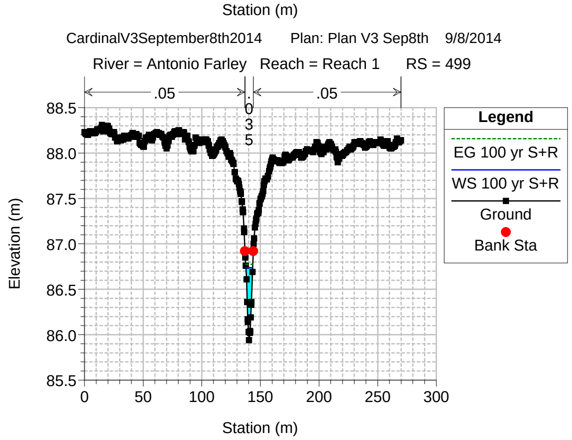

CardinalV3September8th2014 Plan: Plan V3 Sep8th 9/8/2014
River = Antonio Farley Reach = Reach 1 RS = 96
.05
.035
.05
Elevation (m)
Station (m)
Legend
EG 100 yr S+R
WS 100 yr S+R
Ground
Bank Sta

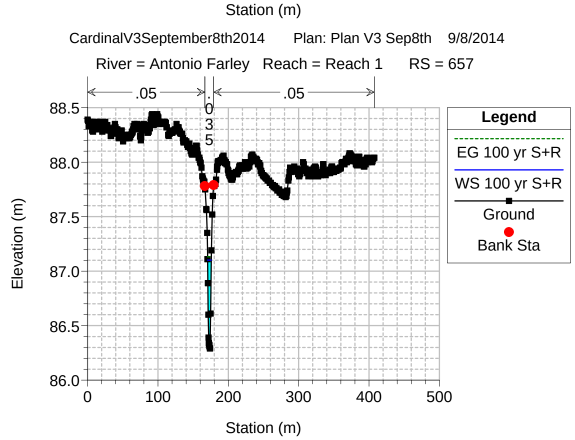

CardinalV3September8th2014 Plan: Plan V3 Sep8th 9/8/2014
River = Antonio Farley Reach = Reach 1 RS = 138
.05
.035
.05
Elevation (m)
Station (m)
Legend
EG 100 yr S+R
WS 100 yr S+R
Ground
Bank Sta

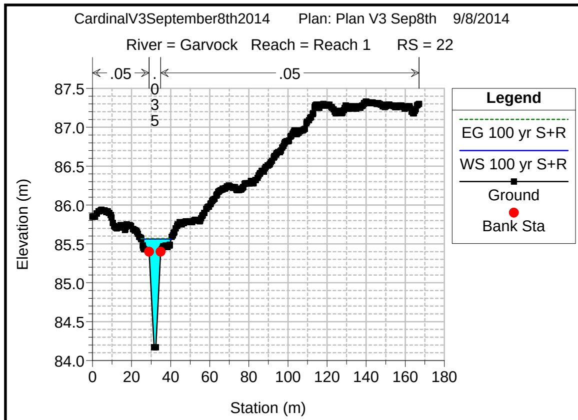

CardinalV3September8th2014 Plan: Plan V3 Sep8th 9/8/2014
River = Antonio Farley Reach = Reach 1 RS = 217
.05
.035
.05
Elevation (m)
Station (m)
Legend
EG 100 yr S+R
WS 100 yr S+R
Ground
Bank Sta

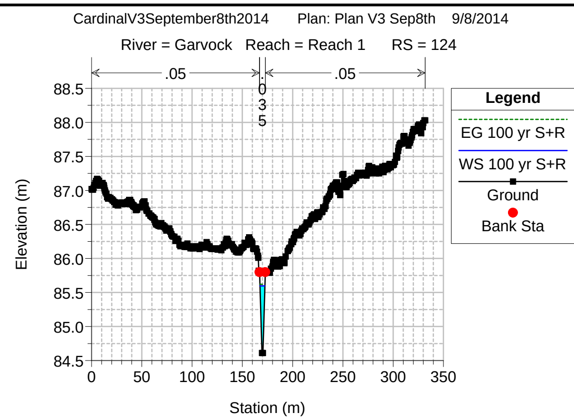

CardinalV3September8th2014 Plan: Plan V3 Sep8th 9/8/2014
River = Antonio Farley Reach = Reach 1 RS = 241
.05
.035
.05
Elevation (m)
Station (m)
Legend
EG 100 yr S+R
WS 100 yr S+R
Ground
Bank Sta

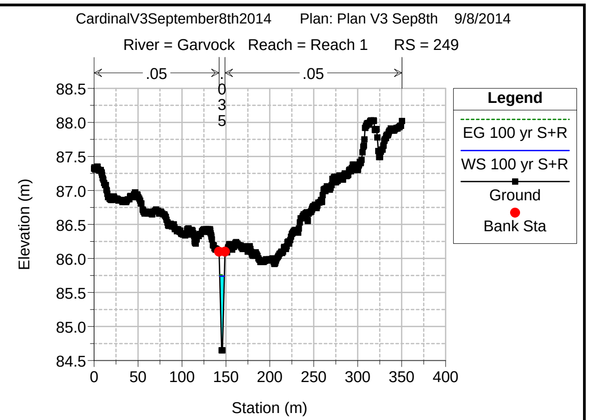

CardinalV3September8th2014 Plan: Plan V3 Sep8th 9/8/2014
River = Antonio Farley Reach = Reach 1 RS = 332
.05
.035
.05
Elevation (m)
Station (m)
Legend
EG 100 yr S+R
WS 100 yr S+R
Ground
Bank Sta

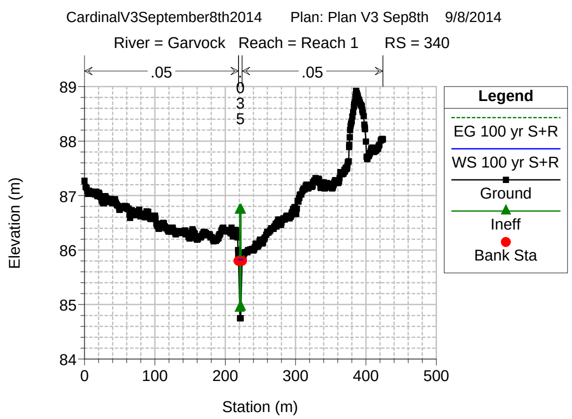

CardinalV3September8th2014 Plan: Plan V3 Sep8th 9/8/2014
River = Antonio Farley Reach = Reach 1 RS = 499
.05
.035
.05
Elevation (m)
Station (m)
Legend
EG 100 yr S+R
WS 100 yr S+R
Ground
Bank Sta

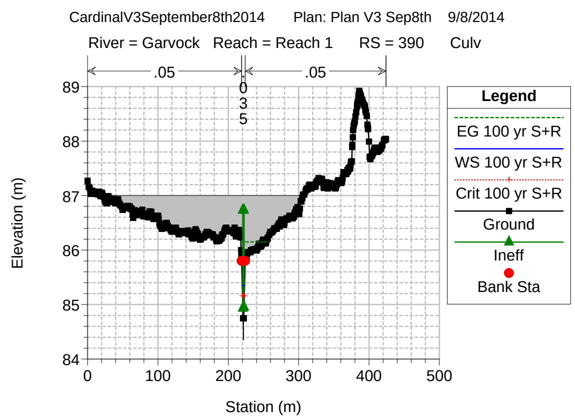

CardinalV3September8th2014 Plan: Plan V3 Sep8th 9/8/2014
River = Antonio Farley Reach = Reach 1 RS = 657
.05
.035
.05
Elevation (m)
Station (m)
Legend
EG 100 yr S+R
WS 100 yr S+R
Ground
Bank Sta

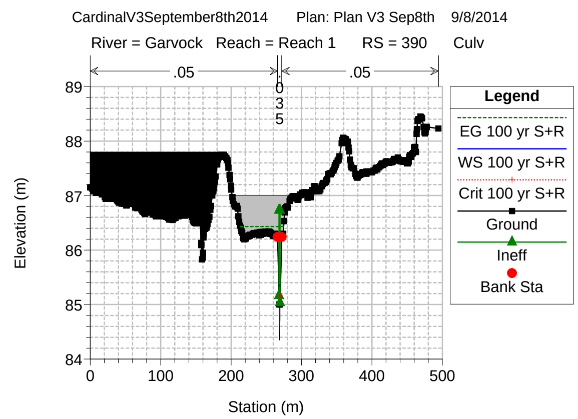

CardinalV3September8th2014 Plan: Plan V3 Sep8th 9/8/2014
River = Garvock Reach = Reach 1 RS = 22
.05
.035
.05
Elevation (m)
Station (m)
Legend
EG 100 yr S+R
WS 100 yr S+R
Ground
Bank Sta

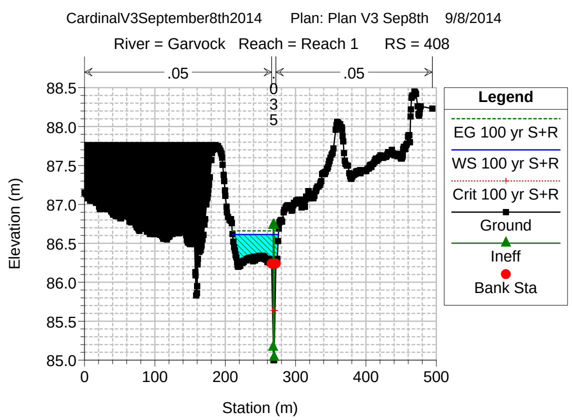

CardinalV3September8th2014 Plan: Plan V3 Sep8th 9/8/2014
River = Garvock Reach = Reach 1 RS = 124
.05
.035
.05
Elevation (m)
Station (m)
Legend
EG 100 yr S+R
WS 100 yr S+R
Ground
Bank Sta

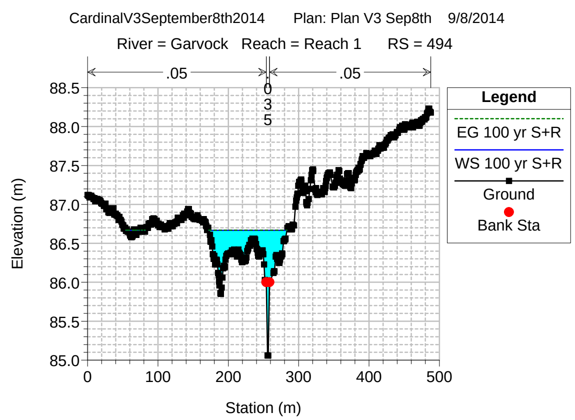

CardinalV3September8th2014 Plan: Plan V3 Sep8th 9/8/2014
River = Garvock Reach = Reach 1 RS = 249
.05
.035
.05
Elevation (m)
Station (m)
Legend
EG 100 yr S+R
WS 100 yr S+R
Ground
Bank Sta


CardinalV3September8th2014 Plan: Plan V3 Sep8th 9/8/2014
River = Garvock Reach = Reach 1 RS = 340
.05
.035
.05
Elevation (m)
Station (m)
Legend
EG 100 yr S+R
WS 100 yr S+R
Ground
Ineff
Bank Sta


CardinalV3September8th2014 Plan: Plan V3 Sep8th 9/8/2014
River = Garvock Reach = Reach 1 RS = 390 Culv
.05
.035
.05
Elevation (m)
Station (m)
Legend
EG 100 yr S+R
WS 100 yr S+R
Crit 100 yr S+R
Ground
Ineff
Bank Sta


CardinalV3September8th2014 Plan: Plan V3 Sep8th 9/8/2014
River = Garvock Reach = Reach 1 RS = 390 Culv
.05
.035
.05
Elevation (m)
Station (m)
Legend
EG 100 yr S+R
WS 100 yr S+R
Crit 100 yr S+R
Ground
Ineff
Bank Sta

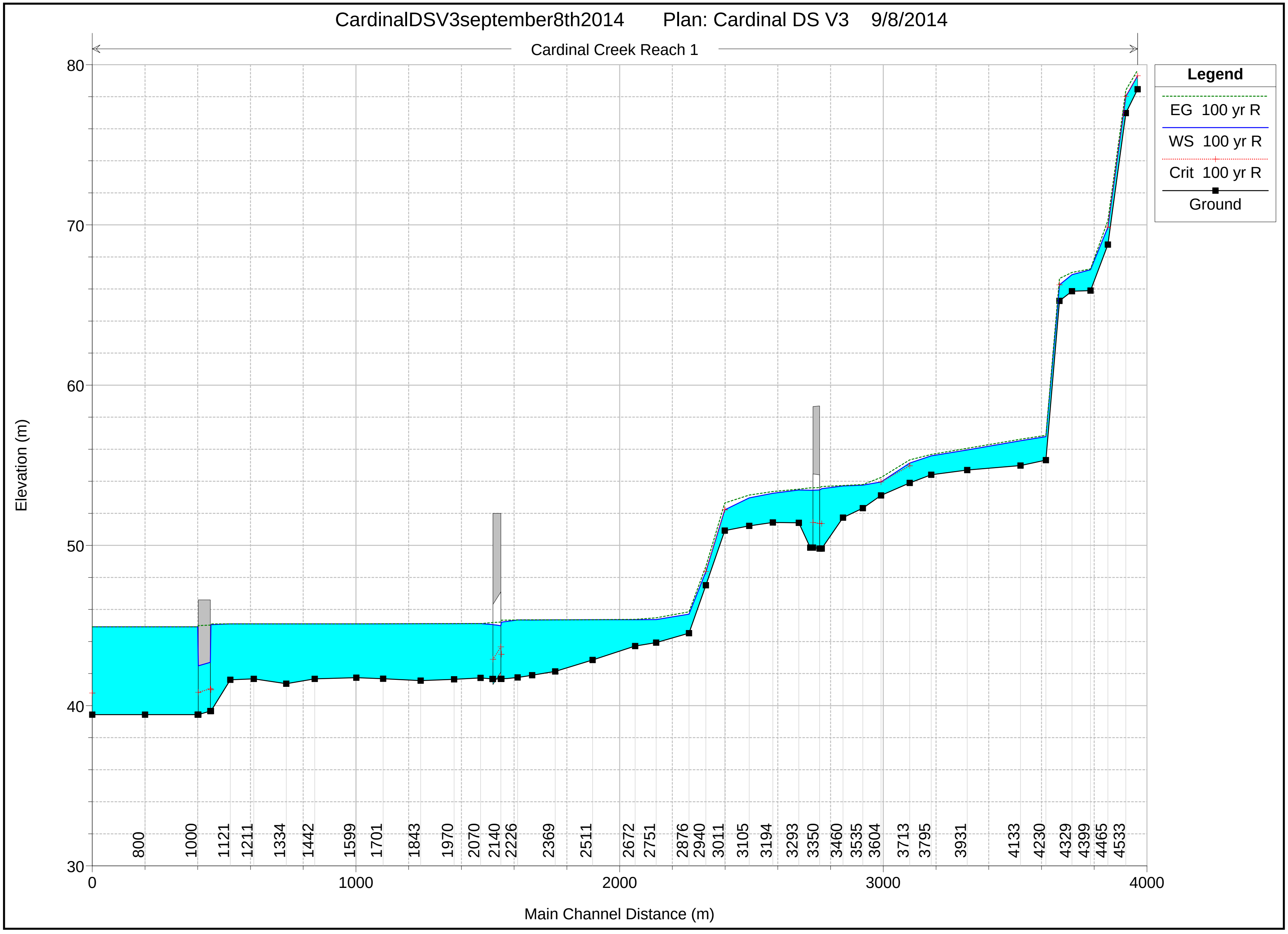

CardinalV3September8th2014 Plan: Plan V3 Sep8th 9/8/2014
River = Garvock Reach = Reach 1 RS = 408
.05
.035
.05
Elevation (m)
Station (m)
Legend
EG 100 yr S+R
WS 100 yr S+R
Crit 100 yr S+R
Ground
Ineff
Bank Sta


CardinalV3September8th2014 Plan: Plan V3 Sep8th 9/8/2014
River = Garvock Reach = Reach 1 RS = 494
.05
.035
.05
Elevation (m)
Station (m)
Legend
EG 100 yr S+R
WS 100 yr S+R
Ground
Bank Sta

Appendix B
HEC-RAS Model Output
Downstream Model
(Cardinal Creek from Ottawa River to Watters Road)

Longitudinal Profiles

Cross-Sections


CardinalDSV3september8th2014 Plan: Cardinal DS V3 9/8/2014
Cardinal Creek Reach 1
Legend
EG 100 yr R
WS 100 yr R
Crit 100 yr R
Ground
Elevation (m)
Main Channel Distance (m)
80
70
60
50
40
30
0
1000
2000
3000
4000
800
1000
1121
1211
1334
1442
1599
1701
1843
1970
2070
2140
2226
2369
2511
2672
2751
2876
2940
3011
3105
3194
3293
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3535
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3713
3795
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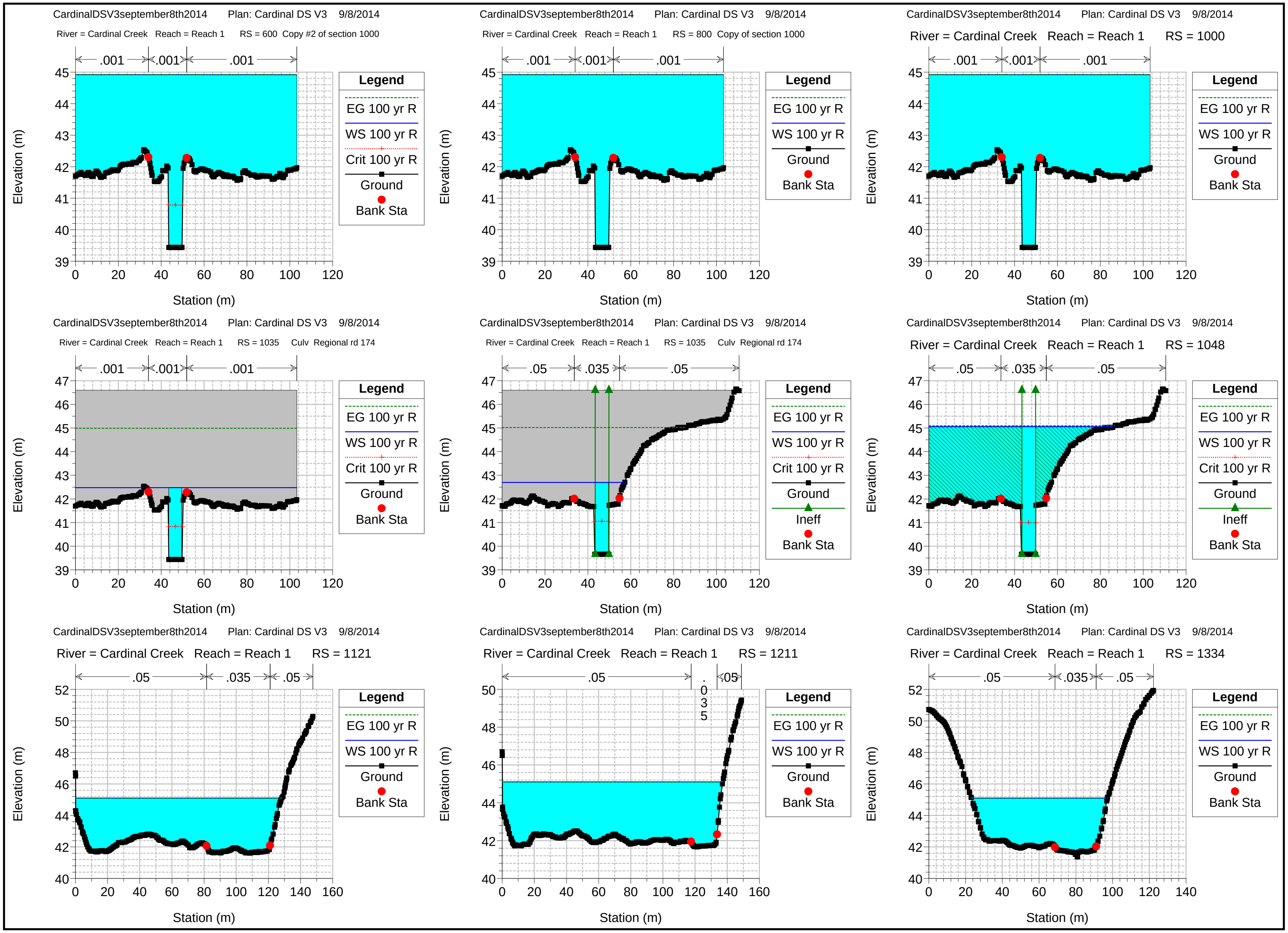
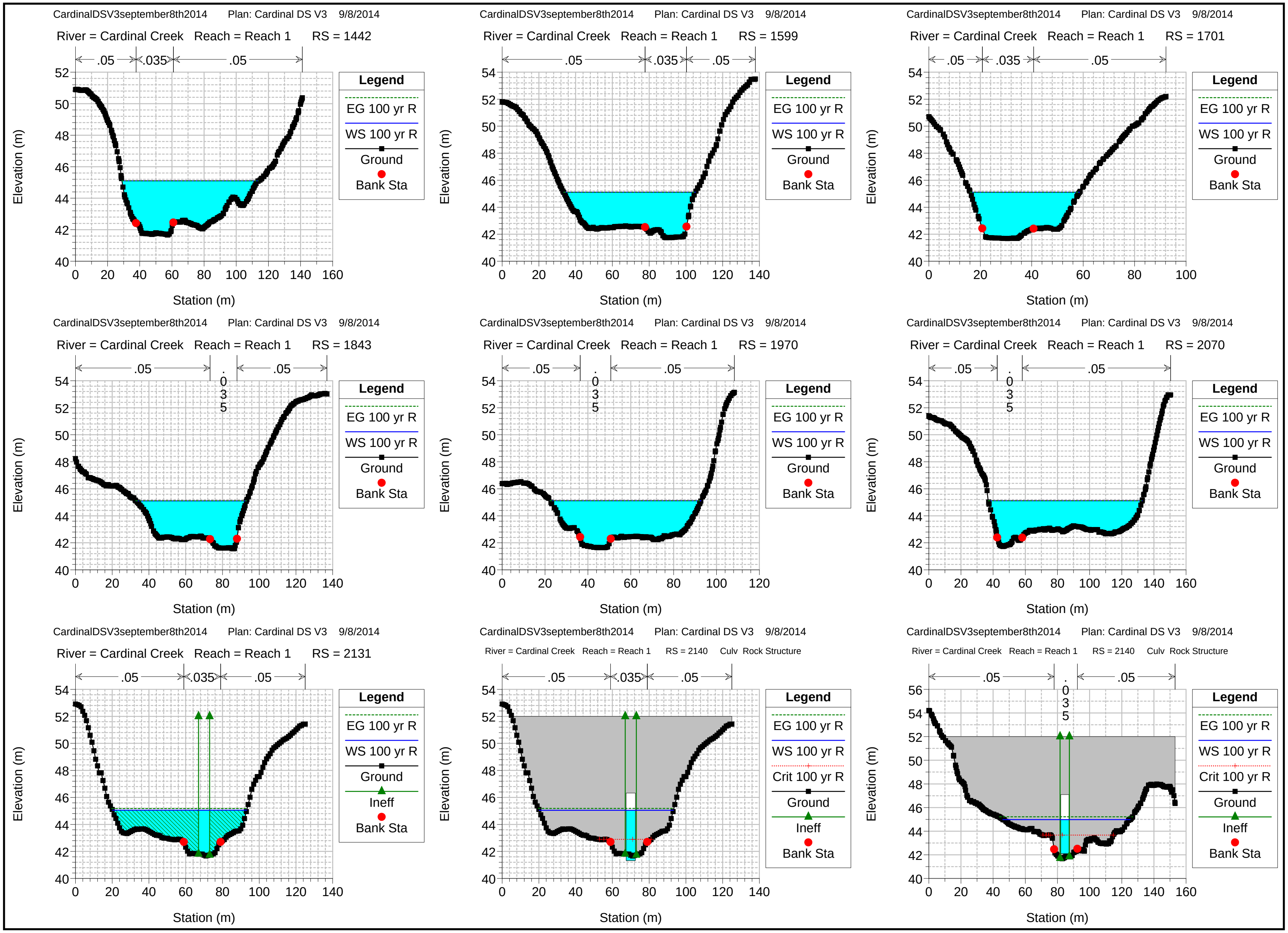
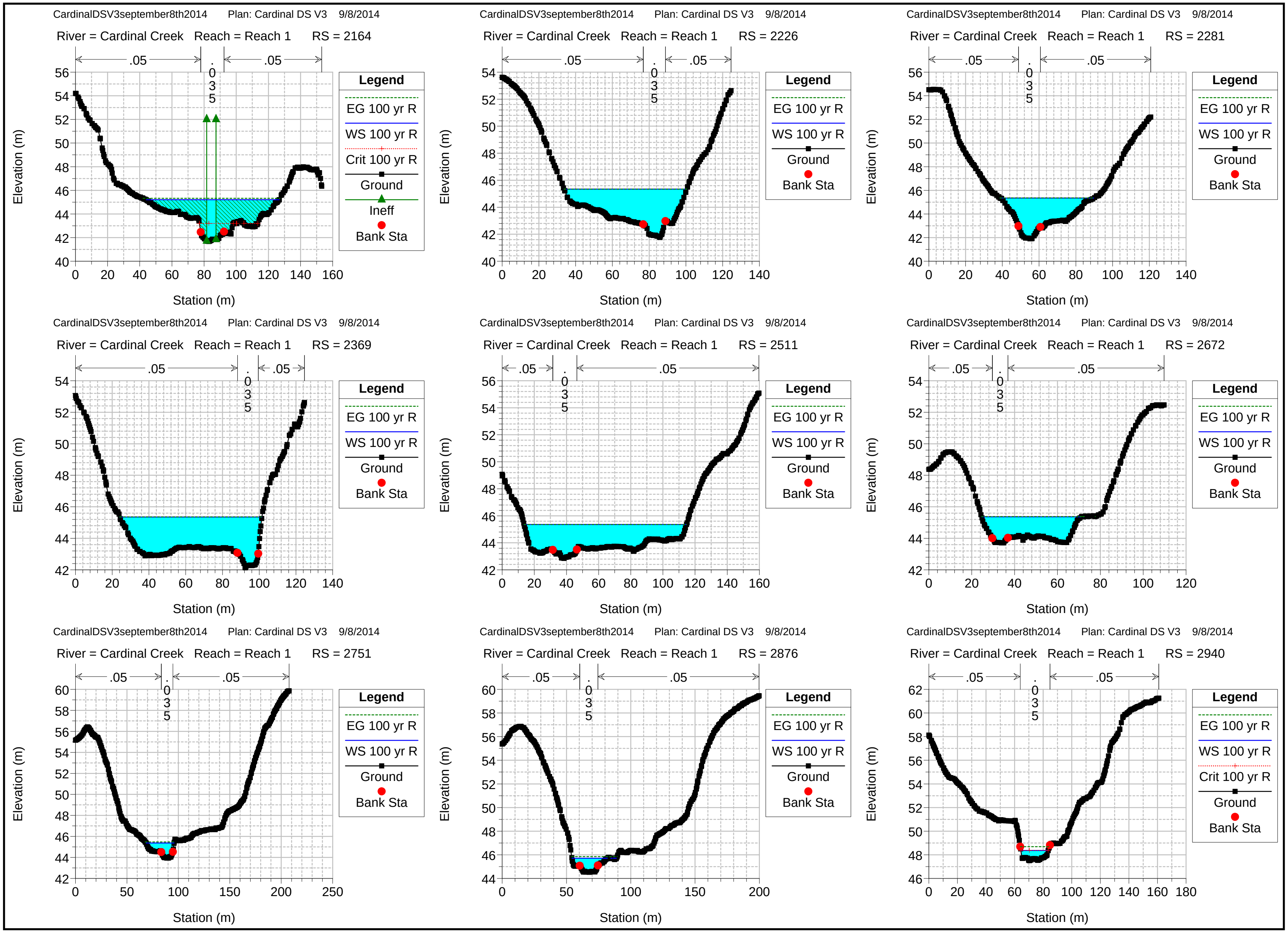
4133
4230
4329
4399
4465
4533

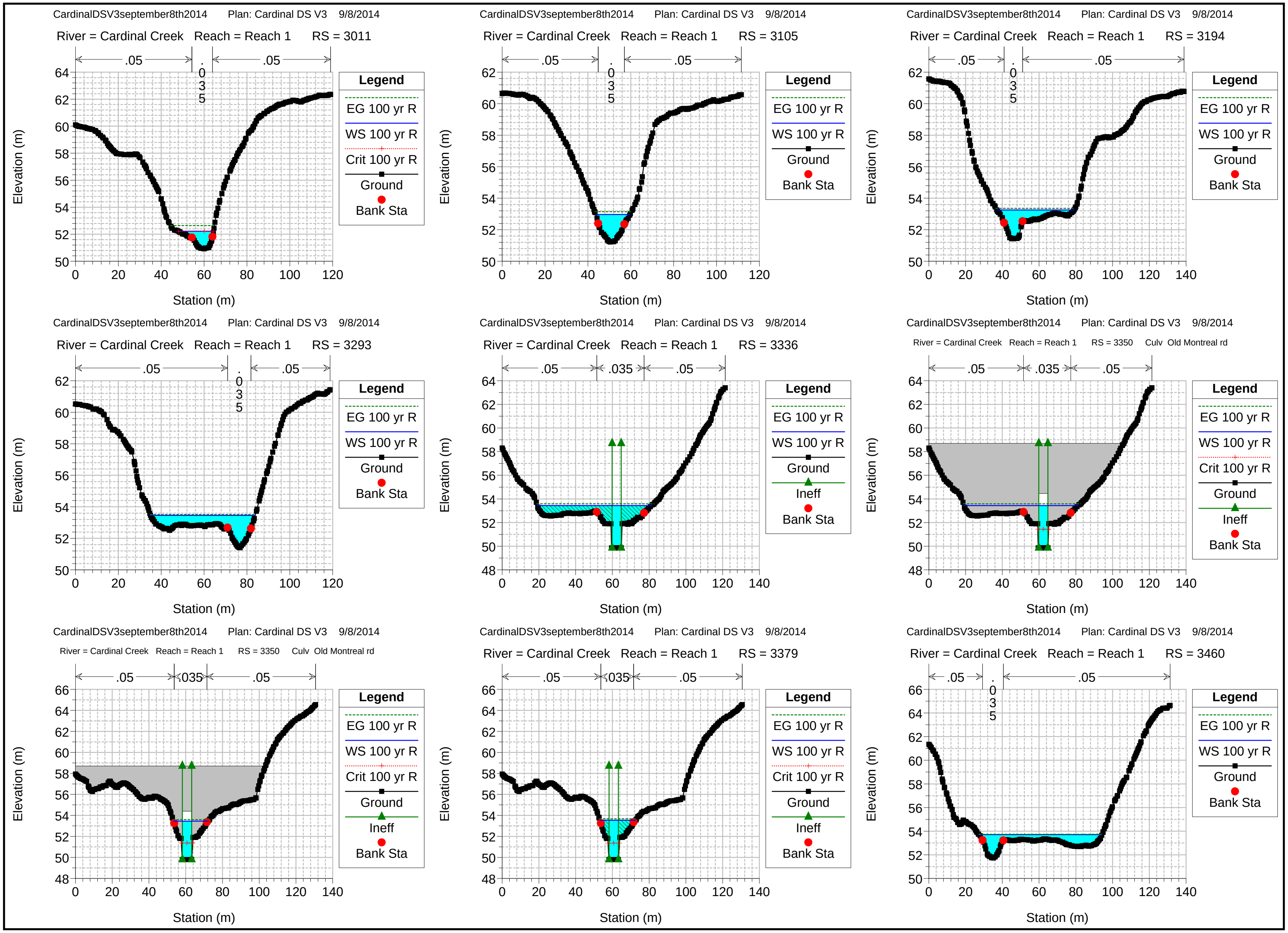


CardinalDSV3september8th2014 Plan: Cardinal DS V3 9/8/2014
River = Cardinal Creek Reach = Reach 1 RS = 600 Copy #2 of section 1000
.001 .001 .001
Legend
EG 100 yr R
WS 100 yr R
Crit 100 yr R
Ground
Bank Sta
Elevation (m)
Station (m)
CardinalDSV3september8th2014 Plan: Cardinal DS V3 9/8/2014
River = Cardinal Creek Reach = Reach 1 RS = 800 Copy of section 1000
.001 .001 .001
Legend
EG 100 yr R
WS 100 yr R
Ground
Bank Sta
Elevation (m)
Station (m)
CardinalDSV3september8th2014 Plan: Cardinal DS V3 9/8/2014
River = Cardinal Creek Reach = Reach 1 RS = 1000
.001 .001 .001
Legend
EG 100 yr R
WS 100 yr R
Ground
Bank Sta
Elevation (m)
Station (m)
CardinalDSV3september8th2014 Plan: Cardinal DS V3 9/8/2014
River = Cardinal Creek Reach = Reach 1 RS = 1035 Culv Regional rd 174
.001 .001 .001
Legend
EG 100 yr R
WS 100 yr R
Crit 100 yr R
Ground
Bank Sta
Elevation (m)
Station (m)
CardinalDSV3september8th2014 Plan: Cardinal DS V3 9/8/2014
River = Cardinal Creek Reach = Reach 1 RS = 1035 Culv Regional rd 174
.05 .035 .05
Legend
EG 100 yr R
WS 100 yr R
Crit 100 yr R
Ground
Ineff
Bank Sta
Elevation (m)
Station (m)
CardinalDSV3september8th2014 Plan: Cardinal DS V3 9/8/2014
River = Cardinal Creek Reach = Reach 1 RS = 1048
.05 .035 .05
Legend
EG 100 yr R
WS 100 yr R
Crit 100 yr R
Ground
Ineff
Bank Sta
Elevation (m)
Station (m)
CardinalDSV3september8th2014 Plan: Cardinal DS V3 9/8/2014
River = Cardinal Creek Reach = Reach 1 RS = 1121
.05 .035 .05
Legend
EG 100 yr R
WS 100 yr R
Ground
Bank Sta
Elevation (m)
Station (m)
CardinalDSV3september8th2014 Plan: Cardinal DS V3 9/8/2014
River = Cardinal Creek Reach = Reach 1 RS = 1211
.05 .035 .05
Legend
EG 100 yr R
WS 100 yr R
Ground
Bank Sta
Elevation (m)
Station (m)
CardinalDSV3september8th2014 Plan: Cardinal DS V3 9/8/2014
River = Cardinal Creek Reach = Reach 1 RS = 1334
.05 .035 .05
Legend
EG 100 yr R
WS 100 yr R
Ground
Bank Sta
Elevation (m)
Station (m)

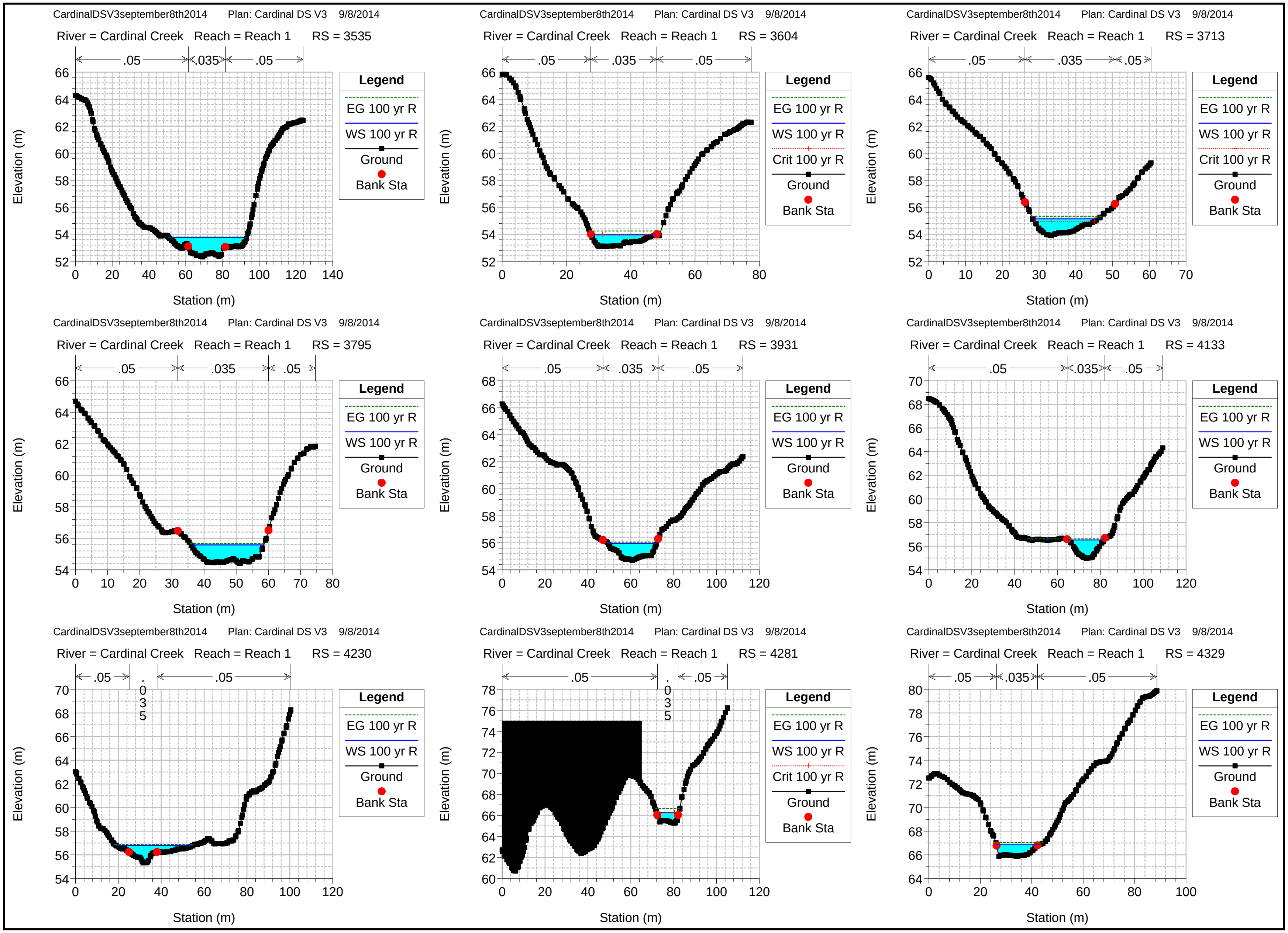


CardinalDSV3september8th2014 Plan: Cardinal DS V3 9/8/2014
River = Cardinal Creek Reach = Reach 1 RS = 1442
.05 .035 .05
Legend
EG 100 yr R
WS 100 yr R
Ground
Bank Sta
Elevation (m)
Station (m)
CardinalDSV3september8th2014 Plan: Cardinal DS V3 9/8/2014
River = Cardinal Creek Reach = Reach 1 RS = 1599
.05 .035 .05
Legend
EG 100 yr R
WS 100 yr R
Ground
Bank Sta
Elevation (m)
Station (m)
CardinalDSV3september8th2014 Plan: Cardinal DS V3 9/8/2014
River = Cardinal Creek Reach = Reach 1 RS = 1701
.05 .035 .05
Legend
EG 100 yr R
WS 100 yr R
Ground
Bank Sta
Elevation (m)
Station (m)
CardinalDSV3september8th2014 Plan: Cardinal DS V3 9/8/2014
River = Cardinal Creek Reach = Reach 1 RS = 1843
.05 .035 .05
Legend
EG 100 yr R
WS 100 yr R
Ground
Bank Sta
Elevation (m)
Station (m)
CardinalDSV3september8th2014 Plan: Cardinal DS V3 9/8/2014
River = Cardinal Creek Reach = Reach 1 RS = 1970
.05 .035 .05
Legend
EG 100 yr R
WS 100 yr R
Ground
Bank Sta
Elevation (m)
Station (m)
CardinalDSV3september8th2014 Plan: Cardinal DS V3 9/8/2014
River = Cardinal Creek Reach = Reach 1 RS = 2070
.05 .035 .05
Legend
EG 100 yr R
WS 100 yr R
Ground
Bank Sta
Elevation (m)
Station (m)
CardinalDSV3september8th2014 Plan: Cardinal DS V3 9/8/2014
River = Cardinal Creek Reach = Reach 1 RS = 2131
.05 .035 .05
Legend
EG 100 yr R
WS 100 yr R
Ground
Ineff
Bank Sta
Elevation (m)
Station (m)
CardinalDSV3september8th2014 Plan: Cardinal DS V3 9/8/2014
River = Cardinal Creek Reach = Reach 1 RS = 2140 Culv Rock Structure
.05 .035 .05
Legend
EG 100 yr R
WS 100 yr R
Crit 100 yr R
Ground
Ineff
Bank Sta
Elevation (m)
Station (m)
CardinalDSV3september8th2014 Plan: Cardinal DS V3 9/8/2014
River = Cardinal Creek Reach = Reach 1 RS = 2140 Culv Rock Structure
.05 .035 .05
Legend
EG 100 yr R
WS 100 yr R
Crit 100 yr R
Ground
Ineff
Bank Sta
Elevation (m)
Station (m)

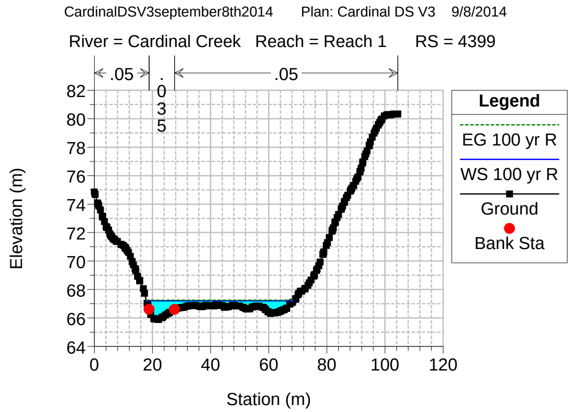

CardinalDSV3september8th2014 Plan: Cardinal DS V3 9/8/2014
River = Cardinal Creek Reach = Reach 1 RS = 2164
Legend
EG 100 yr R
WS 100 yr R
Crit 100 yr R
Ground
Ineff
Bank Sta
Elevation (m)
Station (m)
CardinalDSV3september8th2014 Plan: Cardinal DS V3 9/8/2014
River = Cardinal Creek Reach = Reach 1 RS = 2226
CardinalDSV3september8th2014 Plan: Cardinal DS V3 9/8/2014
River = Cardinal Creek Reach = Reach 1 RS = 2281
CardinalDSV3september8th2014 Plan: Cardinal DS V3 9/8/2014
River = Cardinal Creek Reach = Reach 1 RS = 2369
CardinalDSV3september8th2014 Plan: Cardinal DS V3 9/8/2014
River = Cardinal Creek Reach = Reach 1 RS = 2511
CardinalDSV3september8th2014 Plan: Cardinal DS V3 9/8/2014
River = Cardinal Creek Reach = Reach 1 RS = 2672
CardinalDSV3september8th2014 Plan: Cardinal DS V3 9/8/2014
River = Cardinal Creek Reach = Reach 1 RS = 2751
CardinalDSV3september8th2014 Plan: Cardinal DS V3 9/8/2014
River = Cardinal Creek Reach = Reach 1 RS = 2876
CardinalDSV3september8th2014 Plan: Cardinal DS V3 9/8/2014
River = Cardinal Creek Reach = Reach 1 RS = 2940
.05
.035

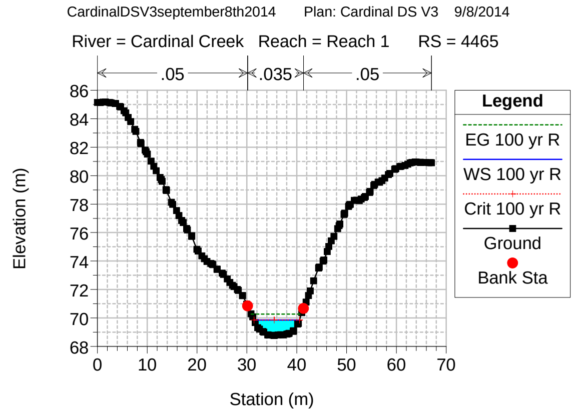


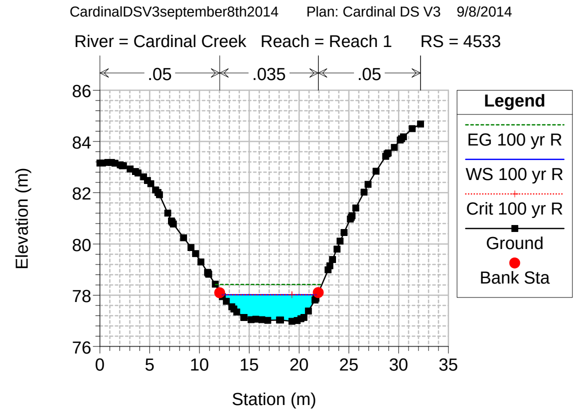
CardinalDSV3september8th2014 Plan: Cardinal DS V3 9/8/2014
River = Cardinal Creek Reach = Reach 1 RS = 3011
.05 .035 .05
Elevation (m)
Station (m)
Legend
EG 100 yr R
WS 100 yr R
Crit 100 yr R
Ground
Bank Sta
CardinalDSV3september8th2014 Plan: Cardinal DS V3 9/8/2014
River = Cardinal Creek Reach = Reach 1 RS = 3105
.05 .035 .05
Elevation (m)
Station (m)
Legend
EG 100 yr R
WS 100 yr R
Ground
Bank Sta
CardinalDSV3september8th2014 Plan: Cardinal DS V3 9/8/2014
River = Cardinal Creek Reach = Reach 1 RS = 3194
.05 .035 .05
Elevation (m)
Station (m)
Legend
EG 100 yr R
WS 100 yr R
Ground
Bank Sta
CardinalDSV3september8th2014 Plan: Cardinal DS V3 9/8/2014
River = Cardinal Creek Reach = Reach 1 RS = 3293
.05 .035 .05
Elevation (m)
Station (m)
Legend
EG 100 yr R
WS 100 yr R
Ground
Bank Sta
CardinalDSV3september8th2014 Plan: Cardinal DS V3 9/8/2014
River = Cardinal Creek Reach = Reach 1 RS = 3336
.05 .035 .05
Elevation (m)
Station (m)
Legend
EG 100 yr R
WS 100 yr R
Ground
Ineff
Bank Sta
CardinalDSV3september8th2014 Plan: Cardinal DS V3 9/8/2014
River = Cardinal Creek Reach = Reach 1 RS = 3350 Culv Old Montreal rd
.05 .035 .05
Elevation (m)
Station (m)
Legend
EG 100 yr R
WS 100 yr R
Crit 100 yr R
Ground
Ineff
Bank Sta
CardinalDSV3september8th2014 Plan: Cardinal DS V3 9/8/2014
River = Cardinal Creek Reach = Reach 1 RS = 3350 Culv Old Montreal rd
.05 .035 .05
Elevation (m)
Station (m)
Legend
EG 100 yr R
WS 100 yr R
Crit 100 yr R
Ground
Ineff
Bank Sta
CardinalDSV3september8th2014 Plan: Cardinal DS V3 9/8/2014
River = Cardinal Creek Reach = Reach 1 RS = 3379
.05 .035 .05
Elevation (m)
Station (m)
Legend
EG 100 yr R
WS 100 yr R
Crit 100 yr R
Ground
Ineff
Bank Sta
CardinalDSV3september8th2014 Plan: Cardinal DS V3 9/8/2014
River = Cardinal Creek Reach = Reach 1 RS = 3460
.05 .035 .05
Elevation (m)
Station (m)
Legend
EG 100 yr R
WS 100 yr R
Ground
Bank Sta

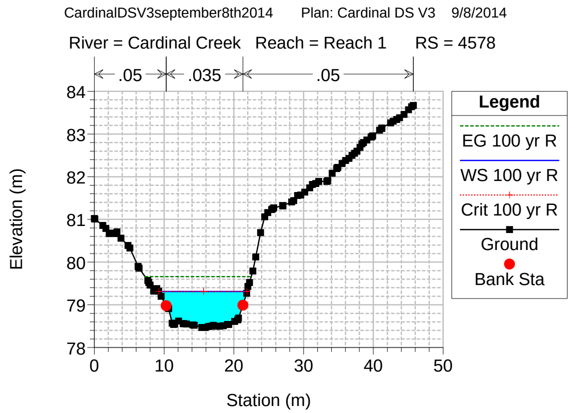


CardinalDSV3september8th2014 Plan: Cardinal DS V3 9/8/2014
River = Cardinal Creek Reach = Reach 1 RS = 3535
.05 .035 .05
Legend
EG 100 yr R
WS 100 yr R
Ground
Bank Sta
Elevation (m)
Station (m)
CardinalDSV3september8th2014 Plan: Cardinal DS V3 9/8/2014
River = Cardinal Creek Reach = Reach 1 RS = 3604
.05 .035 .05
Legend
EG 100 yr R
WS 100 yr R
Crit 100 yr R
Ground
Bank Sta
Elevation (m)
Station (m)
CardinalDSV3september8th2014 Plan: Cardinal DS V3 9/8/2014
River = Cardinal Creek Reach = Reach 1 RS = 3713
.05 .035 .05
Legend
EG 100 yr R
WS 100 yr R
Crit 100 yr R
Ground
Bank Sta
Elevation (m)
Station (m)
CardinalDSV3september8th2014 Plan: Cardinal DS V3 9/8/2014
River = Cardinal Creek Reach = Reach 1 RS = 3795
.05 .035 .05
Legend
EG 100 yr R
WS 100 yr R
Ground
Bank Sta
Elevation (m)
Station (m)
CardinalDSV3september8th2014 Plan: Cardinal DS V3 9/8/2014
River = Cardinal Creek Reach = Reach 1 RS = 3931
.05 .035 .05
Legend
EG 100 yr R
WS 100 yr R
Ground
Bank Sta
Elevation (m)
Station (m)
CardinalDSV3september8th2014 Plan: Cardinal DS V3 9/8/2014
River = Cardinal Creek Reach = Reach 1 RS = 4133
.05 .035 .05
Legend
EG 100 yr R
WS 100 yr R
Ground
Bank Sta
Elevation (m)
Station (m)
CardinalDSV3september8th2014 Plan: Cardinal DS V3 9/8/2014
River = Cardinal Creek Reach = Reach 1 RS = 4230
.05 .035 .05
Legend
EG 100 yr R
WS 100 yr R
Ground
Bank Sta
Elevation (m)
Station (m)
CardinalDSV3september8th2014 Plan: Cardinal DS V3 9/8/2014
River = Cardinal Creek Reach = Reach 1 RS = 4281
.05 .035 .05
Legend
EG 100 yr R
WS 100 yr R
Crit 100 yr R
Ground
Bank Sta
Elevation (m)
Station (m)
CardinalDSV3september8th2014 Plan: Cardinal DS V3 9/8/2014
River = Cardinal Creek Reach = Reach 1 RS = 4329
.05 .035 .05
Legend
EG 100 yr R
WS 100 yr R
Ground
Bank Sta
Elevation (m)
Station (m)


CardinalDSV3september8th2014 Plan: Cardinal DS V3 9/8/2014
River = Cardinal Creek Reach = Reach 1 RS = 4399
.05
.035
.05
Elevation (m)
Station (m)
Legend
EG 100 yr R
WS 100 yr R
Ground
Bank Sta


CardinalDSV3september8th2014 Plan: Cardinal DS V3 9/8/2014
River = Cardinal Creek Reach = Reach 1 RS = 4465
.05
.035
.05
Elevation (m)
Station (m)
Legend
EG 100 yr R
WS 100 yr R
Crit 100 yr R
Ground
Bank Sta


CardinalDSV3september8th2014 Plan: Cardinal DS V3 9/8/2014
River = Cardinal Creek Reach = Reach 1 RS = 4533
.05
.035
.05
Elevation (m)
Station (m)
Legend
EG 100 yr R
WS 100 yr R
Crit 100 yr R
Ground
Bank Sta


CardinalDSV3september8th2014 Plan: Cardinal DS V3 9/8/2014
River = Cardinal Creek Reach = Reach 1 RS = 4578
.05
.035
.05
Elevation (m)
Station (m)
Legend
EG 100 yr R
WS 100 yr R
Crit 100 yr R
Ground
Bank Sta

Appendix C
Structures and Road Crossings

Innes Road

Upstream

Downstream

Frank Kenny Road

Upstream

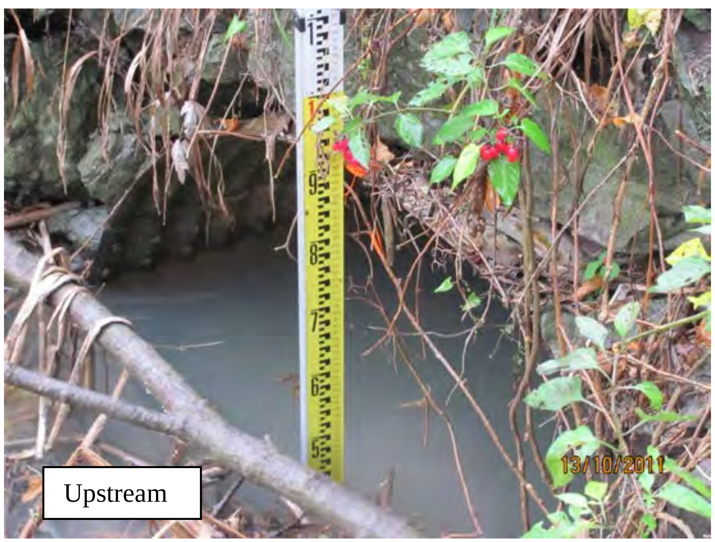
Downstream

Cardinal Creek at O’toole Road

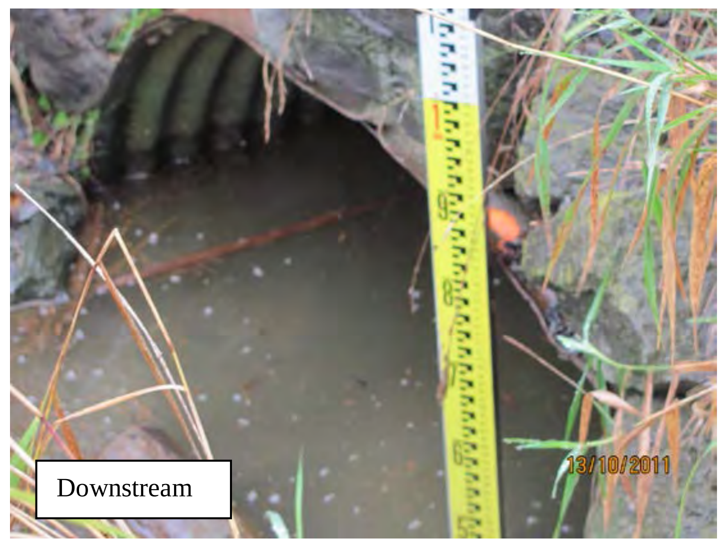
Upstream

Downstream

Garvock Drain at O’toole road



Upstream



Downstream

Old Montreal road

Utility Corridor

Regional road 174

Upstream

Downstream