REPORT

BROOKLYN CREEK MASTER DRAINAGE PLAN

ASSOCIATED ENGINEERING

July
1999

ASSOCIATED ENGINEERING

Mr. Glenn Westendorp
Public Works Superintendent
Town of Comox
1809 Beaufort Avenue
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July 21, 1999
File: 982879

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Re: BROOKLYN CREEK MASTER DRAINAGE PLAN

Dear Mr. Westendorp:

We are pleased to submit the engineering report titled "Brooklyn Creek Master Drainage Plan" in accordance with the proposal dated October 1998. A final draft submission of this report was presented to the Town of Comox on June 28, 1999. Comments we received from the draft report are addressed in this final submission.

We trust that this report provides the information you require regarding storm water management planning in the Brooklyn Creek watershed. If you have any questions or require further information, please contact me.

Respectfully submitted,

ASSOCIATED ENGINEERING (B.C.) LTD.

ORIGINAL SIGNED
BY:

John van der Eerden, M.Eng., P.Eng.
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EXECUTIVE SUMMARY

Brooklyn Creek has experienced increased flows over time due to the gradual increase in population and urbanization of the Comox Valley. Changes in ground cover and land use have increased the volume and rate of flow entering the creek. Since the Town and neighbouring municipalities will continue growing in the future, runoff discharged into Brooklyn Creek will increase if storm water management is not implemented.

The overall existing drainage network of Brooklyn Creek is capable of conveying runoff from future development without frequent flooding problems. Field ponding on agricultural areas is within the ARDSA drainage criteria for both growing and dormant seasons. The area with the most serious drainage concerns is the section of creek between Birkdale Farms and Pritchard Road. Many culvert crossing inlets are submerged and flooding outside of the channel banks occurs in some portions of Brooklyn Creek during high rainfall storms.

We investigated various improvements such as culvert upgrades, channel cleaning, and on-line detention storage. With these results, we found a combination of drainage improvements that will reduce flood elevations, flood durations, head loss and water depths to pre-development levels. While these drainage improvements do increase the flow rates and velocities in the creek, stream velocity was controlled to prevent a severe increase in stream bank erosion. Nonetheless, the creek should be monitored following implementation of these improvements so that stream bank erosion can be arrested.

Our recommended drainage improvements are as follows:

- Construct a 0.56 m high berm plus freeboard around the existing detention pond servicing the Highwood development east of Birkdale Farms. At present, the berm around the pond is only 0.25 m above the discharge pipe and is insufficient in attenuating peak flows for this new residential development.

- Upgrade private crossing between Parry Place and Idiens Way to two 1200 mm by 600 mm arch culverts with flush headwalls.

- Upgrade Anderton Road culvert to 1830 mm by 970 mm arch culvert with flush headwalls and wingwalls.

- Upgrade Guthrie Road culvert to 1650 mm diameter concrete culvert complete with flush headwalls and wingwalls.

- Upgrade Salish Street culvert to 1650 mm diameter concrete culvert with flush headwalls and wingwalls. Also, add riprap at the inlet and outlet.

- Upgrade Pritchard Road culvert to 2400 mm by 1500 mm box culvert complete with flush headwalls and wing walls.

- Upgrade Noel Avenue culvert to 2400 mm by 1500 mm box culvert with flush headwalls and wingwalls. Riprap protection is needed at the inlet of this culvert.

- Construct detention storage ponds upstream of Birkdale Farms near the corner of Parry Place and Idiens Way, the corner of Dryden Road and Anderton Road, and on Anderton Road south of McQuinn Road. Each pond requires approximately 0.2 ha of land.

- Provide bank protection in areas along the creek banks downstream of Salish Park to Noel Avenue and in areas downstream of Dogwood Avenue, especially in sections where evidence of undermining or slope failure is present. Ensure outlet protection is provided for all municipal outfalls and culverts.

- Improve channel conveyance for 200 m downstream of Guthrie Road. This work should be completed in stages to minimize impacts on natural features. Initially remove overgrown vegetation, debris jams, and gravel bar downstream of Guthrie Road culvert. Overall channel conveyance can be improved by removing overgrown vegetation, debris jams, sediment deposits, and re-establishing an effective stream profile and cross section. Ultimately, all flow constrictions downstream of this culvert should be removed and channel sections should have an unrestricted base width of 3.9 m and 2H:1V side slopes.

- Monitor stream flows downstream of the Crown Isle Development and/or water levels in Pond 20 to ensure satisfactory system performance.

TABLE OF CONTENTS

INTRODUCTION

SECTION 1

1.1 PROJECT BACKGROUND

Brooklyn Creek is the main drainage course flowing through the Town of Comox. It has a drainage catchment of approximately 650 ha, beginning at the North Island College and discharging into Comox Harbour. The entire creek below Parry Place is identified as fish bearing habitat.

Drawing no. 982879-1-100 is a site plan of the Brooklyn Creek watershed. Approximately half the length of Brooklyn Creek is contained within the Town limits. The remainder extends into the Regional District of Comox-Strathcona and the City of Courtenay. Flow into Brooklyn Creek begins at the North Island College campus, then through the Crown Isle Development and into an open channel east of Parry Place in the Regional District of Comox-Strathcona. The creek then passes through major culvert crossings at Idiens Way and Anderton Road before reaching the Comox boundary at Guthrie Road. Within the Town, Brooklyn Creek travels through main culvert crossings at Guthrie Road, Salish Street, Pritchard Road, Noel Avenue, Dogwood Avenue, and Balmoral Avenue. Downstream of Dogwood Avenue, the creek soon enters a deep ravine and finally outflows onto the tidal marsh of Comox Harbour.

According to a 1959 report on flooding in Comox by the B.C. Department of Lands and Forests, Water Rights Branch, flooding and concerns regarding increased runoff due to development has been a concern for over 40 years. As the population of Comox and its surrounding municipalities increases, continued urban and rural development contributes to increases in overland runoff. Peak flows rise in developed areas as a result of a reduction in pervious surfaces, reduced depression storage, and the provision of efficient storm drainage connections to receiving waters. These changes in runoff characteristics result in increased frequency of flooding, higher flood levels, increased stream velocities, and additional stream erosion.

1.2 PROJECT GOALS AND OBJECTIVES

The goal of the management plan is to limit the extent of drainage problems to levels consistent with a pre-development state. The main objectives of the plan are as follows:

- Minimize property damage.
- Reduce inconvenience and crop loss from surface ponding and flooding.

- Limit the frequency and extent of flooding.
- Reduce creek processes such as erosion, sedimentation, and slope instability.
- Protect and enhance the environmental aspects within the watershed.

The management plan must also allow for orderly and cost-effective development and reduce impairment to aquatic life and habitat. Since the watershed extends beyond the Town limits of Comox, drainage within the Town can be affected by actions outside of the Town's jurisdiction. Therefore, cooperation between the municipal jurisdictions is important in the long-term development of the watershed.

1.3 BACKGROUND INFORMATION

In recent years, small scale studies have investigated the flooding problems along Brooklyn Creek. Kellerhals Engineering Services produced a letter report concerning the flooding problems at Guthrie Road in 1996. The findings of the report identified sedimentation downstream of Guthrie Road as a main impediment to adequate drainage in the local area.

The Department of Fisheries and Oceans completed a study on Brooklyn Creek to identify the factors involved in the frequent flooding on Birkdale Farms and possible mitigating measures. This 1997 report also identified sedimentation downstream of Guthrie Road as a major problem on Brooklyn Creek and found that the culvert crossing at Guthrie Road is undersized for the 50-year return period storm event using IDF data from 1963 to 1990. Therefore, cooperation in dealing with this problem should not be unreasonably withheld.

As part of this Watershed Management Plan, Associated Engineering performed a field investigation and site survey on the days following the November 24, 1998 rainstorm. The site investigation included taking slope and cross-section measurements along Brooklyn Creek from Parry Place to Anderton Road and from Guthrie Road to Dogwood Avenue. In addition, locations of bank erosion and channel sedimentation were noted and photographs were taken along the creek from Parry Place to the downstream portion of Mack Laing Park.

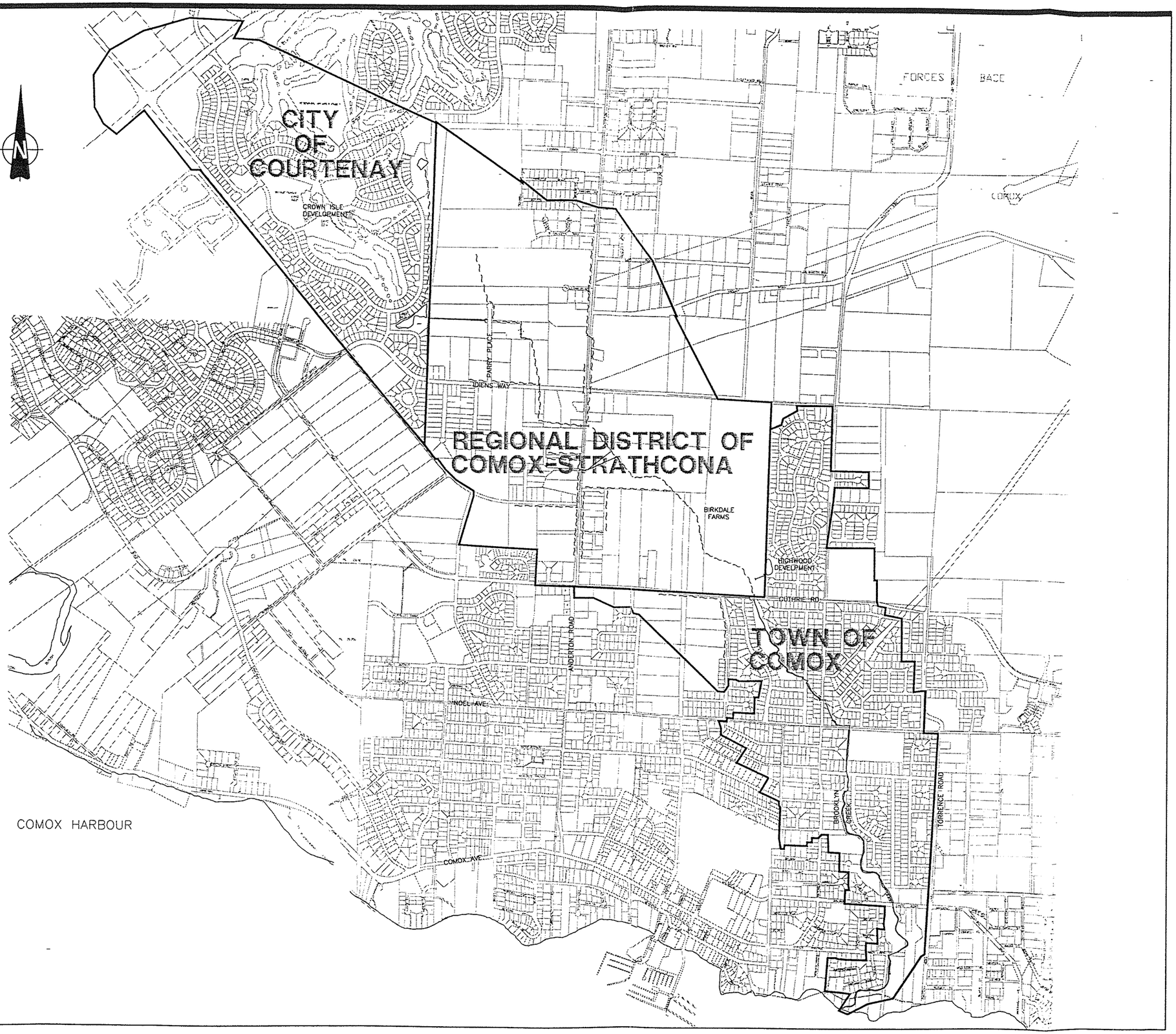
A field survey of each culvert crossing on Brooklyn Creek from Idiens Way to Dogwood Avenue was performed. Elevation measurements were tied to the Town's benchmarks except for the crossings at Idiens Way and Anderton Road. These culverts are in the

Regional District of Comox-Strathcona and benchmarks were not readily available in this area. Local highwater marks were noted where visible for each culvert crossing.

Drawing no. 982879-1-101 is a profile of Brooklyn Creek from Parry Place to Dogwood Avenue using measurements and data collected during the site investigation. Culvert information such as length, opening size, and invert elevations are included on the profile. In addition, field notes regarding erosion, bends, and private crossings are also shown.

Since survey benchmarks are not readily available outside of the Town of Comox, elevations upstream of Guthrie Road were estimated from previous reports and topographic maps. The creek profile was not surveyed through Birkdale Farms. Since the farm land appears to be at a constant grade, the creek slope was estimated from topographic maps and plotted on the profile as a dashed line.

Drawing no. 982879-1-102 shows the creek cross-sections taken at various points along Brooklyn Creek. Each cross-section is noted by the length in metres from the outlet of the nearest upstream culvert.



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REVISIONS

PROJECT NO.	982879
SCALE	1:20,000
DRAWN	R.L.
DESIGNED	J.L.
CHECKED	
APPROVED	
APPROVED	
DATE	MARCH 1999

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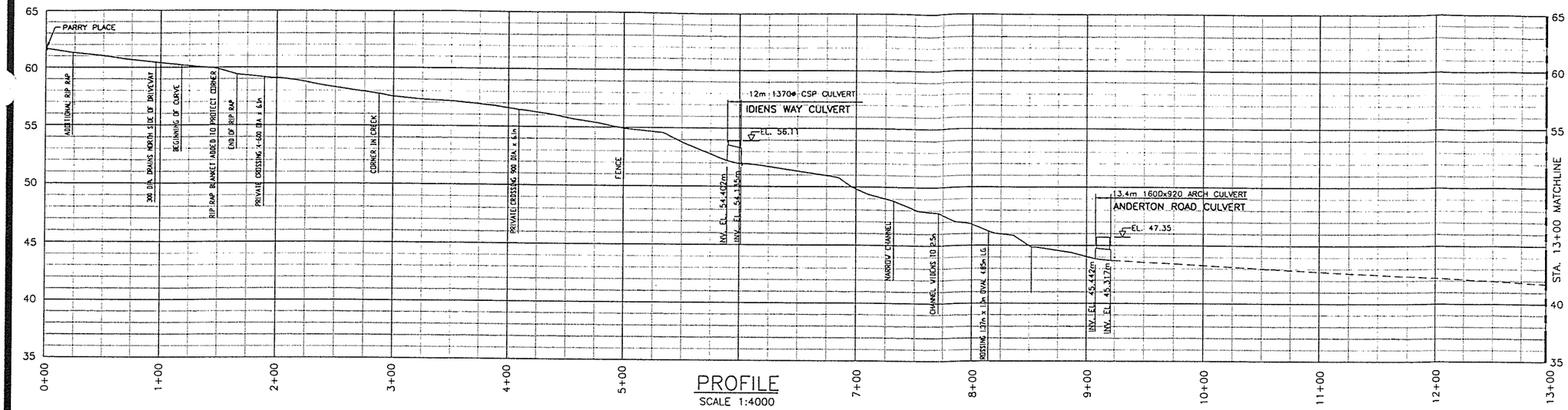
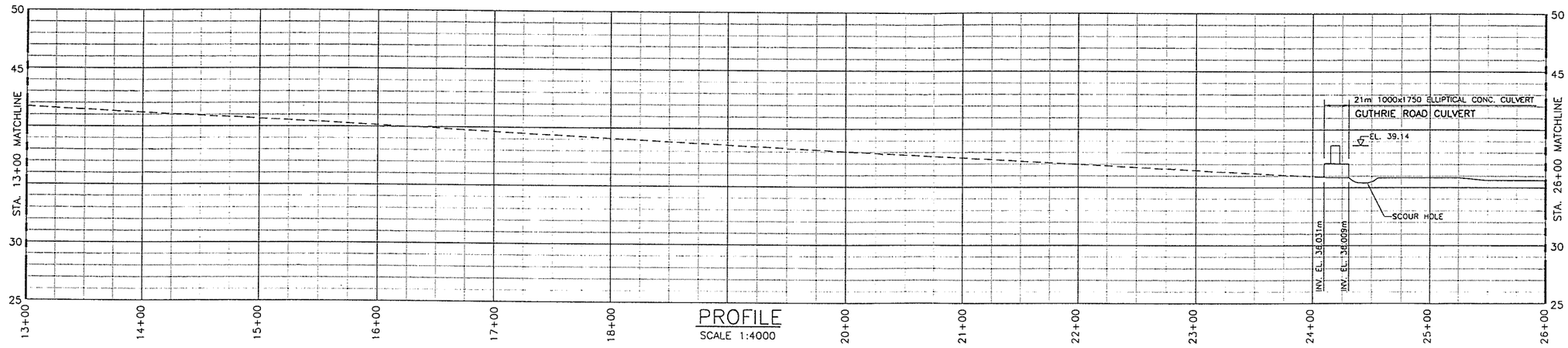
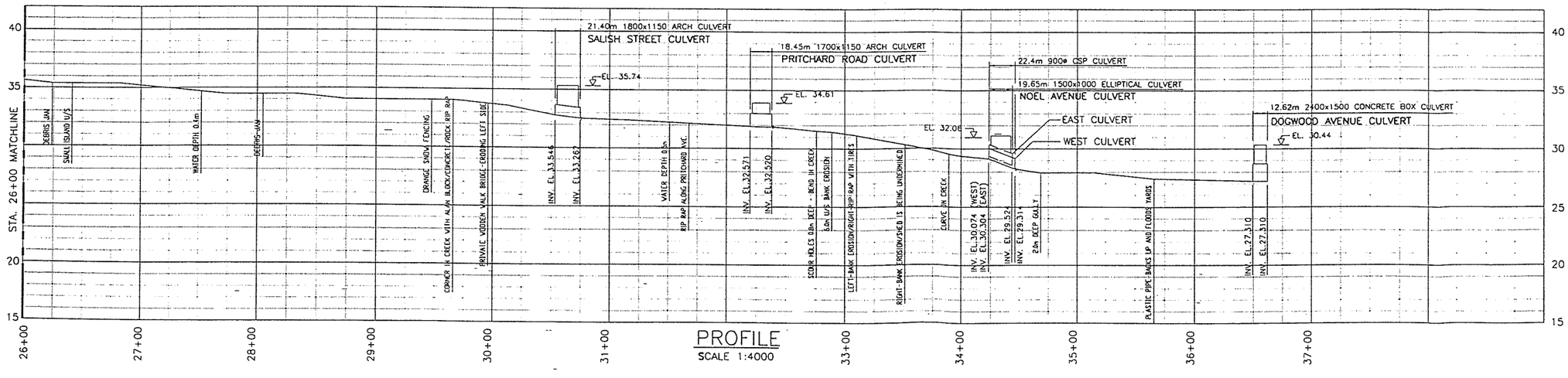
BROOKLYN CREEK MASTER DRAINAGE PLAN

WATERSHED PLAN

DRAWING NUMBER	REV. NO.	SHEET
982879-1-100		







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BROOKLYN CREEK MASTER DRAINAGE PLAN

CREEK PROFILE WITH EXISTING FEATURES

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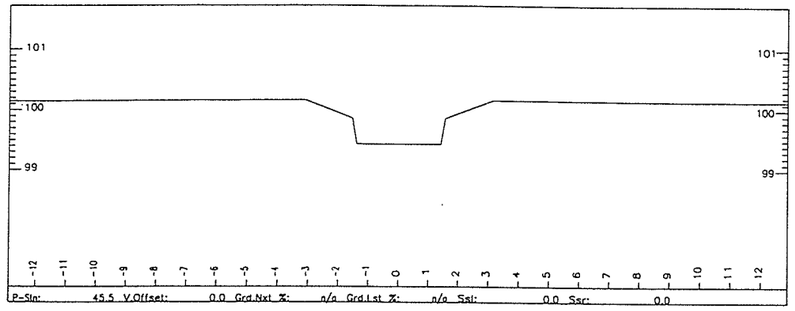

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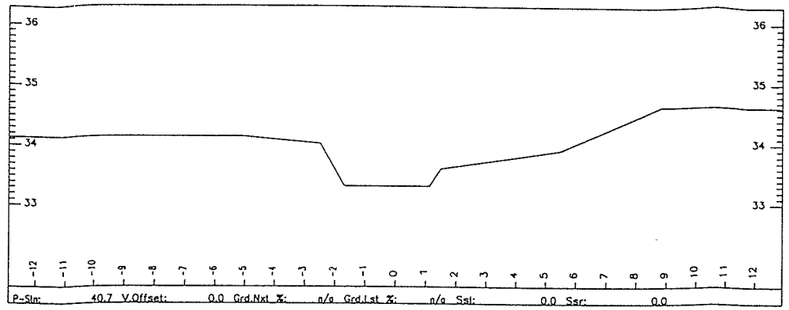

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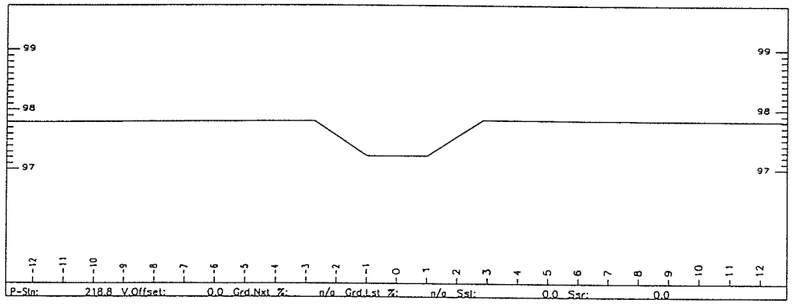

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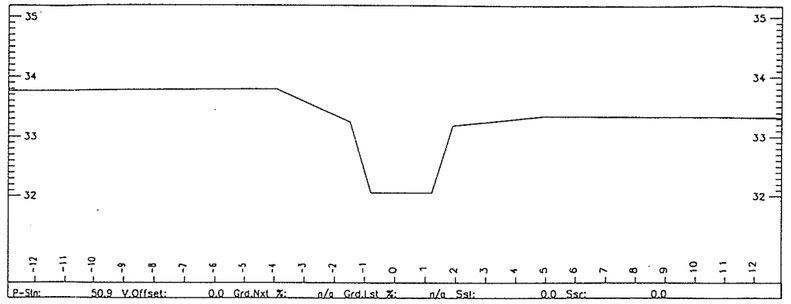

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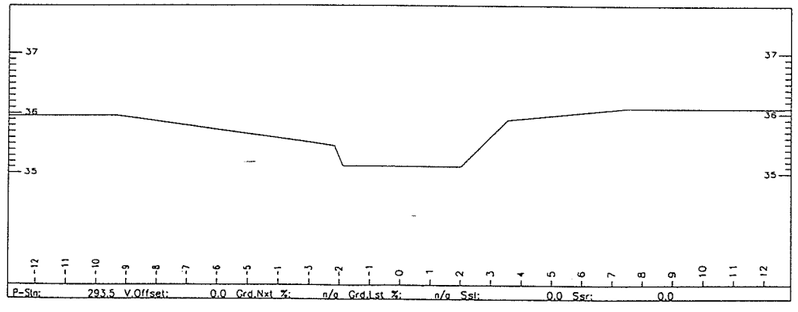

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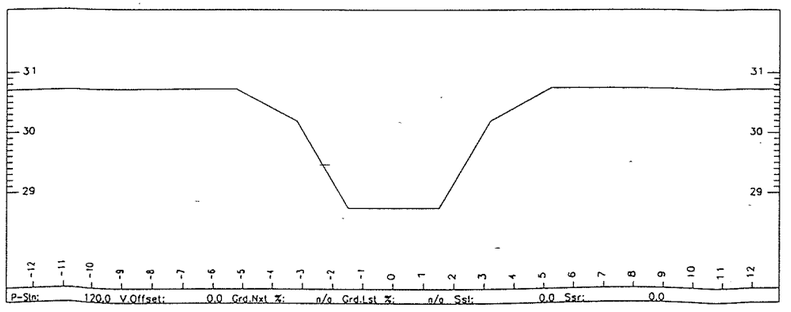

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FROM NOEL AVENUE CULVERT

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BROOKLYN CREEK
MASTER DRAINAGE PLAN

CROSS SECTIONS

DRAWING NUMBER	REV. NO.	SHEET
982879-1-102		

PROJECT ISSUES

SECTION 2

2.1 DRAINAGE CONCERNS

In 1991, Koers & Associates Engineering Ltd. designed a storm water management plan to limit the 100-year return period peak outflows from the Crown Isle site to approximately 60% of estimated pre-development flows. The report titled "Crown Isle Development Drainage Report" implemented on-site detention ponds and an outlet control structure to reduce outflow to a maximum of 0.75 m^3/s. This peak flow limit includes a contribution from the North Island College. In comparison, Koers & Associates estimated the peak pre-development flow for the 100-year return period storm at 1.2 m^3/s using anecdotal information and the rational method. Rainfall data from 1962 to 1989 was used for this analysis.

Currently, Crown Isle is only 12% developed and, according to a 1992 letter from Koers & Associates, construction of the permanent flow control structures and enlargement of the final detention pond are complete. All runoff from the development is contained within the bounds of the Crown Isle sub-catchment and released at the control structure located at the outfall of the last detention pond. However, property owners along Brooklyn Creek have reported a marked increase in creek flow and overland flooding since the start of development in 1991. This observation may not be due to inadequate storm water controls but a result of coincidentally higher rainfall storms in recent years.

A 900 mm x 400 mm rectangular weir/orifice at the outlet of the final pond controls the discharge from Crown Isle to approximately the design limit of 0.75 m^3/s for a 100-year return period storm. There is a possibility of flow exceeding this limit during high rainfall events as the flow can overtop the weir structure. In order to verify the amount of flow discharged from Crown Isle, flow monitoring is recommended. Since the design of the Crown Isle storm water management system is designed to limit flow to 0.75 m^3/s, we have assumed the weir does not overtop for all modelled events.

Longlands Par 3 Golf Course discharges into Brooklyn Creek at the north end of Parry Place. Recent expansions and renovations at this golf course have lead local residents to believe that it may also be contributing to an increase in creek flow. We understand that a pond located in this golf course was recently filled. We are unaware of any drainage control structures for this area and have modelled this golf course without any detention ponds or flow control structures.

Birkdale Farms is located north of Guthrie Road and east of Anderton Road. The owner of the farm has noticed an increase in the level, frequency, and duration of flooding on his property. Adjacent to Birkdale Farms on the eastern boundary is the Highwood development, a recently constructed 33 ha residential subdivision. A detention pond was designed and constructed to attenuate peak flows from this development. However, the owner of Birkdale Farms has observed an increase in ponding on his field since the construction of the subdivision.

Field ponding at Birkdale Farms may not be solely due to development in the upper watershed. Discharge from the farm into lower Brooklyn Creek is controlled by the culvert crossing at Guthrie Road. The hydraulic capacity of this culvert and the downstream channel can affect flooding on Birkdale Farms. Flow restrictions or an undersized culvert can result in an increase in level, frequency, and duration of flooding.

Town of Comox drainage staff acknowledge that the Guthrie Road culvert may be undersized for the amount of flow carried by Brooklyn Creek. However, upgrading this culvert alone may only transfer flooding problems downstream. At present, flooding is a concern along the creek from Guthrie Road to Dogwood Avenue. Culvert crossings at Salish Street and Pritchard Road are often nearly overtopped during high flow storm events.

Culverts at Noel Avenue and Dogwood Avenue have had no recent flooding complaints. The Noel Avenue culvert is contained in a ravine and the Dogwood Avenue crossing was replaced last year with a large concrete box culvert. The upgraded Dogwood Avenue culvert was designed for a 100-year return period storm. Downstream of Dogwood Avenue, Brooklyn Creek soon enters a ravine where flooding is not a major concern.

2.2 EROSION AND SEDIMENTATION CONCERNS

Erosion is a common problem along Brooklyn Creek. Many sections with undermined banks and unstable slopes were identified during our site investigation, particularly between Guthrie Road and Noel Avenue. Attempts at bank stabilization using riprap, Allan block, and even old tires are evident upstream of Salish Street and downstream of Pritchard Road. Some of these efforts on private land have encroached on the channel possibly causing increased backwater effects and increased stream velocities. Creek setback requirements as specified in the Department of Fisheries & Oceans and the

Ministry of Environment, Lands and Parks "Land Development Guidelines for the Protection of Aquatic Habitat", 1992 should be enforced.

Sedimentation and debris are a main concern between Guthrie Road and Salish Street. Immediately downstream of the Guthrie Road culvert is a scour hole approximately 0.5 m deep followed by a gravel bar. From this point, Brooklyn Creek travels through a tangle of debris consisting mostly of branches and vegetation. It appears the channel is not regularly maintained in this area and is susceptible to "choking".

A number of municipal storm water outfalls enter Brooklyn Creek between Guthrie Road and Mack Laing Park. Where outfalls enter the creek, armoring should be provided to prevent scour of the embankments. The outfall elevations and potential for upstream flooding are being evaluated under a separate storm drainage study being completed by Koers and Associates.

2.3 INCREASED URBANIZATION OF THE WATERSHED

Two primary reasons may be responsible for increased flooding on Brooklyn Creek:

- Increased runoff volumes due to upland development.
- Reduced channel capacity due to sedimentation, vegetative growth, and channel encroachments.

Prior to the present state of the area all of Comox, Courtenay, and the Regional District were either undeveloped forested land or cleared lots used for agricultural purposes. By reducing the amount of trees and vegetative growth, interception is decreased and the rate of infiltration into the groundwater system is reduced. Deforestation contributes to an increase in runoff and sedimentation into Brooklyn Creek. The development of farm and rural lots also reduces depression storage and results in an increase in ditches and general channelization of the land. These open channels collect overland flow and increase the rate of discharge into Brooklyn Creek.

Surface soils in much of the watershed are primarily poorly drained and highly erodible silts or silty sand. In the vicinity of Birkdale Farms rich organic soils are present and a deposit of sands and fine gravels exists in the adjacent Highwood development, north of Guthrie Road. The silts allow surface water to penetrate slowly and promote surface pooling and sheet flow runoff in low relief areas. Removal of forest cover and the long

history of agricultural use adds to the fine texture and slow drainage qualities of these soils. The use of drain tiles on agricultural land increases the volume and rate of runoff entering the creek system. Soils become compacted when no longer used for farming which is partly due to the loss of porous organic humus material. The surface soil layers are underlain by clay or clay/glacial till, often within 20-30 cm from the surface and streambed. This material erodes slowly and is essentially impermeable to water, confining rainfall penetration to the shallow surface soil layers.

As the Comox Valley grows in population, so does the amount of urbanization in the area. A larger population requires more roads, houses, schools, and commercial areas. With this increase in development, the amount of impervious surfaces in the watershed will rise leading to an increase in surface runoff. Ground infiltration and depression storage will further decrease and direct discharge into Brooklyn Creek will continue to rise leading to an increase in flooding, erosion, and sedimentation.

Therefore without implementing basin wide storm water management techniques, the gradual growth in population and land development will cause flooding and other drainage concerns in the Brooklyn Creek watershed to worsen. No one residential or commercial development can be identified as the cause of the present storm water problems in the watershed. Rather, incremental changes have lead to a gradual increase in flood and erosion concerns. Ironically, it is the larger developments which have the on-site ability to control runoff that can have the largest positive impact on the drainage concerns. Implementing small scale storm water management techniques for individual lots must be reviewed in the context of the entire watershed. It is preferable to develop larger community-based solutions to address the issue of storm water management.

HYDROLOGIC AND HYDRAULIC MODELLING

SECTION 3

3.1 COMPUTER MODELLING

XP-SWMM 2.20 was used to model the Brooklyn Creek watershed. The watershed was divided into sub-catchments and hydrologic data such as area, overland slope, and percent impervious were measured or estimated for each sub-catchment. In the Town of Comox, sub-catchments were delineated according to the existing municipal storm water network. Each network outfall entering the creek corresponds to one sub-catchment. Outside the Town, sub-catchments were determined by observed flow patterns and from topographic maps.

Drawings nos. 982879-1-103A to C show the delineated catchment plan for the Brooklyn Creek watershed. Each catchment is identified with a name, land use zone, and area in hectares. Drawing no. 982879-1-104 is a schematic of the XP-SWMM network plan with arrows indicating input locations for runoff.

3.2 RAINFALL DATA

The design storms used to model the Brooklyn Creek watershed are composite five-day duration storms for the 5, 10, and 100 year return periods. Each design storm is composed of the maximum rainfall intensities for storm durations ranging from 30 minutes to 24 hours and the maximum daily intensities from 2 to 5 days. This synthetic storm includes all storm durations up to 5 days and ensures that the storm duration is appropriate for the time of concentration for each sub-catchment.

To assemble these design storms, the 1997 Intensity-Duration-Frequency curves and long duration storm analysis data were used from the Atmosphere and Environment Services rainfall gauge station at Comox Airport. Figures 1 through 3 illustrate the hyetograph for the 5, 10, and 100 year return period design storms.

In addition to the 3 design storms, rainfall data from the November 24, 1998 storm was also used. This storm was primarily applied towards calibration of the model using anecdotal information. The November 24 storm exceeded the 100-year return period for durations of 2 hours and greater and is shown on Figure 4. Appendix A contains all the rainfall data used to construct the 3 design storms and the November 24, 1998 storm.

3.3 WATERSHED CHARACTERISTICS AND HYDROLOGIC PARAMETERS

An initial depth of 0.2 m was applied to the main channel of Brooklyn Creek from Comox Harbour to Parry Place. Base flows were estimated from the flow gauge on the Little River at Wilkinson Road. Little River has a drainage area of 19.3 km^2 and a minimum monthly flow between October and January is 0.085 m^3/s. In comparison, the drainage area of Brooklyn Creek is 6.7 km^2. To estimate the base flow value in Brooklyn Creek, the flow per unit area from Little River is applied to Brooklyn Creek. Therefore, the base flow for Brooklyn Creek is approximately 0.03 m^3/s. This flow was distributed over the watershed at various points.

For a given catchment, the percent of impervious area is a function of the land usage. Table 3.1 summarizes the values of percent impervious for the various land use zones in the Brooklyn Creek watershed.

Table 3.1

Land Use	Percent Impervious	Land Use	Percent Impervious
Farm	20 - 30%	Undeveloped, cleared	20%
Residential	50%	School with field	30%
Commercial	90%	Apartment	90%
Park	20%	Forested	10%

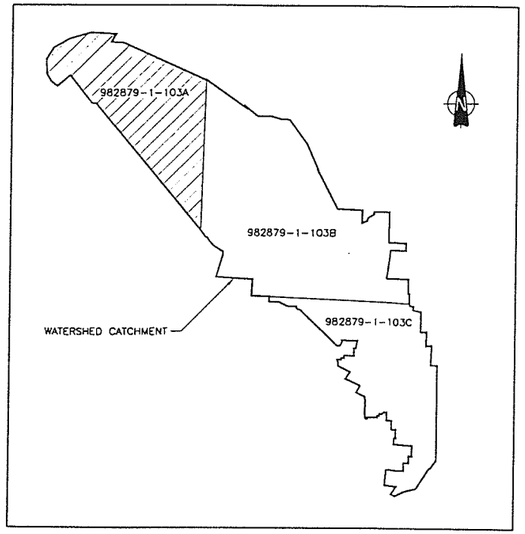
3.4 MODEL CALIBRATION

Since there is no flow monitoring on Brooklyn Creek, calibration of the SWMM model is limited to using anecdotal information. The model results of the November 24, 1998 rainstorm were compared against areas with observed flooding, over bank flow, or surcharge culverts. The following anecdotal information was observed by Town staff or residents during the November 24, 1998 storm:

- Upstream water level at Pritchard Road culvert was lapping at roadside.
- Flow at the Salish Street culvert almost overtopped the road.
- Substantial portion of the front yard at 2016 Idiens Way was flooded.

- High water mark at Anderton Road culvert indicated a submerged inlet.
- At the Dogwood Avenue culvert, approximately 10 cm of freeboard was available from the top of the headwall.
- Storm sewer outfall backing up at Elm Place.
- High water levels in creek channels throughout.

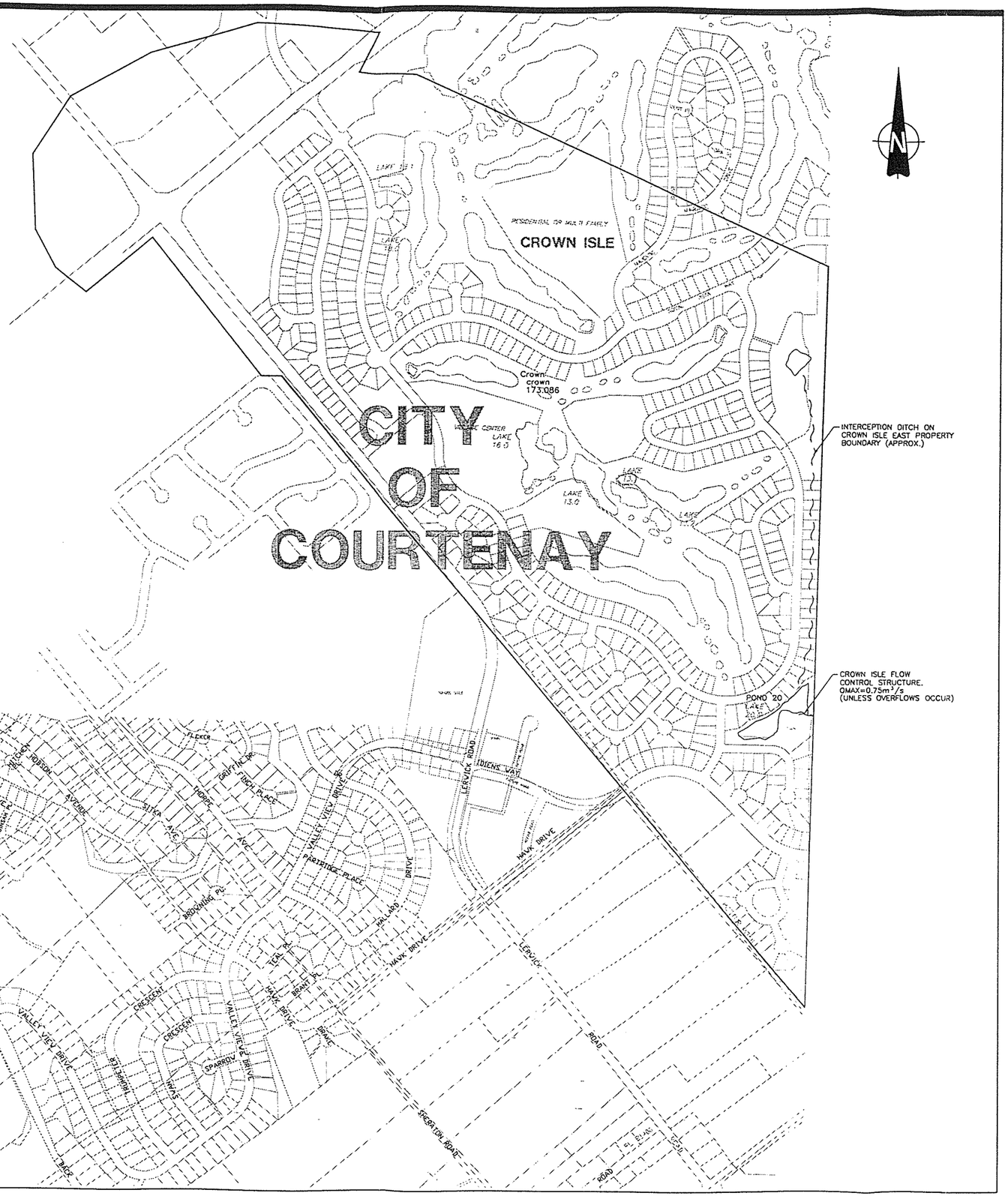
We adjusted the roughness coefficients and other channel properties in our model to emulate the anecdotal data of the November 24, 1998 storm. However, some of the backwater and flooding observations may be due to debris blockages on the channel or at culvert inlets. These conditions are not represented in the model.



KEY PLAN
N.T.S.

LEGEND

CATCHMENT NAME
LAND USE
AREA (ha)



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BROOKLYN CREEK MASTER DRAINAGE PLAN

CATCHMENT PLAN

DRAWING NUMBER	REV. NO.	SHEET
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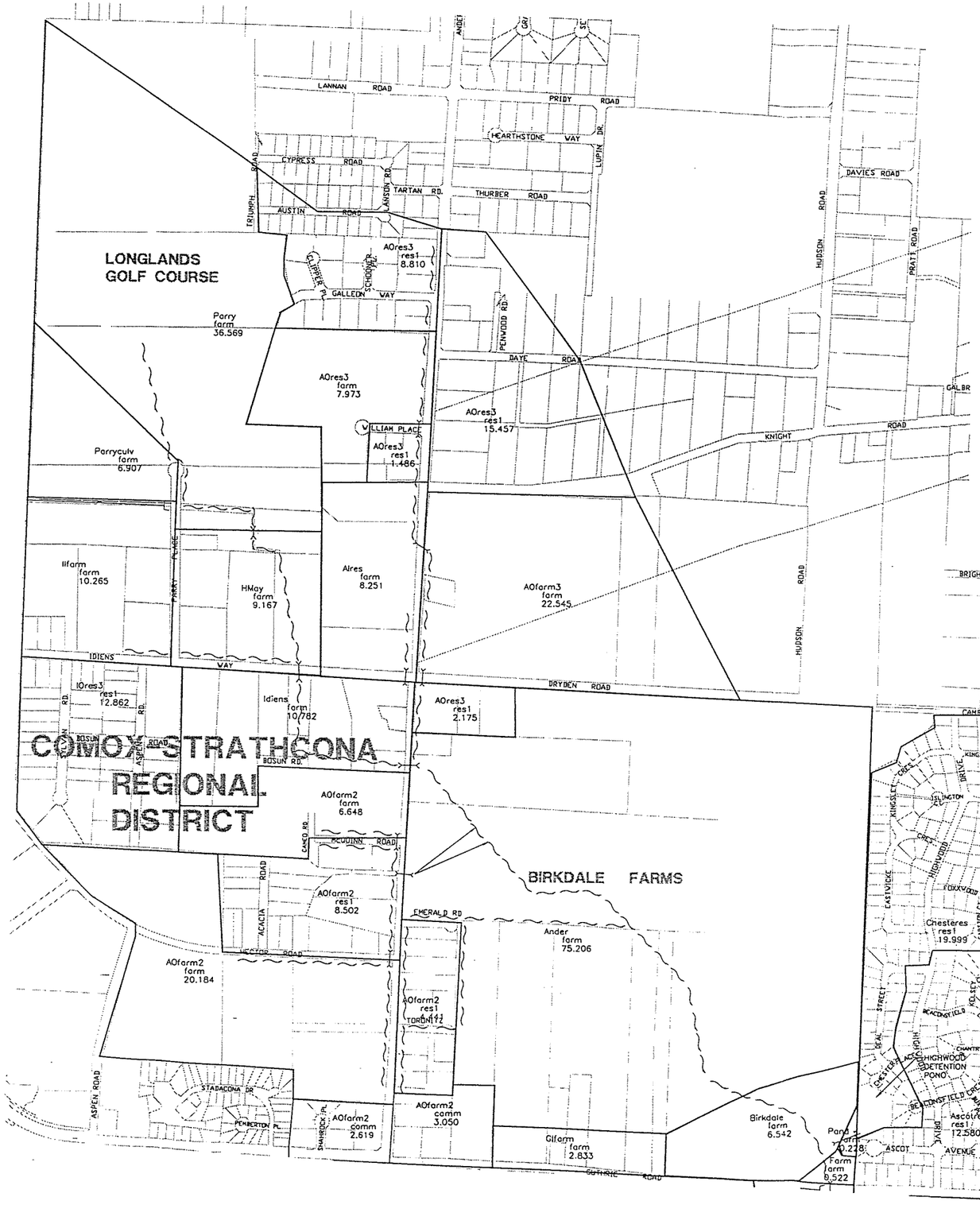

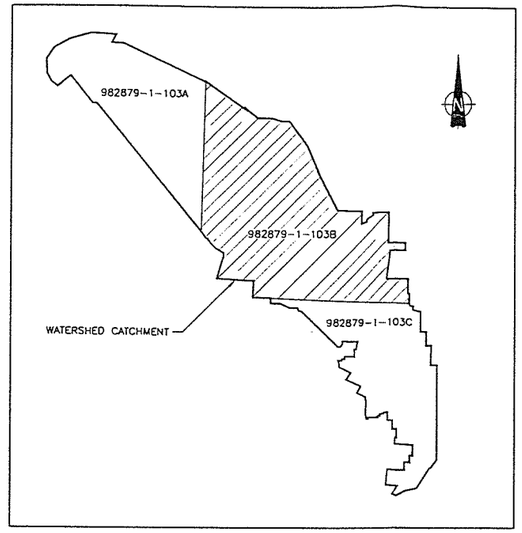

KEY PLAN
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LEGEND

CATCHMENT NAME
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AREA (ha)

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REVISIONS

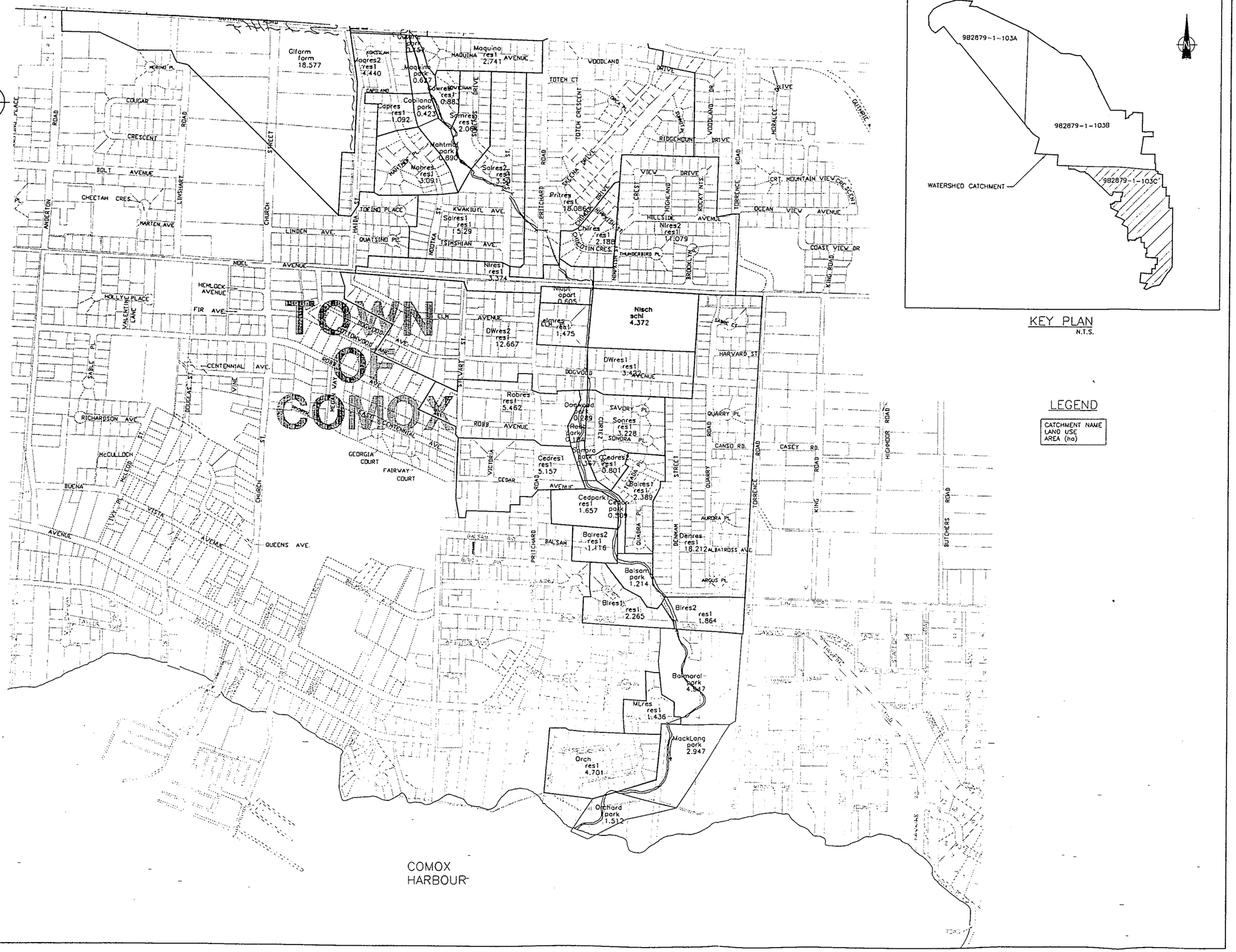
PROJECT NO.	982879
SCALE	1:10,000
DRAWN	R.L.
DESIGNED	J.L.
CHECKED	
APPROVED	
APPROVED	
DATE	MARCH 1999

ASSOCIATED ENGINEERING

BROOKLYN CREEK MASTER DRAINAGE PLAN

CATCHMENT PLAN

DRAWING NUMBER	REV. NO.	SHEET
982879-1-103B		



KEY PLAN
N.T.S.

LEGEND

CATCHMENT NAME
LAND USE
AREA (ha)

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REVISIONS

PROJECT NO.	982879
SCALE	1:10,000
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DESIGNED	J.L.
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APPROVED	
APPROVED	
DATE	MARCH 1999

ASSOCIATED ENGINEERING

BROOKLYN CREEK
MASTER DRAINAGE PLAN

CATCHMENT PLAN

DRAWING NUMBER	REV. NO.	SHEET
982879-1-103C		

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APPROVED	
DATE	MARCH 1999

ASSOCIATED ENGINEERING

BROOKLYN CREEK MASTER DRAINAGE PLAN

NETWORK PLAN

DRAWING NUMBER	REV. NO.	SHEET
982879-1-104		

5 Year Return Period Design Storm
5 Day Duration

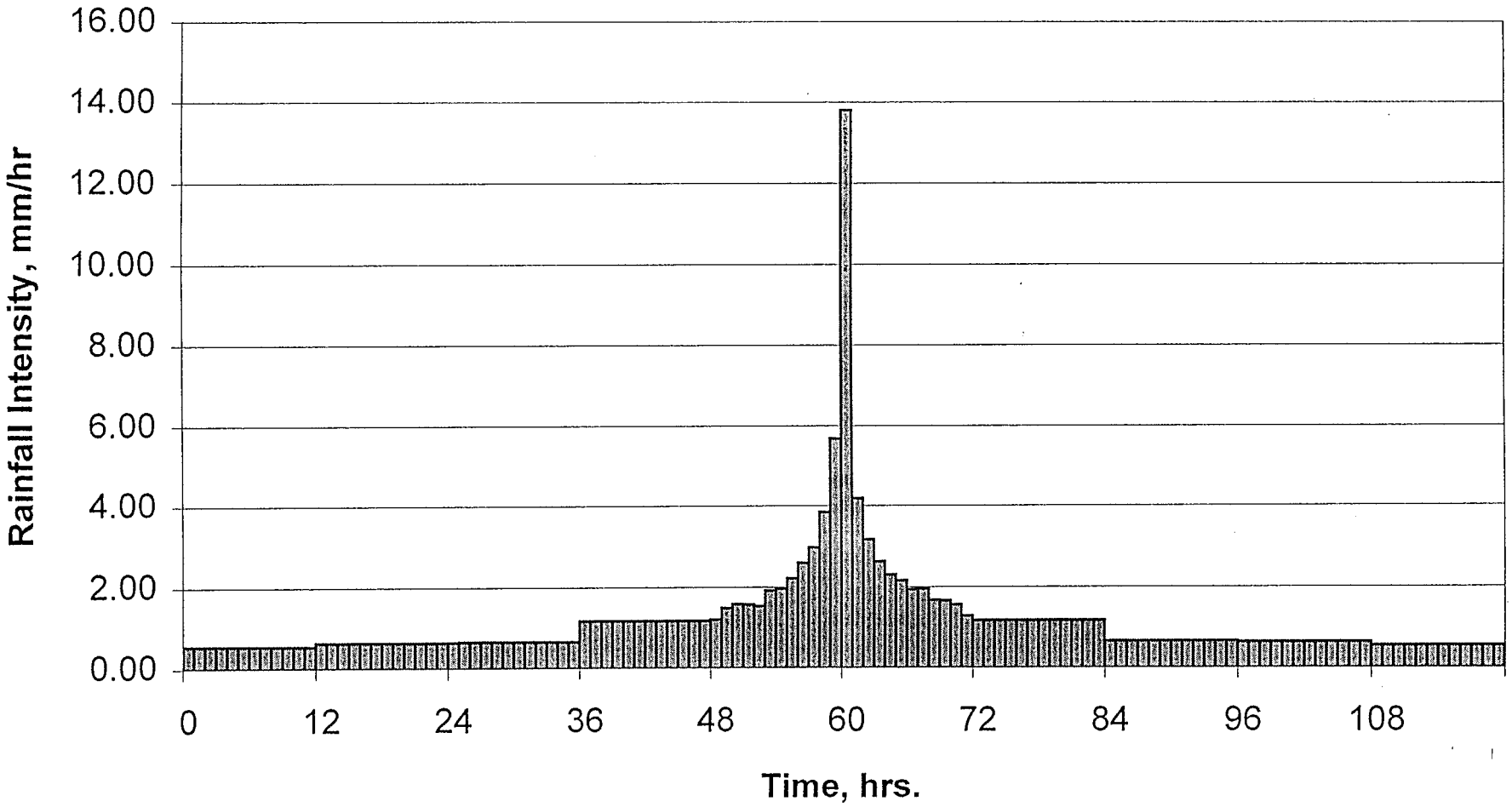


Figure 1

10 Year Return Period Storm
5 Day Duration

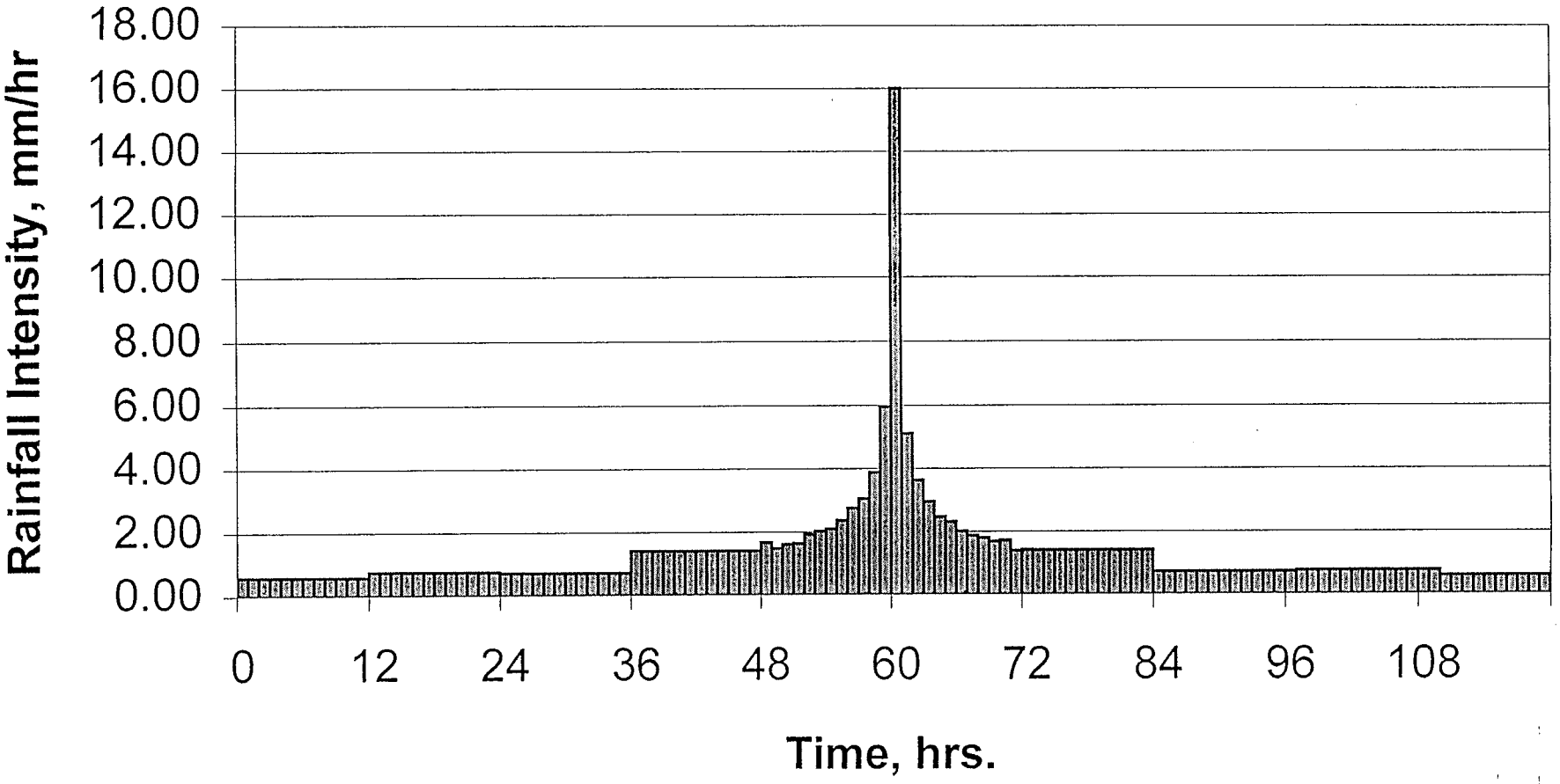


Figure 2

100 Year Return Period Design Storm
5 Day Duration

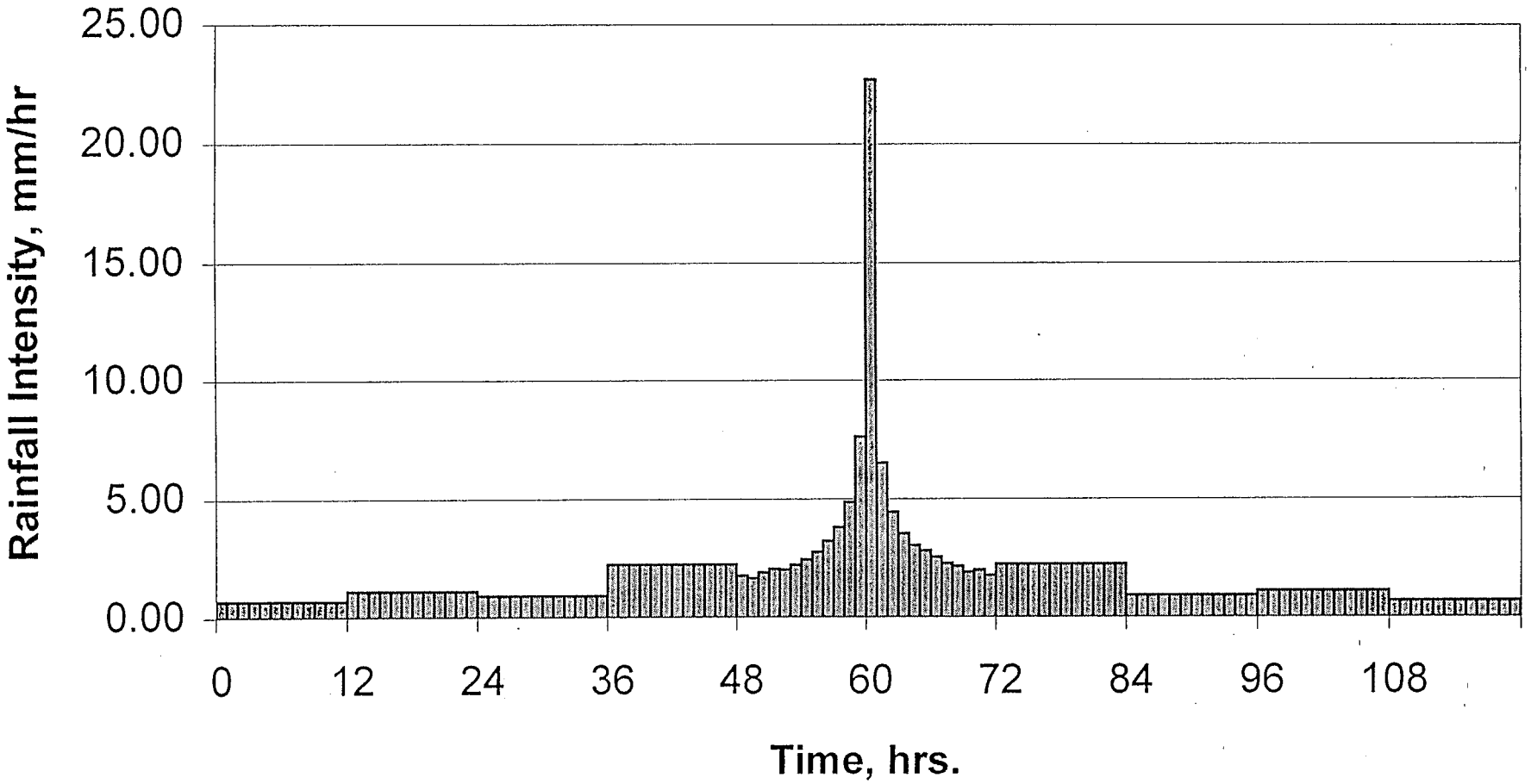


Figure 3

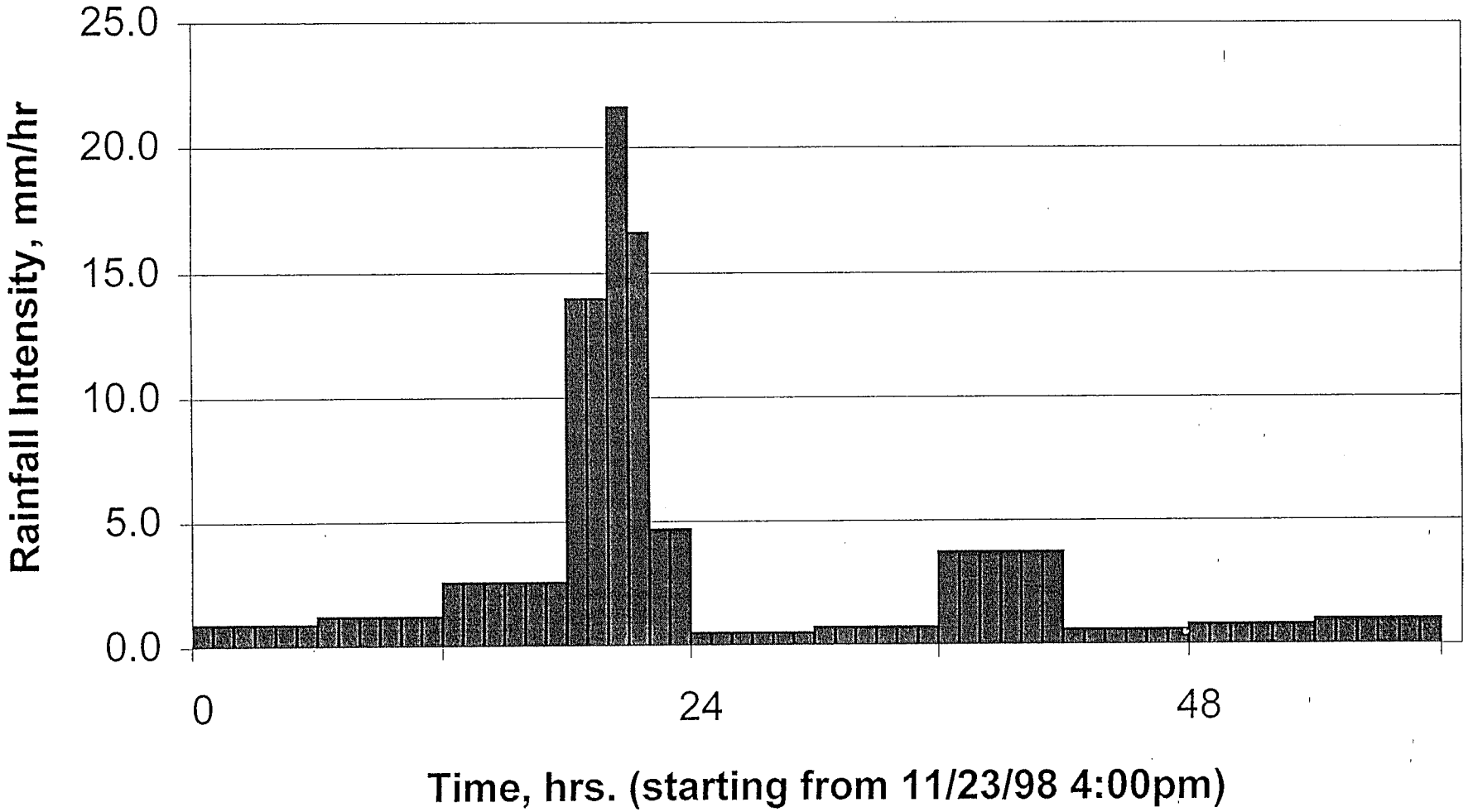

November 1998 Storm
Rainfall Intensity, mm/hr
25.0
20.0
15.0
10.0
5.0
0.0
0
24
48
Time, hrs. (starting from 11/23/98 4:00pm)

Figure 4

PRE-DEVELOPMENT CONDITION AND DRAINAGE SYSTEM ANALYSIS

SECTION 4

4.1 PRE-DEVELOPMENT CONDITION AND DRAINAGE NETWORK

The pre-development condition assumes zero development in the watershed. A percent impervious of 10% is used to represent undeveloped areas and is applied to the entire Brooklyn Creek catchment with an infiltration rate similar to sparsely forested areas. Control structures at Crown Isle and the detention pond east of Birkdale Farms are non-existent in this model condition. However, the existing drainage network of channels and culverts is used to convey the flow so that flood levels at specific locations can be compared. Thus, the pre-development condition is a hypothetical construct of the hydraulic model used as a standard baseline for comparison and approximates historic conditions at an earlier stage of the drainage network.

In the pre-development condition, flooding and submerged culverts are common for the 5, 10, and 100 year return periods. The following table summarizes the model results. A detailed table of model results is found in Appendix B.

Table 4.1

Location	Return Periods	Flooding
Private 4-600 mm diam crossing	10, 100	overtopped culvert
North of Idiens Way	5, 10, 100	over bank flow
Idiens Way culvert	5, 10, 100	none
West of Anderton Road	100	overbank flow
Anderton Road culvert	5, 10, 100	slightly submerged inlet
Ponding in Birkdale Farms	5, 10, 100	field ponding: • 10 hrs. (5) • 12 hrs. (10,100)
Guthrie Road culvert	5, 10, 100	submerged inlet
Downstream of Guthrie Road	5, 10, 100	over bank flow
Salish Street culvert	5, 10, 100	submerged inlet

Location	Return Periods	Flooding
Between Salish and Pritchard	100	over bank flow
Pritchard Road culvert	5, 10, 100	submerged inlet
Noel Avenue culvert:		
900 mm diam	5, 10, 100	submerged inlet
1500 x 1000 mm ellipse	5, 10, 100	no submergence

As a further comparison to historical water levels, a uniform slope was applied to the channel from the Guthrie Road culvert outlet to the Salish Street culvert inlet. This artificial profile is an approximation of the dredged channel condition that existed following development of the agricultural areas. At present, the channel profile in this area is initially flat for approximately 100 m downstream of Guthrie Road and then gradually steepens in slope until it reaches the Salish Street culvert. The application of the uniform historical slope lowers the flood elevation immediately downstream of the Guthrie Road culvert when compared to results with the present day existing slope. Flood durations on Birkdale Farms remain unchanged while flood elevations on the farm decrease insignificantly. Flooding characteristics are not significantly improved elsewhere along the creek when the historical channel slope is applied.

EXISTING DEVELOPMENT CONDITION AND DRAINAGE SYSTEM ANALYSIS

SECTION 5

5.1 EXISTING DEVELOPMENT CONDITION

The existing development condition is based on present day development in the Brooklyn Creek catchment combined with the existing drainage system. This includes storage and control structures at Crown Isle and the Highwood detention pond. It is assumed that the control structure limiting outflow from Crown Isle to 0.75 m^3/s is operating as specified. This implies that the control weir is not overtopped during the 100-year return period storm. The orifice of the control structure is a 900 mm by 400 mm rectangular opening on a concrete wall. However, the concrete wall could be overtopped during a storm that greatly exceeds the 100-year return period.

Most of the sub-catchments discharging into Brooklyn Creek from the Town of Comox are residential areas with a few school sites. The easement along the creek from Comox Harbour to Dogwood Avenue and from Salish Street to Guthrie Road is zoned for park usage. Within the Regional District, most of the sub-catchments are modelled as low-density residential and agricultural use.

Overall, changing the land use to existing development and introducing the existing flow controls did not greatly increase the flood elevation and depth of flow along Brooklyn Creek. If the control structure at Crown Isle is operating as designed, there is less flow entering the creek from this area than compared to pre-development levels. However, flood durations increase due to the overall increase in development of the watershed and the subsequent increase in runoff volume. Table 5.1 summarizes the results from the model and detailed numerical results are included in Appendix B.

Table 5.1

Location	Return Periods	Flooding
Private 4-600 mm diam crossing	5, 10, 100	submerged inlet
North of Idiens Way	100	over bank flow
Idiens Way culvert	5, 10, 100	none
West of Anderton Road	100	over bank flow

Location	Return Periods	Flooding
Anderton Road culvert	5, 10, 100	submerged inlet
Pond east of Birkdale Farms	5, 10, 100	over bank flow
Ponding in Birkdale Farms	5, 10, 100	field ponding: 14 hrs. (5) 18 hrs. (10) 30 hrs. (100)
Guthrie Road culvert	5, 10, 100	submerged inlet
Downstream of Guthrie Road	5, 10, 100	over bank flow
Salish Street culvert	5, 10, 100	submerged inlet
Between Salish and Pritchard	100	over bank flow
Pritchard Road culvert	5, 10, 100	submerged inlet
Noel Avenue culvert: • 900 mm dia. • 1500 x 1000 mm ellipse	 5, 10, 100 5, 10, 100	 submerged inlet no submergence

A recent spot survey of Birkdale Farms was performed to determine the amount of freeboard available during winter base flow conditions. To ensure adequate drainage of agricultural areas, the minimum freeboard required is 1.2 m. The lowest field elevation surveyed was 37.11 m at the south side of the Highwood pond. Base flow in the creek has a water surface elevation of 36.59 m. Therefore, only 0.52 m freeboard is provided. It should be noted that the area of the farm with regular field ponding has an elevation of 37.98 m and is above the 1.2 m freeboard requirement. The surveyed low point of 37.11 m was dry when ponding was observed at the location of 37.98 m. Figure 5 shows the location where the base flow elevation was taken and the areas where the minimum freeboard is not achieved. The total area with less than the 1.2 m freeboard is approximately 0.3 ha. This is about 0.5% of the total farm area. The following table summarizes the approximate duration of flooding that occurs using the five day design storm and measured as the duration required to return to a base flow condition on the creek.

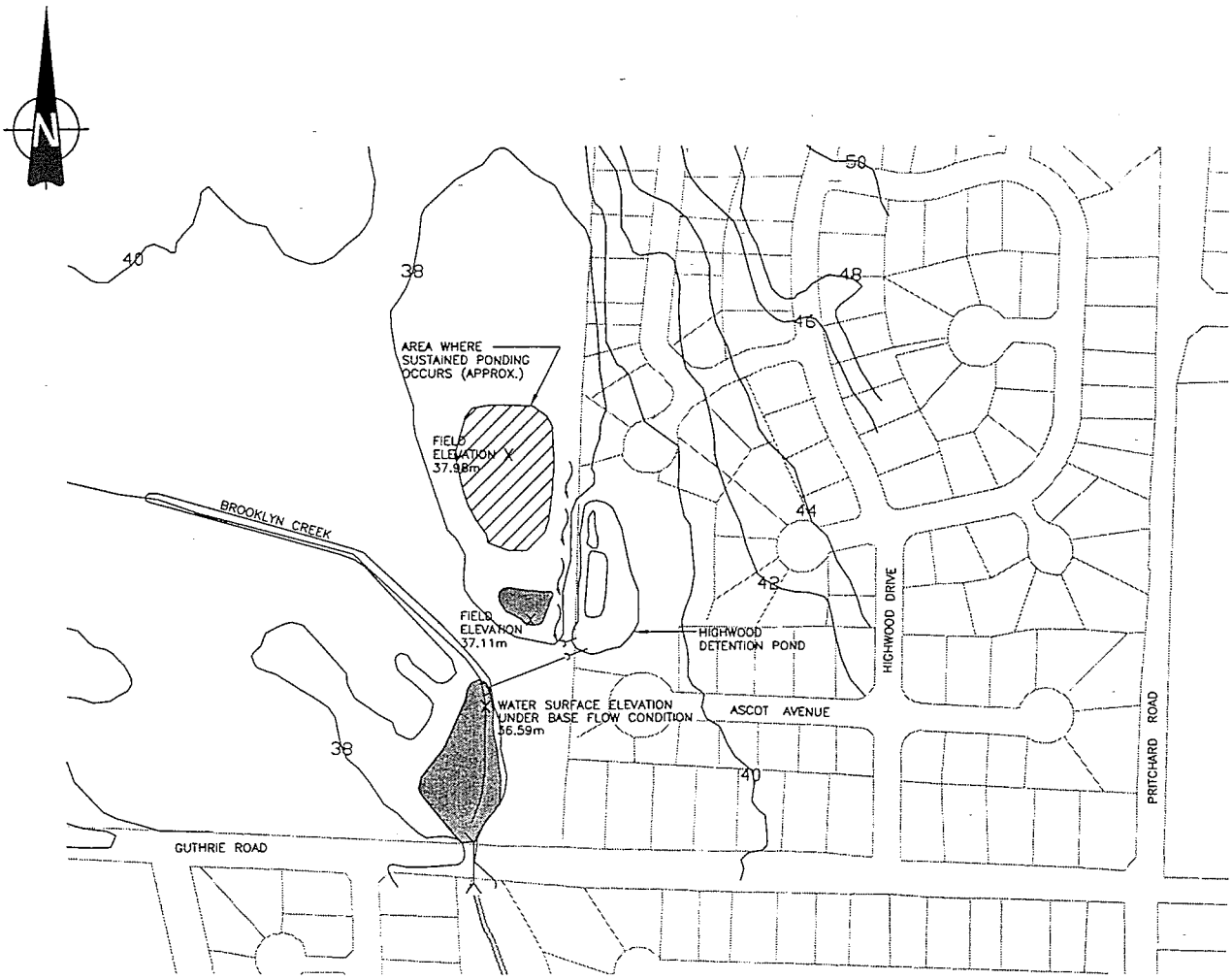
Return Period	Approximate Duration
5 year	2 days
10 year	3 days
100 year	3.5 days

The necessary freeboard can be achieved by either filling low-lying areas or lowering the channel invert through Birkdale Farms, the Guthrie Road culvert, and downstream of the Guthrie Road culvert by approximately 0.68 m. Filling low-lying areas is preferred as lowering the channel invert would have significant environmental impacts. However, this solution will cause increased flood levels on Birkdale Farms. Therefore, a relaxation of the required 1.2 m of freeboard should be pursued in this area with the Agricultural Land Commission.

An area of Birkdale Farms experiences extended surface ponding following a substantial rainfall. This area of localized flooding is not hydraulically connected to Brooklyn Creek. We advise that the landowner improve local drainage by ensuring the sub-drainage system is functioning properly.

Another area of concern is the Longlands Golf Course. Runoff from this golf course is suspected to contribute to the increased incidents of flooding problems on Brooklyn Creek. Since the golf course is privately owned, discussions and planning with the landowner is required to implement storm water management techniques. For comparative purposes, the following table summarizes the runoff from the Longlands Golf Course and the Crown Isle development under existing conditions for various storm events. Flow control or storage has not been incorporated in the storm runoff from the Longlands Golf Course.

Storm Return Period/ Storm Event	Longlands Golf Course Flow, m^3/s	Crown Isle Development Flow, m^3/s
10 year	0.20	0.60
100 year	0.34	0.75
Nov./98 storm	0.35	Unknown



LEGEND

APPROXIMATE FIELD AREA WITH LESS THAN 1.2m FREEBOARD DURING WINTER BASE FLDWS.

AUTOCAD DRAWING No.

DESIGN: J.L.	
CHECK:	
DRAWN: R.L.	
DATE: JULY 1999	
SCALE: 1:4000	
JOB No. 982879	
DWG. No. FIGURE 5	△

BROOKLYN CREEK MASTER DRAINAGE PLAN

FIELD SPOT ELEVATIONS ON BIRKDALE FARMS

ASSOCIATED ENGINEERING

FUTURE DEVELOPMENT CONDITION AND DRAINAGE SYSTEM ANALYSIS

SECTION 6

6.1 FUTURE DEVELOPMENT CONDITION

To determine future land use, the Official Community Plans for the Town of Comox and the City of Courtenay, and the Anderton Road Local Area Plan from the Regional District of Comox-Strathcona were used. In general, development in the watershed within Comox and Courtenay will not significantly increase. The Town of Comox plans to develop a 3 ha commercial area at the northeast corner of Guthrie Road and Anderton Road. Also, an area south of Guthrie Road and west of Brooklyn Creek is zoned for comprehensive development.

A significant increase in residential development is proposed for the watershed within the Regional District. West of Anderton Road and south of Hector Road is zoned for residential development on 0.5 acre lots. The rest of the catchment area, outside of the Agricultural Land Reserve, is zoned for residential development on 1 acre lots.

The flow increase due to future development conditions when compared to existing development conditions is mostly due to the increase in urban development in the Regional District. The future development condition assumes no storm water management controls are implemented within the Regional District and that the Crown Isle Development is completed with a properly functioning discharge control system. Table 6.1 summarizes the results from the model and detailed numerical results are included in Appendix B.

Table 6.1

Location	Return Period	Flooding
Private 4-600 mm diam crossing	5, 10, 100	submerged inlet over topped culvert (100)
North of Idiens Way	10, 100	over bank flow
Idiens Way culvert	5, 10, 100	none
West of Anderton Road	100	over bank flow
Anderton Road culvert	5, 10, 100	submerged inlet

Location	Return Period	Flooding
Pond east of Birkdale Farms	5, 10, 100	over bank flow
Ponding in Birkdale Farms	5, 10, 100	field ponding: 18 hrs. (5) 24 hrs. (10) 30 hrs. (100)
Guthrie Road culvert	5, 10, 100	submerged inlet
Downstream of Guthrie Road	5, 10, 100	over bank flow
Salish Street culvert	5, 10, 100	submerged inlet
Between Salish and Pritchard	10, 100	over bank flow
Pritchard Road culvert	5, 10, 100	submerged inlet
Noel Avenue culvert: • 900 mm dia. • 1500 x 1000 mm ellipse	 5, 10, 100 5, 10, 100	 submerged inlet no submergence

FUTURE DEVELOPMENT CONDITION AND DRAINAGE SYSTEM IMPROVEMENT ALTERNATIVES

SECTION 7

Drawing no. 982879-1-105 is a deficiency plan identifying areas of head loss and flooding as indicated by our model results of the existing and future conditions. Observed drainage deficiencies from our site investigation are also shown on this drawing. This includes erosion, over bank flow, and flooding.

7.1 EROSION AND SEDIMENTATION CONTROL

Increased runoff due to development will continue to destabilize the creek channels and cause ongoing erosion and sedimentation problems. At present, bank erosion is a common problem along Brooklyn Creek particularly from Guthrie Road to the Mack Laing Park.

Possible mitigation measures for channel bank erosion would include armouring the channel banks with vegetation, native rock/boulders, riprap, gabion baskets, live crib walls, brush layering, log revetments, or a combination of the previous. Due to limited ravine access and the presence of natural materials, such as large woody debris and cobbles, the mitigative measures should utilize these materials wherever possible. Not only do these materials keep costs down, they provide bank protection in a manner which is consistent with the habitat values of the surrounding area. Constructing tree revetments, sufficiently anchored with log tie backs, steel cables, large boulders, or gabion baskets can provide effective creek bank protection. Rock armouring and log protection interspersed with vegetation can enhance the environmental value of the stream and provide a natural looking solution. Well-established vegetation on the channel bank will further prevent erosion and enhance the riparian habitat of the channel.

Possible mitigation measures for unstable ravine slopes downstream of Dogwood Avenue may include cutting back the unstable slope, slope stabilization using vegetation, installing willow shoot pole drains, vegetated cellular grids, live slope grating, or any combination of the previous. Willow shoot pole drains are effective at controlling surface runoff and preventing gully erosion. They convey runoff down the slope like a gutter system, and the bundled willow shoots eventually sprout new growth. This stabilizes the steep slopes by providing drainage and establishing vegetation. Figure 6 shows the approximate locations of erosion concerns downstream of Dogwood Avenue.

7.2 DRAINAGE SYSTEM IMPROVEMENT ALTERNATIVES

The 10-year return period, future development condition was used as the initial design criteria for the generation of drainage improvement alternatives. The results of the following alternative improvement scenarios provide indications towards which combination of improvements and upgrades should be recommended.

7.2.1 Alternative 1: Culvert Upgrades Between Guthrie Road and Noel Avenue

This alternative involves upgrading the existing culverts at Guthrie Road, Salish Street, Pritchard Road, and Noel Avenue with larger circular culverts and flush headwalls and wingwalls. The upgraded culverts are set at the same inverts as the existing structures and flow characteristics of the channel remain unchanged.

The culvert upgrades reduces the duration of field ponding on Birkdale Farms but also increases the amount of flooding downstream of Guthrie Road. Conveyance is improved locally due to the larger culverts, resulting in lower flow depths and decreased head losses through the culverts. However, the overall flow movement along Brooklyn Creek is limited by debris blockages and an irregular channel profile.

By increasing the culvert size at Pritchard Road, flow velocity upstream and downstream of the culvert rises from 10% to 25%. Increased channel velocity is a concern as it may result in more channel erosion and bank instability. However, the increase in stream velocity is not excessive and erosion can be mitigated by implementing bank protection.

7.2.2 Alternative 2: Channel Maintenance Between Guthrie Road and Noel Avenue

Alternative 2 consists of improving the conveyance within the main channel of Brooklyn Creek from Guthrie Road to Noel Avenue. Flow impediments such as debris and vegetation are removed from the channel. This removal of flow restrictions includes cleaning all existing debris from downstream of Guthrie Road. From the outlet of the Guthrie Road culvert to about 200 m downstream, there are frequent debris jams and other channel constrictions due to vegetation and sedimentation.

These channel improvements result in an increase in the conveyance capacity of the channel. However, undersized culverts continue to restrict the flow at some crossings. Field ponding on Birkdale Farms remains the same as without any improvements. However, flooding downstream of Guthrie Road is decreased.

By clearing debris and vegetation in the creek, much of the existing natural protection to the channel bed and banks is also removed. As stated earlier, a rise in flow velocity can further an increase in erosion and bank instability. According to our model results, cleaning debris from the channel downstream of Guthrie Road will lead to an increase in stream velocity of up to 25% from existing values.

7.2.3 Alternative 3: Culvert Upgrades and Channel Maintenance Between Guthrie Road and Noel Avenue

Alternative 3 combines both culvert upgrades and channel improvements as discussed in Alternatives 1 and 2. Culvert crossings at Guthrie Road, Salish Street, Pritchard Road, and Noel Avenue are replaced with larger culvert openings and channel debris and restrictions are removed.

This results in much less flooding on Birkdale Farms, both in terms of flood level and duration. In addition, head loss and inlet flow depths at the culverts are decreased. The flood elevation in the channel downstream of Guthrie Road and between Salish Street and Pritchard Road is almost the same as under existing conditions. However, the duration of flooding in these areas has been reduced. Flow velocities along the creek from Guthrie Road to Noel Avenue are increased due to these improvements in channel conveyance.

7.2.4 Alternative 4: Detention Storage Upstream of Guthrie Road

Alternative 4 retains the existing channel characteristics and culvert sizes but incorporates a detention pond on Birkdale Farms. The purpose of this pond is to retain flow volume and reduce the amount of flow entering the creek below Guthrie Road. This pond is immediately upstream of Guthrie Road and is excavated into the field at the elevation of the channel invert. At present, field ponding at Birkdale Farms begins when the channel banks are overtopped. The existing storage is defined by the elevation contours within the field.

Over bank flooding and water depths at culvert inlets are somewhat reduced by establishing a defined detention pond upstream of Guthrie Road. However, the pond required to reduce peak flows downstream of Guthrie Road to a target level of 2.7 m^3/s is approximately 200 m by 200 m. The field beyond the pond remains submerged during periods of high runoff. It appears that since the present Guthrie Road culvert and the elevation contours on the field are effectively retaining a large amount of runoff, the added storage in the pond is of little benefit. For a total pond storage volume of 26,500 m^3, the flood elevation downstream of Guthrie Road and between Salish and Pritchard is only reduced by a few centimetres. Therefore, providing additional detention storage on Birkdale Farms does not result in a substantial reduction in flooding downstream.

Detention storage on Birkdale Farms can have a positive effect on peak flow rates and the potential for erosion. This option would involve removing a portion of Birkdale Farms from the Agricultural Land Reserve. Since acceptable flood levels and durations can be achieved without detention storage in this area, this alternative was not pursued further.

7.3 DRAINAGE SYSTEM IMPROVEMENTS FOR THE REGIONAL DISTRICT OF COMOX-STRATHCONA

According to the Anderton Road Local Area Plan, much of the Brooklyn Creek watershed within the Regional District will be developed into residential areas. Future development is not planned for areas contained within the Agricultural Land Reserve which include Birkdale Farms and the area bounded by Anderton Road, Dryden Road, Knight Road, and Hudson Road.

Drainage system improvements for the Regional District aim to limit runoff flows to pre-development levels. Although detention storage that limits post-development peak flows to pre-development levels can be specified as a condition of development, this approach can lead to a proliferation of detention storage cells. The result is a system that is difficult to manage and maintain. We recommend that the Regional District develop larger, community-based facilities.

There are three main tributaries entering Brooklyn Creek within the Regional District which are described as follows:

- Drainage ditch along the north side of Idiens Way, west of Brooklyn Creek. This tributary services the catchments between Brooklyn Creek, the Crown Isle development property line, and the north end of Parry Place.
- Drainage ditch along the east side of Anderton Road, south of Dryden Road. This ditch collects runoff from catchments north of Dryden Road along Anderton Road.
- Drainage ditches on both sides of Anderton Road, south of McQuinn Road. These ditches collect runoff from catchments on either side of Anderton Road north of Guthrie Road and enter Brooklyn Creek within Birkdale Farms.

To control peak post-development flowrates to pre-development levels before the flow enters Brooklyn Creek, three detention storage sites are required. A field investigation was conducted to identify drainage network patterns and to confirm suitable locations for detention ponds. Therefore, detention storage sites are proposed at the following sites: downstream corner of Parry Place and Idiens Way, corner of Anderton Road and Dryden Road, and Anderton Road between McQuinn Road and Hector Road.

All three storage sites would require approximately 0.2 ha of land and add to the ecological green space of the local area. If they are designed as wet ponds, these storm water facilities provide an enhanced wetland for wildlife. The following table summarizes the basic design requirements for the three detention ponds.

Table 7-5

Base area	225 m^2
Internal side slope	4H:1V
Minimum area required	2000 m^2
Maximum depth	2 m
Total live storage	1250 m^3

A suitable area to locate one of the ponds is along Idiens Way, east of Parry Place where rural-residential lots presently exist. Suitable alternative pond locations to this are downstream of the Idiens Way culvert and at the corner of Parry Place and Idiens Way where a nursery currently owns both lots on the north side. A preferable location for the

second pond is at the northeast corner of Anderton Road and Dryden Road. There is a large vacant lot with only one house on Anderton Road between Knight Road and Dryden Road. However, this property is contained within the Agricultural Land Reserve. The northwest corner is also suitable and is presently occupied as a rural field. A suitable location for the third detention pond is along Anderton Road between McQuinn Road and Hector Road. Two empty lots are located on the west side in this area and are ideally suited for a storage pond. An alternative storage location is the southwest corner of Hector and Anderton where two rural homes are situated on a large forested area.

The Regional District does not have the legislative authority to implement community-based storm water control facilities. To acquire this authority, the Regional District must obtain approval from the Minister of Municipal Affairs. The approval process involves a community referendum. Approval would allow the Regional District to financially support the creation of community based storm water control facilities. For cost and engineering effectiveness, we recommend the Regional District pursue the implementation of large community-based facilities. If approval is not granted an alternative is to require on-site storm water management facilities as a condition of development. A pilot study is also recommended for on-site facilities to measure their effectiveness.

In addition to constructing the three detention structures, two culvert crossing upgrades are recommended within the Regional District. The Anderton Road culvert is recommended to be upgraded to a 1830 mm by 970 mm arch culvert and the private crossing between Parry Place and Idiens Way is recommended to be upgraded to two 1200 mm by 600 mm arch culverts.

7.4 HIGHWOOD DEVELOPMENT

To investigate the effects of development in the Highwood subdivision, the 10-year storm was modelled using both the fully developed condition and the pre-development condition. The Highwood development is approximately 33 ha and located immediately east of Birkdale Farms.

This development is serviced by a detention pond near the southwestern corner of the residential subdivision. The present pond area is approximately 3,620 m^2 with an observed berm height of approximately 0.25 m from the lowest outlet pipe invert to the lowest point on the top of berm. A pair of 150 mm diameter PVC pipes discharge flow

from the pond to a collector ditch which then travels into a 300 mm diameter pipe into Brooklyn Creek.

The existing detention pond is insufficient for attenuating peak flows from the development to pre-development levels. The discharge pipes are also undersized and much of the flow from the pond is traveling as uncontrolled, overland flow. In order to increase the storage capacity of the detention pond, the height of the berm must be raised.

To achieve pre-development peak flow rates, the berm must be raised to 0.56 m above the invert of the discharge pipe as a minimum. It would encircle the entire pond with side slopes of 2H:1V. The improved pond outlet is a combination of discharge pipes and an overflow swale and enters the creek at the same location as the existing pipes. The discharge pipes accommodate flows up to the 10-year return period flow of 0.76 m^3/s. Flows greater than this limit overtops the berm crest and spills into an overflow swale. For the 100-year return period storm, the overflow swale carries 0.54 m^3/s. The table below summarizes the design requirements of this pond.

Table 7.1

Base area	3000 m^2
Berm side slopes	2H:1V
Approximate length	100 m
Invert elevation of discharge pipe	37.12 m
Elevation at top of berm	37.68 m
Total live storage for 10 year storm	1800 m^3
Discharge through outlet pipes	0.76 m^3/s
Discharge into overflow swale (1:100 year)	0.54 m^3/s

7.5 REVIEW OF IMPROVEMENT ALTERNATIVES

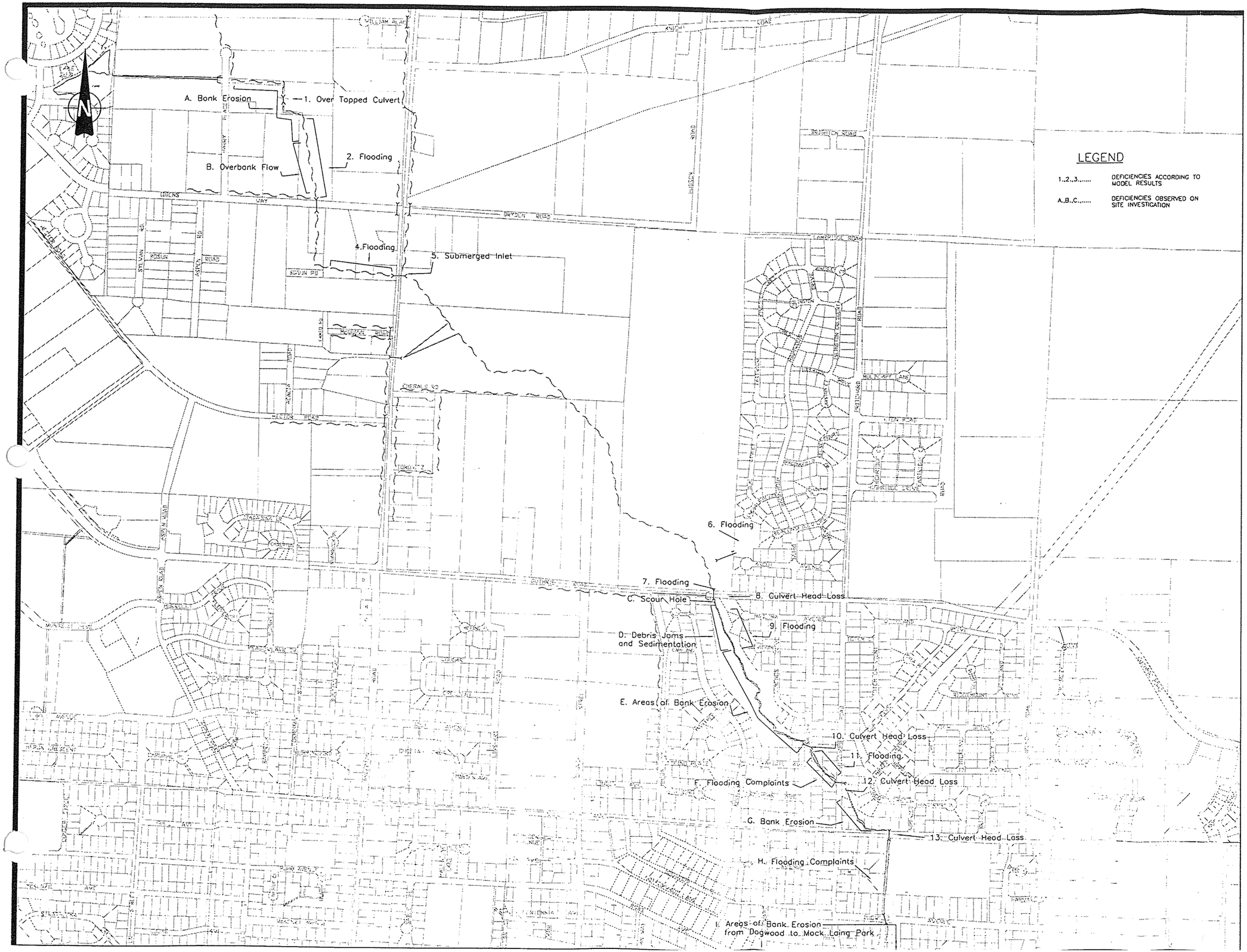
To determine a recommended combination of network improvements, a review of the improvement alternative results was completed. According to the results from Alternatives 1 through 3, upgrading the culverts from Guthrie Road to Noel Avenue combined with improving the conveyance capacity of the creek will reduce flooding problems but also increase flow velocity. Increased stream velocity can increase the amount of erosion in the channel and lead to sedimentation downstream. Many sections of Brooklyn Creek already suffer from undermined or unstable banks so high stream velocities should be avoided.

Constructing a detention pond on Birkdale Farm, as modelled in Alternative 4, does not substantially reduce flood elevations. Therefore, it is not recommended to construct additional detention storage on Birkdale Farms. However, community detention ponds in the Regional District and improving the capacity of the Highwood development pond are recommended as they attenuate peak future development flows from their respective development areas to pre-development levels.

Drawing no. 982879-1-106 shows the hydraulic grade line for the pre-development, existing, and future development conditions in addition to improvement Alternatives 1 to 4 using the 10-year return period design storm. With increased development, flood levels and durations increased along the creek. The numerical values used to compile these graphs are found in Appendix B.

Salish Park provides an opportunity for construction of a sediment pond along Brooklyn Creek. The Town of Comox could pursue this on-line facility to reduce sediment concentrations in baseflows and first flush conditions.

The expanded detention pond for the Highwood development does not substantially improve field ponding on Birkdale Farms during major storm events. This is due to the fact that the volume of flow discharged from the Highwood development is much less than the discharge upstream of the farm. However, it does improve flow depth and duration for smaller storms. As the detention pond is presently used by wildlife, the detailed design of the improvements should maintain the habitat values of the site. In addition, measures should be taken to prevent the pond from becoming a trap for overwintering salmonids.



VERIFY SCALES

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NO.	DATE	ENG.	BY	SUBJECT

REVISIONS

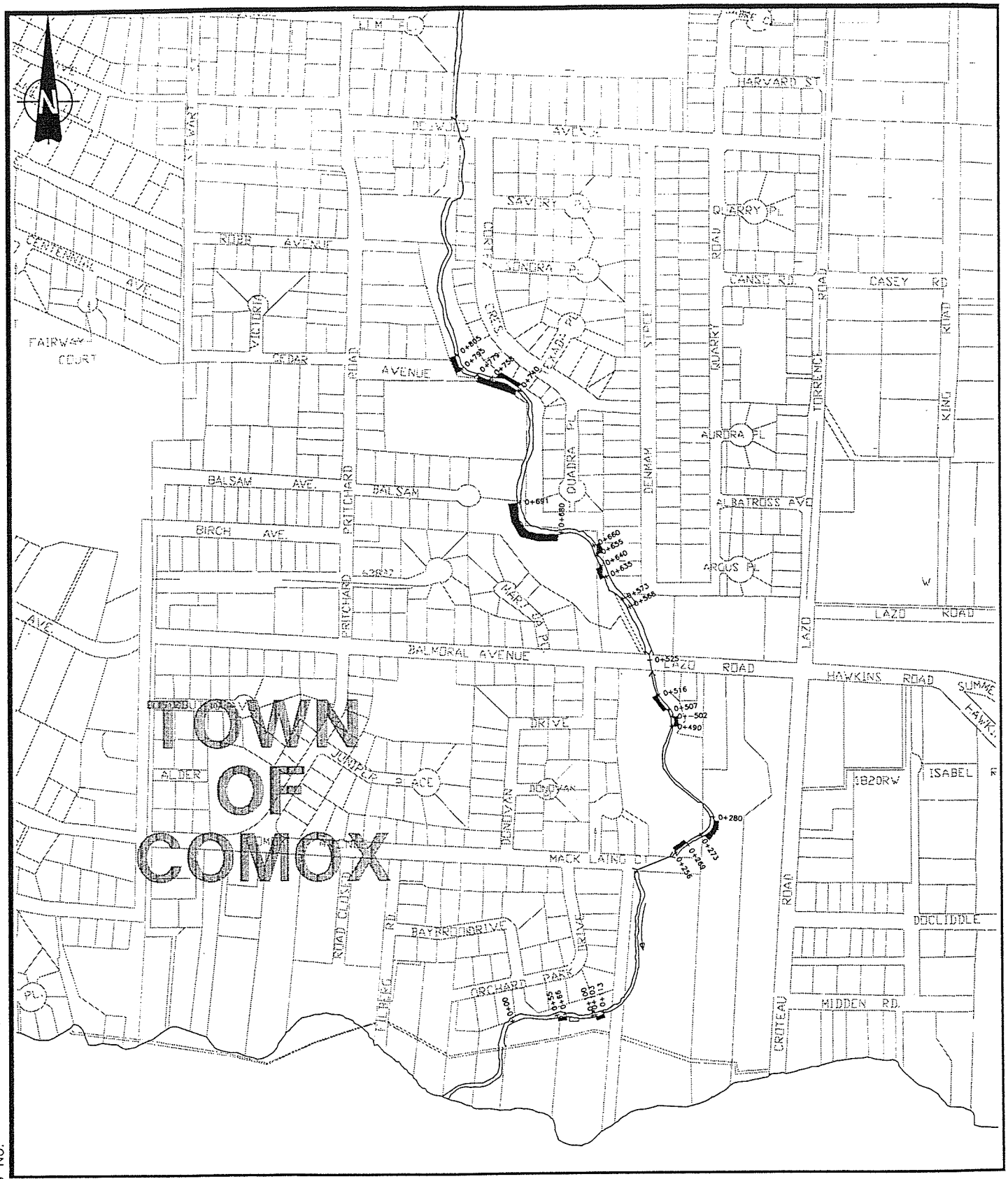
PROJECT NO.	982879
SCALE	1:10,000
DRAWN	R.L.
DESIGNED	J.L.
CHECKED	
APPROVED	
APPROVED	
DATE	MARCH 1999

ASSOCIATED ENGINEERING

BROOKLYN CREEK MASTER DRAINAGE PLAN

DEFICIENCY PLAN

DRAWING NUMBER	REV. NO.	SHEET
982879-1-105		



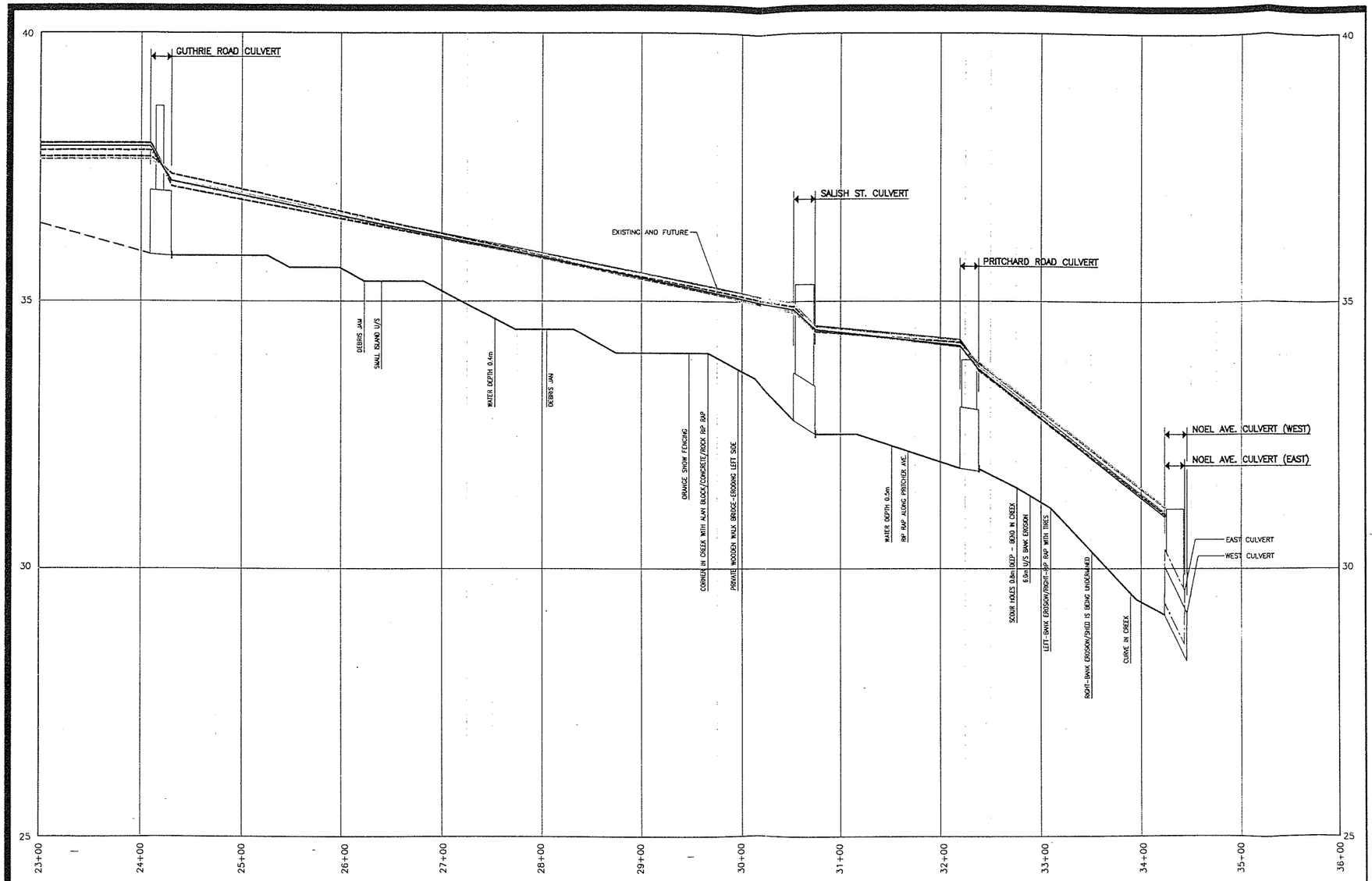
AUTOCADD DRAWING No.

DESIGN: J.L.	
CHECK:	
DRAWN: R.L.	
DATE: JULY 1999	
SCALE: 1:7,500	
JOB No. 982879	
DWG. No. FIGURE 6	△

BROOKLYN CREEK MASTER DRAINAGE PLAN

SITES OF EROSION CONCERN DOWNSTREAM OF DOGWOOD AVENUE

ASSOCIATED ENGINEERING



PROFILE

SCALE HOR. 1:4000
VER. 1:75

LEGEND

- PRE-DEVELOPMENT CONDITION
- EXISTING DEVELOPMENT CONDITION
- FUTURE DEVELOPMENT CONDITION
- ALT#1 (ENLARGE CULVERTS)
- ALT#2 (CLEANED CHANNEL)
- ALT#3 (COMBINED ALT#1 & 2)
- ALT#4 (DETENTION STORAGE)

VERIFY SCALES

BAR IS BASED ON ORIGINAL DRAWING

0 —— 10mm

IF NOT 10mm ON THE SHEET, ADJUST SCALES ACCORDINGLY

NO.	DATE	ENG.	BY	SUBJECT

REVISIONS

PROJECT NO.	982879
SCALE	AS SHOWN
DRAWN	R.L.
DESIGNED	
CHECKED	
APPROVED	
APPROVED	
DATE	MARCH 1999

ASSOCIATED ENGINEERING

BROOKLYN CREEK MASTER DRAINAGE PLAN

HYDRAULIC GRADE LINES
10 YEAR STORM FOR
ALT#1 THROUGH ALT#4

DRAWING NUMBER	REV. NO.	SHEET
982879-1-106		

RECOMMENDED IMPROVEMENTS

SECTION 8

The aim of network improvements is to reduce flood elevations, culvert head losses, and culvert headwater depths to levels similar to the pre-development condition. In addition, field ponding on Birkdale Farms should be similar to pre-development conditions and meet ARDSA drainage criteria. These objectives are achievable using Best Management Practices for storm water management. This includes controlling sediment runoff from agricultural areas, controlling land development, and implementing a regular ditch cleaning program.

The 10-year return period storm was used as the design criteria for all improvement alternatives. In addition, each alternative was compared against pre-development levels for the 5-year and the 100-year return periods.

Drawing no. 982879-1-107 compares our recommended improvements against the pre-development, existing, and future conditions for the 10-year return period design storm. The recommended improvements result in water surface elevations at or below pre-development levels. Increased velocities between Salish Street and Pritchard Road and upstream of Noel Avenue result in the need for bank protection in these areas.

Our recommendations for improvements on the Brooklyn Creek drainage network are summarized on drawing no. 982879-1-108 and consist of the following:

- Construct a minimum 0.56 m high berm with 2H:1V side slopes around the existing detention pond servicing the Highwood development east of Birkdale Farms. This improved pond discharges into Brooklyn Creek at the same location as the existing outlet location.
- Construct detention storage ponds upstream of Birkdale Farms near the corner of Parry Place and Idiens Way, the corner of Dryden Road and Anderton Road, and on Anderton Road south of McQuinn Road. Each pond requires approximately 0.2 ha of land.
- Remove the gravel bar at the outlet of the Guthrie Road culvert and re-grade local channel to a flat slope. Selectively remove debris obstructions and vegetation encroaching the stream channel on accumulated sediment deposits downstream of this culvert for a distance of 200 m. The channel grade should be monitored in this area for changes due to short term sediment transport. The capacity of the channel should be comparative to a cross-section with a 3.9 m base width and

2H:1V side slopes. This recommended channel cross-section should be maintained along the creek downstream of Guthrie Road.

- Place bank protection in areas along Brooklyn Creek, particularly upstream of Salish Street to Noel Avenue and in areas downstream of Dogwood Avenue where signs of undermining or slope failure are presently evident. In addition, ensure that erosion protection is provided for all municipal outfalls and culverts.
- Upgrade the private crossing between Parry Place and Idiens Way to two 1200 mm by 600 mm arch culverts with flush headwalls.
- Upgrade the Anderton Road culvert to a 1830 mm by 970 mm arch culvert with flush headwalls and wing walls.
- Upgrade the Guthrie Road culvert to a 1650 mm diameter concrete culvert with flush headwalls and wing walls.
- Upgrade the Salish Street culvert to a 1650 mm diameter concrete culvert with flush headwalls and wing walls. Erosion protection is needed at the inlet and outlet of this culvert.
- Upgrade the Pritchard Road culvert to a 2400 mm by 1500 mm concrete box culvert with flush headwalls and wing walls.
- Upgrade the Noel Avenue culvert to a 2400 mm by 1500 mm concrete box culvert with flush headwalls and wing walls. Riprap protection is also needed at the inlet.
- Monitor flowrates discharging from the Crown Isle development.
- Enforce setback requirements as specified in the joint DFO/MoELP "Land Development Guidelines for the Protection of Aquatic Habitat" (DFO/MoELP, 1992).
- Establish minimum building elevations adjacent to the creek based on the hydraulic grade lines for the recommended alternative.
- Require storm water management facilities as part of future development. This includes the comprehensive development area south of Guthrie Road.

These recommendations maintain flood levels on Birkdale Farms at a maximum elevation of 37.83 m and flood duration of 12 hours during the 10-year return period storm. The duration of field ponding is reduced to near pre-development levels for the 5 and 10 year return periods. Flooding duration for the 100-year return period is 24 hours which is higher than the pre-development level but much less than the existing condition. Flood duration on Birkdale Farms is within the ARDSA drainage criteria even for the 100-year return period.

Table 8.1 summarizes the model results for the recommended improvements in

comparison to the pre-development condition for the 10-year return period storm. A complete table of model results for the 5 and 100 year return periods is found in Appendix B.

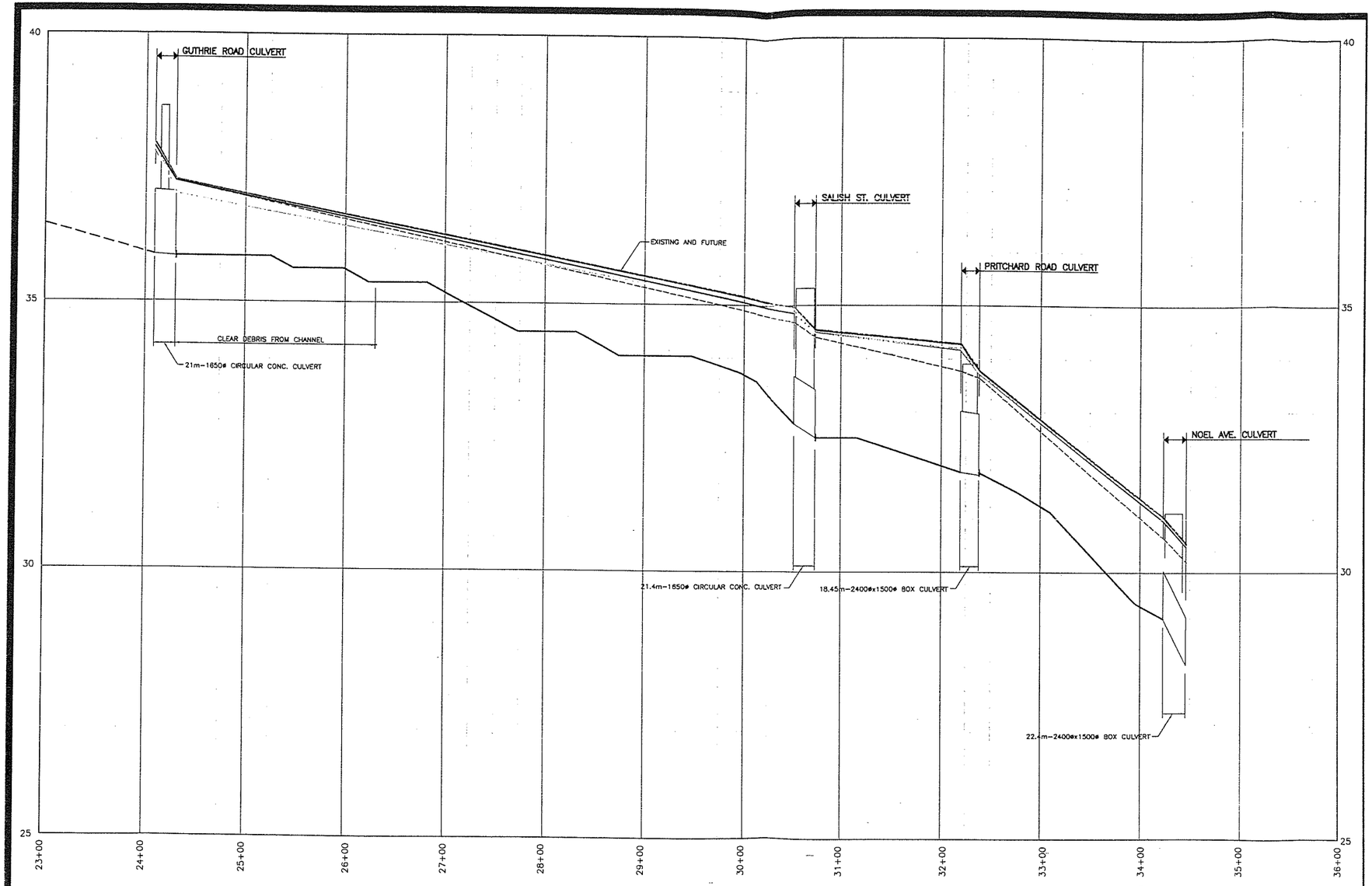
Table 8.1

Location		Pre-development Condition	Recommended Improvements
Private crossing upstream of Idiens Way two 1200 mm by 600 mm arches	head loss, m	.31	.16
	flood elev., m	60.37	59.99
Anderton Road culvert 1830 mm by 970 mm arch	head loss, m	.33	.19
	flood elev., m	46.76	46.71
Ponding upstream of Guthrie Road approx. field elev. = 37.03	flood elev., m	37.92	37.83
	duration, hrs	12	12
Guthrie Road culvert 1650 mm diameter	head loss, m	.58	.45
	flood elev., m	37.92	37.83
Downstream of Guthrie Road U/S bank elev. = 36.80 m	flood elev., m	37.26	37.27
Salish Street culvert 1650 mm diameter	head loss, m	.39	.29
	flood elev., m	34.87	34.70
Between Salish St. and Pritchard Rd. U/S bank elev. = 34.39 m	flood elev., m	34.22	34.10
Pritchard Road culvert 2400 x 1500 mm box	head loss, m	.44	.13
	flood elev., m	34.18	33.77

Location		Pre-development Condition	Recommended Improvements
Noel Avenue culverts (2 culvert crossing) a) 1500 x 1000 mm elliptical (east culvert)	head loss, m	.56	
	flood elev., m	30.97	
b) 900 mm CSP (west culvert)	head loss, m	.48	.42
	flood elev., m	30.97	30.61

The ARDSA criteria limits field ponding due to a 10-year return period storm to 2 days in the growing season and 5 days in the dormant season. According to our modelling results, overland flooding on Birkdale Farms is limited to approximately 24 hours using winter drainage conditions. This is within the ARDSA criteria for both summer and winter.

To maintain efficient flow conveyance through the creek, channel maintenance must be performed on a regular basis. This may result in an increase to the present budget cost of creek maintenance and can only be done during the fisheries window. In addition, it is recommended that a flow monitoring program be implemented at the outlet for Crown Isle.



PROFILE

SCALE HOR. 1:4000
VER. 1:75

LEGEND

- PRE-DEVELOPMENT CONDITION
- EXISTING DEVELOPMENT CONDITION
- FUTURE DEVELOPMENT CONDITION
- RECOMMENDED IMPROVEMENTS
- NATURAL CREEK SLOPE CONDITION

VERIFY SCALES

BAR IS BASED ON ORIGINAL DRAWING

0 ——— 10mm

IF NOT 10mm ON THE SHEET, ADJUST SCALES ACCORDINGLY

NO.	DATE	ENG.	BY	SUBJECT

REVISIONS

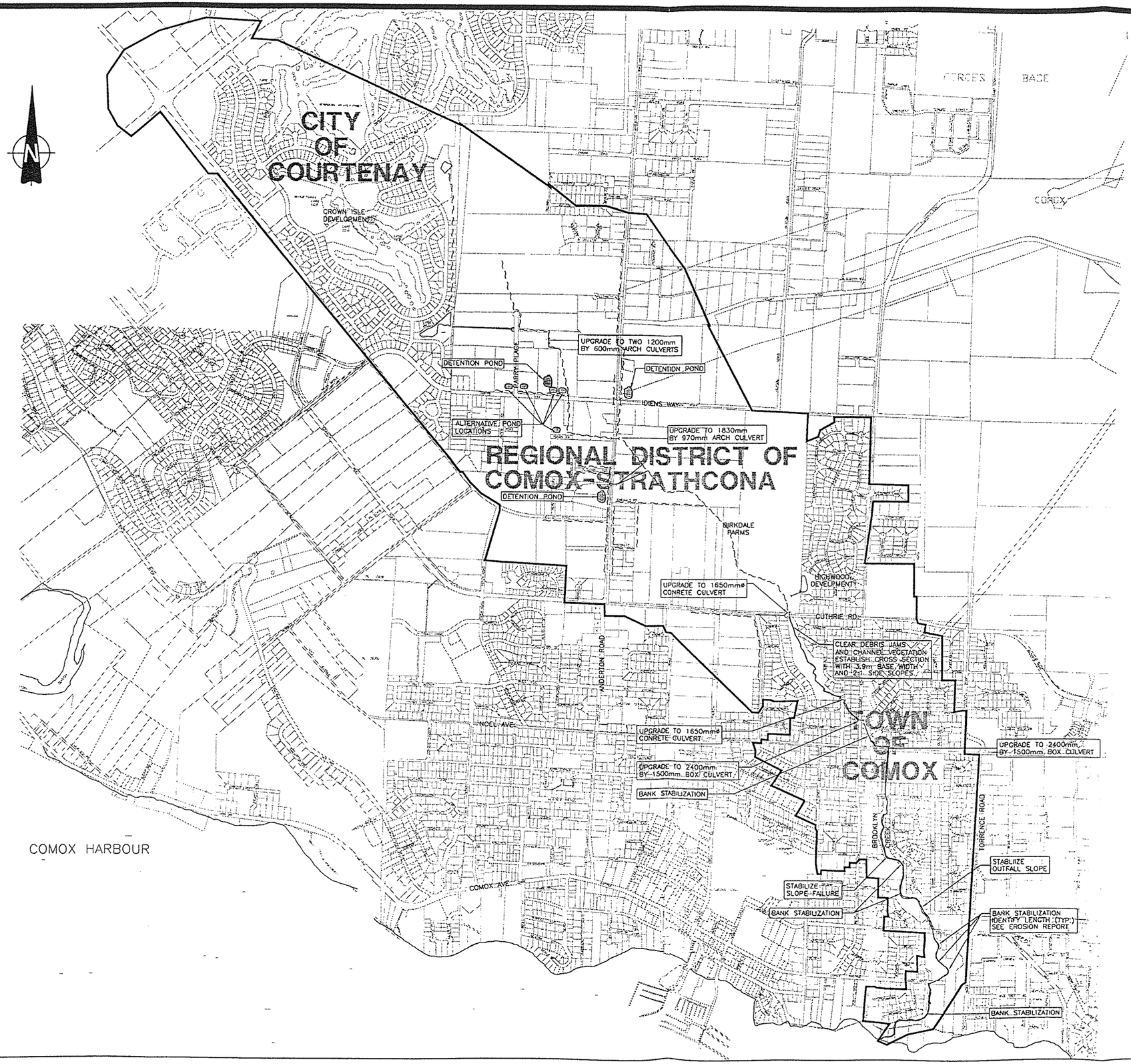
PROJECT NO.	982879
SCALE	AS SHOWN
DRAWN	R.L.
DESIGNED	
CHECKED	
APPROVED	
APPROVED	
DATE	MARCH 1999

ASSOCIATED ENGINEERING

BROOKLYN CREEK MASTER DRAINAGE PLAN

HYDRAULIC GRADE LINES
10 YEAR STORM USING
RECOMMENDED IMPROVEMENTS

DRAWING NUMBER	REV. NO.	SHEET
982879-1-107		



VERIFY SCALES
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NO.	DATE	ENG.	BY	SUBJECT

REVISIONS

PROJECT NO.	982879
SCALE	1:20,000
DRAWN	R.L.
DESIGNED	J.L.
CHECKED	
APPROVED	
APPROVED	
DATE	MARCH 1999

ASSOCIATED ENGINEERING

BROOKLYN CREEK MASTER DRAINAGE PLAN

SUMMARY OF RECOMMENDED IMPROVEMENTS

DRAWING NUMBER	REV. NO.	SHEET
982879-1-108		

IMPLEMENTATION PLAN AND COST ESTIMATE

SECTION 9

In general, the recommended improvements to the Brooklyn Creek drainage system should be implemented from the downstream outlet at Comox Harbour to upstream headwaters at the Crown Isle Development. However, minor clearing of debris and vegetation can occur in isolated areas prior to any downstream improvements.

Debris jams and in-stream vegetation downstream of the Guthrie Road culvert in Salish Park should be cleared manually in the short term. This will provide a small increase in channel capacity without substantially increasing peak flow volumes. During high flows, initial flushing of accumulated sediment will likely occur and is a negative impact on the aquatic habitat. These impacts may be reduced by using temporary sediment trapping facilities.

The potentially severe erosion problems between Pritchard Road and Noel Avenue should be addressed as soon as possible. Localized attempts at bank protection and isolated areas of severe bank undermining are evident in this length of creek. Erosion control measures should then be implemented from Mack Laing Park upstream to Dogwood Avenue and between Guthrie Road and Salish Street. Following this, the Noel Avenue and Pritchard Road culvert crossings should be upgraded to 2400 mm by 1500 mm box culverts along with the implementation of bank protection and slope stability measures for the channel between Salish Street and Noel Avenue. The Salish Street culvert crossing can then be upgraded to a 1650 mm diameter culvert and the Guthrie Road culvert can be increased to a 1650 mm diameter culvert. At this time, the existing gravel bar at the outlet of the Guthrie Road culvert can be removed and the channel can be locally re-graded to a zero slope.

The upgrade to the berm around the Highwood pond should take place following the upgrade of the Guthrie Road culvert. A minimum 0.56 m high berm with 2H:1V side slopes and related discharge controls is recommended around the existing detention pond to control the amount of flow entering Brooklyn Creek from the Highwood residential development.

Drainage network improvements in the Regional District of Comox-Strathcona can occur prior to or concurrent with the improvements south of Guthrie Road. Detention storage in this area should precede significant residential development. The recommended implementation procedure is to construct the detention ponds in conjunction with

residential development and then upgrade the Anderton Road culvert and the private crossing between Parry Place and Idiens Way.

Table 9.1 contains preliminary cost estimates for the recommended drainage network upgrades along Brooklyn Creek and is listed in the recommended implementation order.

Table 9.1

Recommended Upgrade	Cost
Bank stabilization between Pritchard Road and Noel Avenue	$176,000
Channel clearing downstream of Guthrie Road	$18,000
Bank stabilization between Guthrie Road and Salish Street	$90,000
Bank stabilization downstream of Balmoral Avenue	$45,000
Bank stabilization between Dogwood Avenue and Balmoral Avenue	$45,000
Noel Avenue culvert	$140,000
Pritchard Road culvert	$140,000
Salish Road culvert	$82,000
Guthrie Road culvert	$82,000
Highwood pond improvements	$38,000
Sediment pond at Salish Park	$80,000
Anderton Road culvert	$82,000
Isolated bank stabilization downstream of Parry Place	$12,000
Private Crossing between Parry Place and Idiens Way	$50,000
Three detention ponds in the Regional District*	$440,000
SUB-TOTAL	*$1,520,000*
Engineering and Contingencies (25%)	$380,000
TOTAL	**$1,900,000**

* Cost does not include cost of land acquisition

RAINFALL DATA

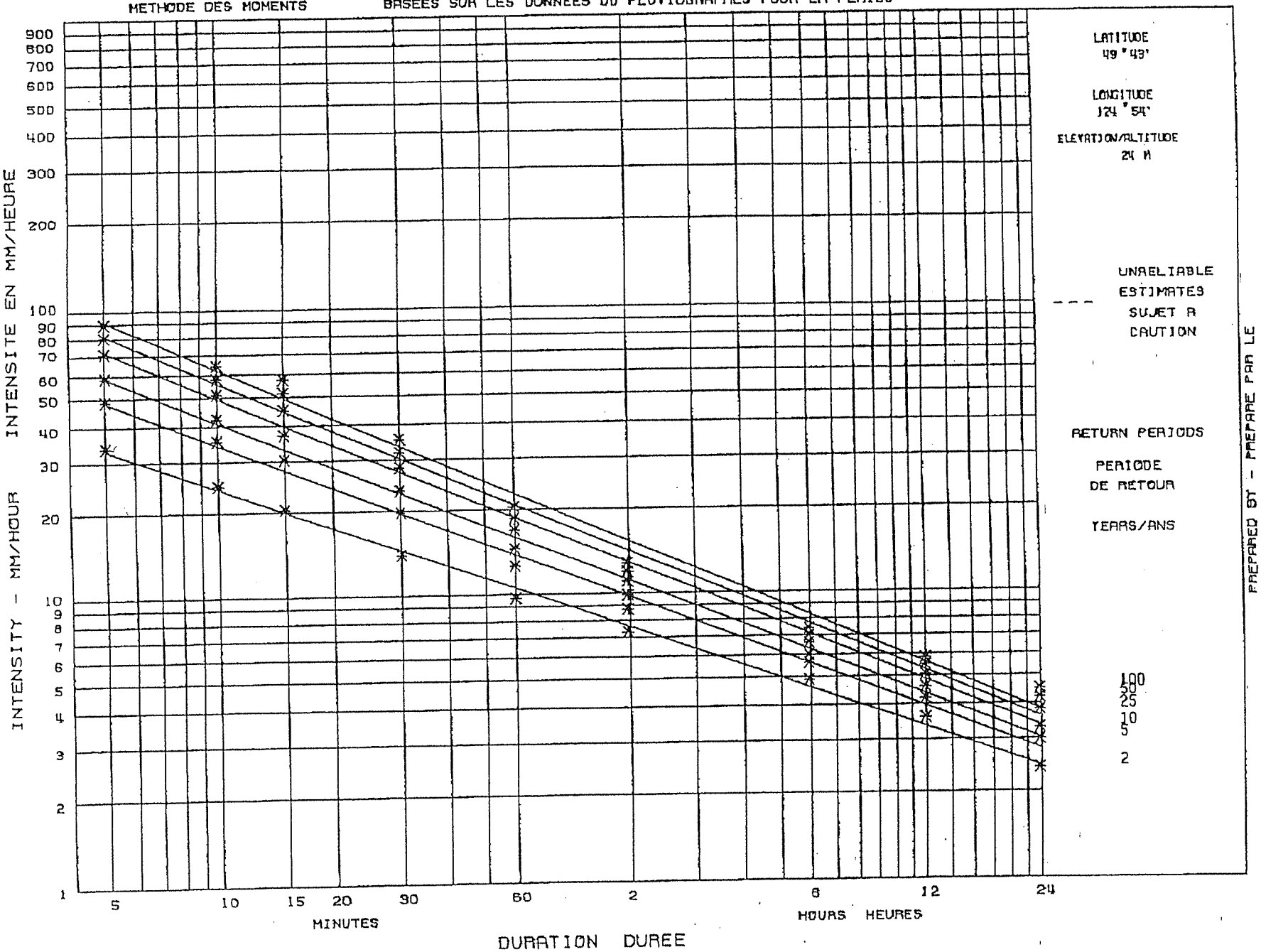
APPENDIX A

SHORT DURATION RAINFALL INTENSITY-DURATION FREQUENCY DATA FOR- COMOX A

DONNEES SUR L'INTENSITE, LA DUREE ET LA FREQUENCE DES CHUTES DE PLUIE DE COURTE DUREE A

GUMBEL-METHOD OF MOMENTS
METHODE DES MOMENTS

BASED ON RECORDING RAIN GRUGE DATA FOR THE PERIOD- 1962 - 1997 36 YEARS/AN
BASEES SUR LES DONNEES DU PLUVIOGRAPHES POUR LA PERIOD



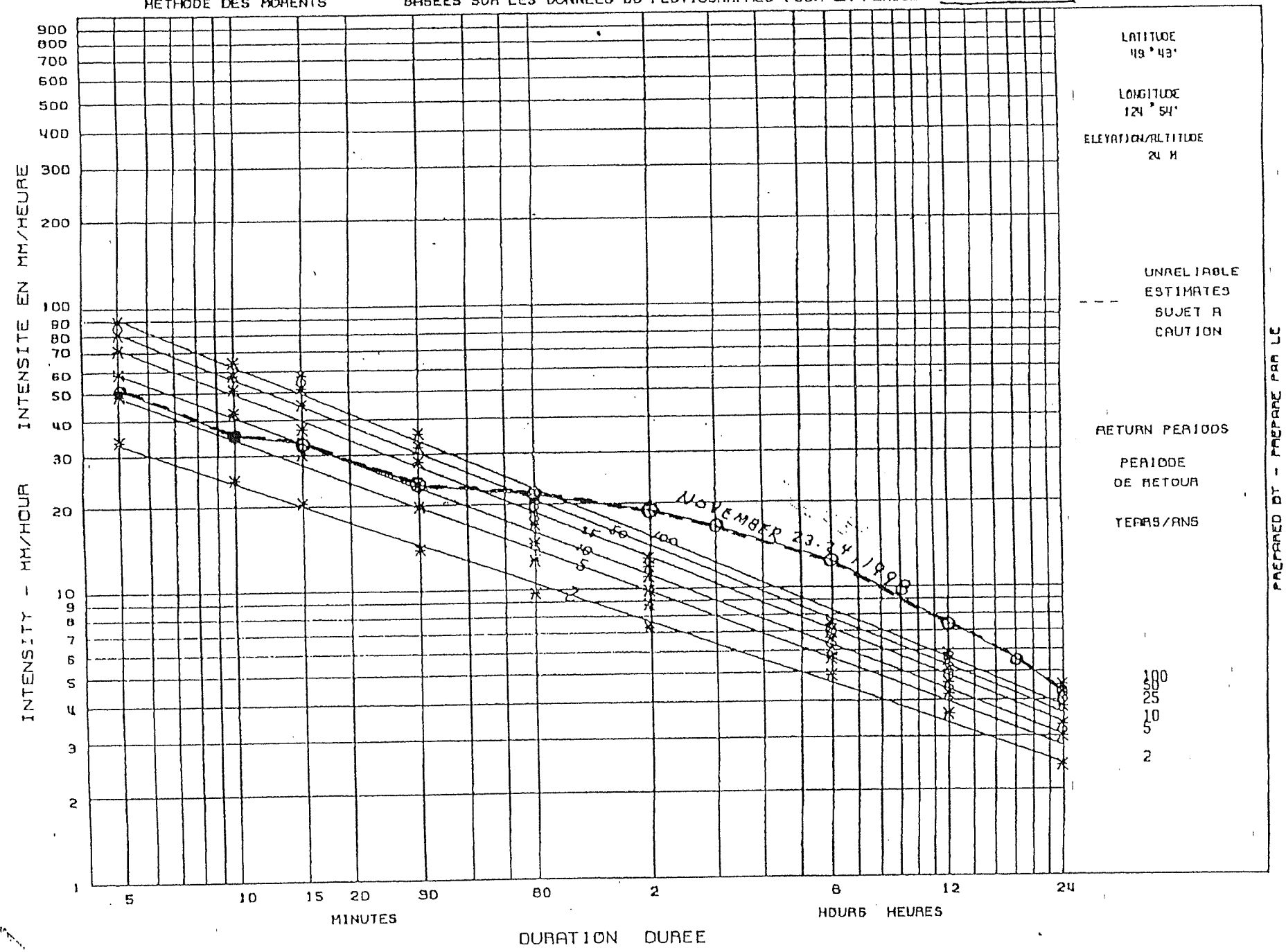
PREPARED BY - PREPARE PAR LE
ATMOSPHERIC ENVIRONMENT SERVICE - ENVIRONMENT CANADA
SERVICE DE L'ENVIRONNEMENT ATMOSPHERIQUE - ENVIRONNEMENT CANADA

SHORT DURATION RAINFALL INTENSITY - DURATION FREQUENCY DATA FOR- COMOX A

DONNEES SUR L'INTENSITE, LA DUREE ET LA FREQUENCE DES CHUTES DE PLUIE DE COURTE DUREE A

GUMBEL-METHOD OF MOMENTS
METHODE DES MOMENTS

BASED ON RECORDING RAIN GAUGE DATA FOR THE PERIOD- 1962 - 1997 36 YEARS/AN
BASEES SUR LES DONNEES DU PLUVIOGRAPHES POUR LA PERIOD



PREPARED BY - PREPARE PAR LE

ATMOSPHERIC ENVIRONMENT SERVICE - ENVIRONMENT CANADA
SERVICE DE L'ENVIRONNEMENT ATMOSPHERIQUE - ENVIRONNEMENT CANADA

RECORDING RAIN GAUGE
DAILY CHART 99 FEUILLE JOURNALIERE
PLUVIOMETRE ENREGISTREUR
(SI)

DAY JOUR ____ MONTH MOIS NOV 23 1998 19

2200 NORMAL TIME OF CHART CHANGE (nearest hour) TEMPS NORMAL DE POSE DE LA FEUILLE (heure la plus proche)

H.N P S.T. (TIME ZONE) (FUSEAU HORAIRE)

38.8 mm STANDARD GAUGE TOTAL TOTAL PLUVIOMETRE STANDARD

STATION COMOX [A] BC (YQQ)

GREATEST FALL OF RAIN IN PLUIE MAXIMUM EN	5 MIN	10 MIN	15 MIN	30 MIN	1H	2H	6H	12H
RECORDED: ENREGISTREE	5.0 ~~2.0~~	5.8	7.8	11.0	20.4	36.0	47.0	47.1
CORRECTED: CORRIGEE	4.2	6.1	8.3	11.7	21.6	38.2	49.8	49.

RECORDED ENREGISTREE	20.4	15.6	8.6	3.2	0.2											0.8		1.0	3.4	5.4	4.6	4.8	5.6	1.6
CORRECTED CORRIGEE	21.6	16.5	9.1	2.3	0.8											0.9		1.1	3.6	5.7	4.9	5.1	5.9	1.7

HOURS AFTER NORMAL TIME OF CHART CHANGE / HEURES DEPUIS LE TEMPS NORMAL DE POSE DE LA FE

THIS SIDE UNDER / CE COTE EN DESSOUS MILLIMETRES

2.0|8.0 4.0|6.0 6.0|4.0 8.0|2.0

74.2

10 PM — 12 am Nov 24/98

RECORDING RAIN GAUGE
DAILY CHART 99 FEUILLE JOURNALIERE
PLUVIOMETRE ENREGISTREUR
(SI)

DAY JOUR ____ MONTH MOIS NOV 22 1998 19

2200 NORMAL TIME OF CHART CHANGE (nearest hour) TEMPS NORMAL DE POSE DE LA FEUILLE (heure la plus proche)

H.N P S.T. (TIME ZONE) (FUSEAU HORAIRE)

53.4 mm STANDARD GAUGE TOTAL TOTAL PLUVIOMETRE STANDARD

STATION COMOX [A] BC (YQQ) PROV

GREATEST FALL OF RAIN IN PLUIE MAXIMUM EN	5 MIN	10 MIN	15 MIN	30 MIN	1H	2H	6H	12H
RECORDED: ENREGISTREE	1.4	2.8	4.6	7.4	11.8	17.2	34.6	46.8
CORRECTED: CORRIGEE	1.4	2.9	4.7	7.6	12.2	17.7	35.6	48.2

RECORDED ENREGISTREE						0.2						1.8	3.0	2.0	2.2	1.6	1.0	1.8	3.6		0.8	6.4	10.8	5.6	11.0
CORRECTED CORRIGEE						0.2						1.9	3.1	2.1	2.3	1.6	1.0	1.9	3.7		0.8	6.4	11.1	5.8	11.3

HOURS AFTER NORMAL TIME OF CHART CHANGE / HEURES DEPUIS LE TEMPS NORMAL DE POSE DE LA FEU

THIS SIDE UNDER / CE COTE EN DESSOUS MILLIMETRES

2.0|8.0 4.0|6.0 6.0|4.0 8.0|2.0

51.8

10 PM — 12 am Nov 23/98 — 12 pm — 6 pm — 10 pm

1. HR	21.6 mm
2 HR	38.2
3 HR	49.5
6 HR	75.4
12 HR	90.7
24 HR	103.1

Rainfall Data - 6 Hour Cumulative, and Peak Intensities

Comox Airport Nov 24, 1998

Preliminary Verbal Data from AES - 6 Hour Cumulative

Day	Date	Time	Cumulative Rainfall - mm	Average Rainfall per Hour (mm.Hr)	Approx Return Period (6 hr duration)*
Monday	11/23/98 10:00 PM	10:00 PM	7	1.2	<2
Tuesday	11/24/98 4:00 AM	4:00 AM	17	2.8	<2
	11/24/98 10:00 AM	10:00 AM	29	4.8	4
	11/24/98 4:00 PM	4:00 PM	54	9.0	50
	11/24/98 10:00 PM	10:00 PM	2	0.3	<2
Wednesday	11/25/98 4:00 AM	4:00 AM	3	0.5	<2
	11/25/98 10:00 AM	10:00 AM	22	3.7	<2
	11/25/98 4:00 PM	4:00 PM	2	0.3	<2
	11/25/98 10:00 PM	10:00 PM	5	0.8	<2
Thursday	11/26/98 4:00 AM	4:00 AM	6	1.0	<2

Peak Rainfall Data

Period	Date/Time	Cumulative Rainfall - mm	Average Rainfall per Hour (mm.Hr)	Approx Return Period*
Peak 24 Hour Period:	Monday 4:00pm - Tuesday 4:00pm	102.00	4.3	> 100
Peak 12 Hour Period:	Tuesday 4:00am - 4:00pm	83.00	6.9	> 100

The data below was obtained verbaly from the Airport Weather Office on Nov 24, 98

Peak 2 Hour Period	Monday 10:00pm - Tuesday 10:00pm**	36.00	18.0	> 100
Peak 1 Hour Period	Monday 10:00pm - Tuesday 10:00pm**	20.40	20.4	50
Peak 30 Min Period	Monday 10:00pm - Tuesday 10:00pm**	11.00	22.0	15
Peak 15 Min Period	Monday 10:00pm - Tuesday 10:00pm**	7.80	31.2	12
Peak 10 Min Period	Monday 10:00pm - Tuesday 10:00pm**	5.80	34.8	9
Peak 5 Min Period	Monday 10:00pm - Tuesday 10:00pm**	4.00	48.0	8

* Based on Town of Comox IDF Curves - Drawing SE-1 (91/08/06)

** Occured sometime during the 24 hour period

ATMOSPHERIC ENVIRONMENT SERVICE
RAINFALL INTENSITY, DURATION, FREQUENCY VALUES
PREPARED BY THE HYDROMETEOROLOGY DIVISION, CANADIAN CLIMATE CENTRE

****

STATION : Comox A

STATION NUMBER 1021830

CRITICAL PERIOD : 1ST OF MONTH 01 TO THE END OF MONTH 12

NOTE : MODIFIED GUMBEL 12/82

YEARS	TOTAL DAYS	% VALID	FLAG		1 DAY	2 DAY	3 DAY	4 DAY	5 DAY	6 DAY	7 DAY	8 DAY	9 DAY	10 DAY	15 DAY	20 DAY	25 DAY	30 DAY
1944	184	100		START DATE	25/11	24/11	3/11	22/11	3/11	3/11	3/11	3/11	2/11	1/11	28/10	22/10	2/11	1/11
				MAX VALUE	362	415	474	536	634	718	814	935	993	1003	1213	1534	1749	1974
1945	365	100		START DATE	6/ 2	6/ 2	16/ 3	16/ 3	15/ 3	16/ 3	15/ 3	15/ 3	13/ 3	16/ 3	7/ 3	7/ 3	11/11	8/11
				MAX VALUE	635	893	917	1199	1259	1372	1432	1437	1587	1641	2077	2346	2817	3081
1946	365	100		START DATE	6/ 1	6/ 1	2/12	6/ 1	3/ 1	2/ 1	1/ 1	2/ 1	1/ 1	1/ 1	3/ 1	2/ 1	1/ 1	1/ 1
				MAX VALUE	377	512	529	643	773	889	919	1020	1050	1050	1206	1802	2025	2057
1947	365	100		START DATE	11/12	11/12	9/12	9/12	11/12	11/12	11/12	9/12	9/12	9/12	9/12	4/12	11/12	11/12
				MAX VALUE	645	710	739	804	1118	1354	1424	1448	1518	1521	2287	2478	2888	3480
1948	366	100		START DATE	19/11	19/11	17/11	16/11	15/11	14/11	13/11	13/11	13/11	13/11	14/11	13/11	13/11	3/11
				MAX VALUE	658	752	831	955	1115	1450	1554	1648	1651	1725	2266	2717	2887	3194
1949	365	100		START DATE	21/ 2	20/ 2	20/ 2	22/11	22/11	22/11	24/11	24/11	22/11	22/11	20/11	16/11	10/11	7/11
				MAX VALUE	404	540	588	622	840	862	1010	1094	1271	1355	1584	1696	1860	2002
1950	365	100		START DATE	25/11	10/ 4	26/10	24/10	24/10	24/10	24/10	24/10	24/10	24/10	22/10	17/10	4/10	3/10
				MAX VALUE	414	714	773	924	1256	1380	1402	1420	1420	1521	1732	1968	2432	2712
1951	365	100		START DATE	26/11	25/11	24/11	24/11	25/11	24/11	23/11	24/11	24/11	23/11	17/11	17/11	23/11	17/11
				MAX VALUE	472	802	1134	1337	1397	1729	1787	1821	1879	1937	2150	2238	2718	2885
1952	366	100		START DATE	30/12	29/12	28/12	28/12	29/12	28/12	27/12	26/12	26/12	26/12	28/12	30/12	26/12	28/12
				MAX VALUE	579	690	799	864	963	1072	1112	1120	1120	1120	1583	1966	2338	2725
1953	365	100		START DATE	18/11	12/11	11/11	10/11	9/11	9/11	7/11	7/11	5/11	5/11	10/11	5/11	5/11	4/11
				MAX VALUE	386	607	937	1100	1236	1360	1498	1622	1701	1825	2457	3058	3401	3553
1954	365	100		START DATE	17/11	17/11	16/11	15/11	15/11	13/11	13/11	13/11	13/11	12/11	7/11	7/11	13/11	13/11
				MAX VALUE	566	1058	1182	1313	1412	1894	1993	2084	2153	2163	2399	2623	2971	3592
1955	365	100		START DATE	12/ 1	1/11	31/10	30/10	22/10	22/10	22/10	26/10	25/10	23/10	22/10	22/10	22/10	22/10
				MAX VALUE	512	800	865	966	1063	1174	1324	1517	1608	1706	2315	2508	2508	2853
1956	366	100		START DATE	20/10	20/10	20/10	17/10	16/10	15/10	16/10	16/10	15/10	16/10	5/ 1	1/ 1	1/ 1	1/ 1
				MAX VALUE	594	599	680	935	1108	1116	1194	1335	1343	1393	1721	2082	2243	2243
1957	365	100		START DATE	22/12	22/12	22/12	22/12	22/12	22/12	22/12	16/12	17/12	16/12	13/12	15/12	22/12	16/12
				MAX VALUE	1130	1348	1437	1739	1814	1974	2001	2158	2336	2549	2863	2998	3606	4275
1958	365	100		START DATE	22/ 1	22/ 1	21/ 1	20/ 1	20/ 1	22/ 1	22/ 1	21/ 1	20/ 1	14/ 1	9/ 1	9/ 1	7/ 1	17/12
				MAX VALUE	622	1129	1208	1253	1280	1352	1448	1527	1572	1857	2676	2995	3302	3477
1959	365	100		START DATE	7/ 1	7/ 1	6/ 1	6/ 1	6/ 1	6/ 1	6/ 1	6/ 1	6/ 1	6/ 1	6/ 1	6/ 1	6/ 1	6/ 1
				MAX VALUE	699	942	1145	1291	1365	1505	1586	1586	1608	1699	1848	2118	2227	2245
1960	366	100	**	START DATE	29/ 1	28/ 1	28/ 1	26/ 1	28/ 1	28/ 1	23/ 1	22/ 1	22/ 1	23/ 1	23/ 1	26/ 1	22/ 1	22/ 1
				MAX VALUE	653	1025	1025	1073	1236	1261	1636	1661	1661	1847	2436	3075	3676	3746

1961	365	100		START DATE	12/ 3	10/ 1	9/ 1	8/ 1	10/ 1	9/ 1	8/ 1	7/ 1	6/ 1	5/ 1	3/ 1	3/ 1	28/ 1	3/ 1
				MAX VALUE	414	610	861	921	1197	1448	1508	1551	1682	1756	2258	2258	2626	3097
1962	365	100		START DATE	29/11	24/11	29/11	23/11	3/ 8	24/11	23/11	24/11	23/11	23/11	23/11	10/11	11/11	7/11
				MAX VALUE	554	608	734	752	847	1205	1306	1385	1486	1496	2001	2352	2840	3211
1963	365	100		START DATE	20/10	21/12	21/12	21/12	2/ 2	2/ 2	16/12	15/12	14/12	13/12	21/12	14/12	14/12	21/12
				MAX VALUE	532	951	1015	1015	1240	1240	1261	1331	1504	1579	1874	2381	2668	2849
1964	366	100		START DATE	24/ 1	30/11	30/11	30/11	24/ 1	24/ 1	23/ 1	24/ 1	23/ 1	15/ 1	17/ 1	13/ 1	7/ 1	3/ 1
				MAX VALUE	371	417	536	549	688	767	799	976	1008	1095	1510	1749	2005	2318
1965	365	100		START DATE	19/11	4/10	3/10	16/11	1/12	3/12	3/12	1/12	1/12	30/11	26/11	19/11	14/11	10/11
				MAX VALUE	487	733	741	754	817	954	1089	1261	1396	1411	1967	2352	2755	3087
1966	365	100		START DATE	27/11	30/11	29/11	27/11	27/11	27/11	27/11	27/11	27/11	27/11	27/11	26/11	25/11	19/11
				MAX VALUE	635	688	995	1353	1680	1781	1902	2006	2021	2096	2629	3412	3895	4314
1967	365	100		START DATE	15/ 3	14/ 3	14/ 3	4/10	3/10	2/10	30/ 9	5/10	4/10	3/10	28/ 9	31/12	31/12	21/12
				MAX VALUE	490	620	680	792	918	943	974	1127	1243	1369	1605	2605	2621	3295
1968	366	100		START DATE	18/ 1	17/ 1	12/ 1	12/ 1	14/ 1	13/ 1	12/ 1	12/ 1	12/ 1	11/ 1	7/ 1	4/ 1	11/ 1	7/ 1
				MAX VALUE	770	966	1117	1231	1378	1962	2205	2269	2405	2415	2592	2621	2943	3120
1969	365	100		START DATE	22/12	11/12	11/12	10/12	9/12	8/12	11/12	11/12	9/12	11/12	8/12	3/12	3/12	23/11
				MAX VALUE	584	764	1010	1023	1117	1218	1322	1342	1429	1565	2400	2658	2714	2886
1970	365	100		START DATE	10/12	15/12	14/12	14/12	13/12	10/12	10/12	10/12	9/12	10/12	6/12	3/12	6/12	23/11
				MAX VALUE	367	551	637	712	770	841	1062	1137	1147	1226	1535	1605	1849	1975
1971	365	100		START DATE	8/11	7/11	7/11	6/11	5/11	7/11	6/11	6/11	1/11	1/11	29/10	6/11	1/11	5/11
				MAX VALUE	537	770	889	919	934	1070	1100	1122	1148	1151	1397	1841	2070	2328
1972	366	100	**	START DATE	17/12	16/12	17/12	16/12	16/12	16/12	16/12	16/12	2/11	17/12	16/12	366/11	31/12	26/12
				MAX VALUE	422	597	828	1003	1021	1095	1113	1116	1181	1310	1755	2073	2695	3285
1973	365	100		START DATE	14/ 1	14/ 1	14/ 1	13/ 1	14/ 1	11/ 1	14/ 1	13/ 1	14/ 1	14/ 1	11/ 1	11/ 1	11/ 1	27/11
				MAX VALUE	663	1029	1180	1255	1345	1459	1688	1763	1818	2085	2534	2672	2829	2981
1974	365	100		START DATE	24/11	23/11	22/11	22/11	14/ 1	19/11	18/11	17/11	17/11	17/11	11/11	5/11	4/11	17/11
				MAX VALUE	699	752	851	851	1090	1168	1173	1401	1401	1433	2061	2586	2683	3038
1975	365	100		START DATE	28/10	11/11	11/11	11/11	10/11	10/11	8/11	28/10	28/10	4/11	31/10	26/10	23/10	15/10
				MAX VALUE	587	837	1144	1295	1379	1379	1419	1460	1787	1920	2651	3309	3647	3992
1976	366	100		START DATE	27/12	26/12	25/12	25/12	26/12	22/12	11/ 2	25/10	19/ 3	18/ 3	17/ 3	8/12	25/10	3/ 1
				MAX VALUE	283	491	501	501	509	566	603	611	721	736	812	926	1102	1179
1977	365	100		START DATE	28/10	28/10	28/10	10/12	28/10	27/10	22/10	25/10	24/10	23/10	22/10	21/10	22/10	21/10
				MAX VALUE	462	566	664	850	1092	1124	1152	1282	1468	1631	1928	2329	2872	2924
1978	365	100		START DATE	10/12	6/ 3	9/12	8/12	9/12	8/12	10/12	10/12	9/12	8/12	3/12	4/ 1	23/11	24/ 3
				MAX VALUE	400	486	520	557	582	619	647	819	902	939	975	1098	1323	1408
1979	365	100		START DATE	24/10	23/10	23/10	21/10	21/10	21/10	18/10	17/10	17/10	17/10	13/10	8/ 2	8/ 2	4/ 2
				MAX VALUE	537	927	982	1307	1362	1412	1487	1653	1708	1758	1934	2198	2390	2590
1980	366	100		START DATE	27/12	1/ 2	25/12	25/12	23/12	22/12	21/12	1/11	1/11	1/11	1/11	1/11	1/11	1/11
				MAX VALUE	409	622	931	941	1049	1183	1252	1308	1338	1351	1477	1679	2023	2682
1981	365	100		START DATE	14/11	13/11	13/11	11/11	11/11	27/10	26/10	25/10	26/10	11/11	10/11	26/10	11/11	25/10
				MAX VALUE	484	705	783	1019	1097	1188	1308	1312	1326	1387	1786	2411	2706	3119
1982	365	100		START DATE	24/10	23/10	22/10	22/10	21/10	21/10	20/10	20/10	20/10	20/10	21/10	20/10	20/10	20/10
				MAX VALUE	582	1034	1368	1673	1853	1921	1939	1939	1939	1939	2131	2696	2740	3085
1983	365	100		START DATE	11/ 2	11/ 2	9/ 2	9/ 2	8/ 2	9/11	9/11	8/11	8/11	8/11	9/11	8/11	1/11	28/10
				MAX VALUE	802	995	1202	1395	1421	1480	1652	1796	1917	1961	2629	3013	3739	3841
1984	366	100		START DATE	8/10	8/10	8/10	8/10	8/10	8/10	7/10	7/10	5/10	5/10	5/10	9/ 2	7/ 2	2/11
				MAX VALUE	536	712	1048	1136	1194	1332	1390	1414	1456	1480	1493	1981	2233	2476

1985	365	100	**	START DATE	11/ 2	10/ 2	19/10	18/10	18/10	17/10	18/10	366/10	366/10	366/10	366/10	31/12	31/12	366/11
				MAX VALUE	400	412	559	631	671	679	693	820	958	1158	1265	2381	2691	3083
1986	365	100		START DATE	21/12	21/12	21/12	19/12	21/12	21/12	21/12	21/12	21/12	13/12	21/12	14/12	11/12	13/12
				MAX VALUE	1055	1238	1250	1301	1404	1514	1569	1719	1869	2008	2706	2854	3542	3705
1987	365	100		START DATE	3/ 3	30/11	29/11	29/11	29/11	29/11	29/11	29/11	30/11	29/11	29/11	20/11	19/11	9/11
				MAX VALUE	416	636	866	1014	1024	1252	1327	1357	1554	1784	1947	2341	2472	2579
1988	366	100		START DATE	6/11	2/11	1/11	1/11	2/11	1/11	1/11	30/10	1/11	1/11	30/10	1/11	1/11	30/10
				MAX VALUE	447	605	877	883	1071	1343	1351	1399	1489	1563	1919	2141	2835	3001
1989	365	100	**	START DATE	3/12	2/12	2/12	20/10	20/10	2/12	17/10	20/10	17/10	17/10	20/10	16/10	17/10	31/12
				MAX VALUE	382	604	622	712	718	856	890	897	974	1055	1138	1338	1441	1646
1990	365	100		START DATE	3/12	2/12	1/12	1/12	29/11	28/11	28/11	28/11	28/11	28/11	19/11	14/11	9/11	5/11
				MAX VALUE	858	954	1034	1056	1233	1548	1570	1570	1570	1574	2039	2191	2820	3085
1991	365	100		START DATE	18/11	17/11	1/ 2	15/11	31/ 1	30/ 1	1/ 2	31/ 1	31/ 1	30/ 1	31/ 1	30/ 1	1/11	30/12
				MAX VALUE	704	716	851	1190	1328	1338	1513	1663	1783	1793	2015	2141	2208	3198
1992	366	100		START DATE	29/ 1	29/ 1	29/ 1	28/ 1	29/ 1	29/ 1	27/ 1	26/ 1	23/ 1	22/ 1	20/ 1	15/ 1	10/ 1	8/ 1
				MAX VALUE	520	660	1084	1194	1504	1618	1882	2006	2192	2303	3027	3131	3420	3480
1993	364	100		START DATE	9/12	8/12	11/12	9/12	9/12	8/12	7/12	7/12	6/12	3/12	29/11	26/11	21/11	15/11
				MAX VALUE	436	742	869	1059	1375	1681	1772	1834	1854	1892	2532	2846	2858	2974
1994	365	100		START DATE	16/ 2	15/ 2	14/ 2	14/ 2	12/ 2	12/ 2	12/ 2	10/ 2	12/ 2	12/ 2	14/12	12/ 2	10/ 2	15/12
				MAX VALUE	512	842	986	1041	1459	1514	1520	1522	1592	1600	1807	2388	2404	2804
1995	365	100		START DATE	16/11	15/11	9/12	8/12	9/12	8/12	8/12	8/12	8/12	8/12	14/11	5/11	5/11	15/11
				MAX VALUE	695	793	1169	1349	1399	1579	1695	1719	1797	1871	1983	2563	3058	3777
1996	366	100		START DATE	18/10	18/10	5/ 2	5/ 2	4/ 2	13/10	13/10	13/10	6/ 1	6/ 1	11/10	11/10	5/10	11/10
				MAX VALUE	350	422	473	561	581	698	770	770	855	930	1113	1324	1466	1709
1997	365	100		START DATE	17/ 3	17/ 3	17/ 3	17/ 3	17/ 3	16/ 3	15/ 3	11/ 3	1/10	1/10	26/ 9	26/ 9	16/ 9	14/ 9
				MAX VALUE	668	1112	1136	1138	1175	1177	1189	1198	1341	1534	1993	2104	2524	2857
1998	212	100		START DATE	23/ 1	23/ 1	23/ 1	23/ 1	22/ 1	23/ 1	22/ 1	21/ 1	17/ 1	17/ 1	14/ 1	13/ 1	13/ 1	14/ 1
				MAX VALUE	556	728	938	1044	1114	1278	1348	1422	1463	1569	2031	2287	2479	2843

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	1 DAY	2 DAY	3 DAY	4 DAY	5 DAY	6 DAY	7 DAY	8 DAY	9 DAY	10 DAY	15 DAY	20 DAY	25 DAY	30 DAY
MEAN EXTREME(MM)	63.1	79.1	93.2	105.2	117.7	132.0	140.5	148.4	155.3	162.9	201.3	231.7	261.4	290.5
STD. DEV.(MM)	18.9	22.0	24.5	29.2	30.5	34.7	36.3	36.2	36.9	38.9	50.4	53.2	59.9	66.2
YEARS ANALYSED	51.0	51.0	51.0	51.0	51.0	51.0	51.0	51.0	51.0	51.0	51.0	51.0	51.0	51.0

** NOTE ** MEAN AND STANDARD DEVIATION HAVE BEEN ADJUSTED FOR ONE OBSERVATION PER DAY.

NOTE ** VALUE IN FLAG INDICATES YEAR NOT INCLUDED IN ANALYSIS BASED ON % DAYS OPERATIONAL (<90.0%)

ATMOSPHERIC ENVIRONMENT SERVICE
RAINFALL INTENSITY, DURATION, FREQUENCY VALUES
PREPARED BY THE HYDROMETEOROLOGY DIVISION, CANADIAN CLIMATE CENTRE

STATION : Comox A STATION NUMBER 1021830

CRITICAL PERIOD : 1ST OF MONTH 01 TO THE END OF MONTH 12 NOTE : MODIFIED GUMBEL 12/82

RETURN PERIOD VALUES (MM) WITH 50% CONFIDENCE LIMITS

RETURN PERIOD YEARS	1 DAY	2 DAY	3 DAY	4 DAY	5 DAY
2	59.95+/- 1.64	75.50+/- 1.90	89.20+/- 2.13	100.46+/- 2.53	112.72+/- 2.64
5	76.64+/- 2.76	94.92+/- 3.21	110.87+/- 3.58	126.24+/- 4.26	139.63+/- 4.44
10	87.72+/- 3.73	107.80+/- 4.33	125.25+/- 4.84	143.36+/- 5.76	157.48+/- 6.01
25	101.69+/- 5.02	124.05+/- 5.84	143.39+/- 6.52	164.94+/- 7.76	180.00+/- 8.10
50	112.05+/- 6.01	136.10+/- 6.99	156.84+/- 7.80	180.95+/- 9.28	196.70+/- 9.69
100	122.35+/- 7.00	148.08+/- 8.14	170.21+/- 9.09	196.87+/-10.82	213.31+/-11.29
PROBABLE MAXIMUM RAINFALL	378.40	451.27	510.91	605.06	637.69

RETURN PERIOD YEARS	6 DAY	7 DAY	8 DAY	9 DAY	10 DAY
2	126.31+/- 3.01	134.53+/- 3.15	142.49+/- 3.14	149.25+/- 3.20	156.54+/- 3.37
5	156.94+/- 5.06	166.60+/- 5.30	174.47+/- 5.28	181.83+/- 5.38	190.86+/- 5.67
10	177.27+/- 6.84	187.89+/- 7.16	195.69+/- 7.14	203.46+/- 7.27	213.64+/- 7.66
25	202.90+/- 9.22	214.73+/- 9.65	222.46+/- 9.62	230.73+/- 9.81	242.36+/-10.33
50	221.91+/-11.03	234.63+/-11.55	242.30+/-11.51	250.95+/-11.73	263.65+/-12.35
100	240.82+/-12.85	254.43+/-13.45	262.04+/-13.41	271.06+/-13.67	284.83+/-14.39
PROBABLE MAXIMUM RAINFALL	723.27	759.63	767.43	786.22	828.52

RETURN PERIOD YEARS	15 DAY	20 DAY	25 DAY	30 DAY
2	193.08+/- 4.36	222.99+/- 4.61	251.60+/- 5.19	279.64+/- 5.74
5	237.55+/- 7.34	269.94+/- 7.76	304.53+/- 8.74	338.10+/- 9.66
10	267.06+/- 9.93	301.10+/-10.48	339.66+/-11.81	376.89+/-13.05
25	304.27+/-13.38	340.40+/-14.13	383.96+/-15.93	425.81+/-17.59
50	331.87+/-16.01	369.54+/-16.90	416.81+/-19.06	462.09+/-21.04
100	359.31+/-18.65	398.52+/-19.70	449.48+/-22.20	498.16+/-24.52
PROBABLE MAXIMUM RAINFALL	******	******	******	******

HYDRAULIC SUMMARY TABLE

APPENDIX B

Hydraulic Summary Table

Each identified deficiency location is quantified by:
1. Culvert - flow, head loss, and water depth at the inlet
2. Flooding - maximum flood elevation and approximate duration of surface ponding
3. Channel Sections - maximum flow in the channel and maximum flood elevation

LOCATION / DESCRIPTION	RETURN PERIOD					ALTERNATIVES (10 yr future cond.)				RECOMMENDED ALTERNATIVE	RECOMMENDED IMPROVEMENTS
			PRE-DEV	EXISTING	FUTURE	# 1	#2	#3	#4		
1. Private crossing on Heidi May's property 4 - 600 mm diam approximated road elev. = 60.37 m	5	flow, m^3/s	1.89	1.16	1.48					1.55	Upgrade to 2 - 1200mm by 600mm arch culverts with flush headwalls.
		head loss, m	.28	.11	.12					.11	
		water elevation, m	60.19	59.85	60.00					59.90	
	10	flow, m^3/s	2.08	1.28	1.67	1.75	1.75	1.75	1.75	1.81	
		head loss, m	.31	.11	.14	.23	.23	.23	.23	.16	
		water elevation, m	60.37*	59.91	60.09	60.13	60.13	60.13	60.13	59.99	
	100	flow, m^3/s	2.11	1.93	2.07					2.14	
		head loss, m	.32	.28	.31					.21	
		water elevation, m	60.38*	60.33	60.37*					60.23	
	Nov/98 storm	flow, m^3/s		2.11							
		head loss, m		.31							
		water elevation, m		60.39*							
2. North of Idiens Way bank elev. = 57.21 m	5	flow, m^3/s	1.84	1.27	1.60					1.74	None
		flood elev., m	57.31	57.06	57.14					57.16	
	10	flow, m^3/s	2.15	1.40	1.82	1.88	1.87	1.88	1.88	1.78	
		flood elev., m	57.34	57.10	57.26	57.20	57.21	57.21	57.21	57.28	
	100	flow, m^3/s	2.30	2.12	2.32					2.49	
		flood elev., m	57.35	57.34	57.35					57.36	
	Nov/98 storm	flow, m^3/s		2.45							
		flood elev., m		57.36							

Note:
- Recommended Alternative includes Highwood detention pond improvements and storm water facilities in the Regional District.
- Water level which exceeds road elevation is denoted by an asterisk (*).
- The control structure at Crown Isle is assumed to be working as designed (ie. limiting discharge to 0.75 m^3/s for events < 100 year return period).

LOCATION / DESCRIPTION	RETURN PERIOD					ALTERNATIVES (10 yr future cond.)				RECOMMENDED ALTERNATIVE	RECOMMENDED IMPROVEMENTS
			PRE-DEV	EXISTING	FUTURE	# 1	#2	#3	#4		
3. Roadside Ditch on Idiens way (downstream from proposed detention pond)	5	flow, m^3/s	.14	.17	.30					.25	None
		flood elev., m	55.39	55.21	55.37					55.31	
	10	flow, m^3/s	.19	.24	.36	.29	.29	.29	.29	.29	
		flood elev., m	55.50	55.31	55.41	55.37	55.37	55.37	55.37	55.37	
	100	flow, m^3/s	.37	.45	.56					.34	
		flood elev., m	55.57	55.52	55.63					55.51	
4. Idiens Way culvert 1370 mm CSP approximated road elev. = 56.11 m	5	flow, m^3/s	1.85	1.30	1.80					1.60	None
		head loss, m	.55	.42	.51					.48	
		water elevation, m	55.40	55.21	55.37					55.30	
	10	flow, m^3/s	2.12	1.52	1.72	1.77	1.77	1.77	1.77	1.71	
		head loss, m	.59	.48	.53	.52	.52	.52	.52	.51	
		water elevation, m	55.50	55.30	55.41	55.36	55.36	55.36	55.36	55.34	
	100	flow, m^3/s	2.35	2.07	2.34					2.23	
		head loss, m	.63	.57	.48					.59	
		water elevation, m	55.57	55.52	55.63					55.52	
	Nov/98 storm	flow, m^3/s		2.62							
		head loss, m		.56							
		water elevation, m		55.75							
5. West of Anderton Road bank elev. = 50.45 m	5	flow, m^3/s	2.02	1.75	2.19					2.04	None
		flood elev., m	50.36	50.31	50.39					50.36	
	10	flow, m^3/s	2.26	1.92	2.40	2.27	2.27	2.27	2.27	2.28	
		flood elev., m	50.39	50.35	50.41	50.39	50.39	50.39	50.39	50.39	
	100	flow, m^3/s	2.71	2.52	2.84					2.80	
		flood elev., m	50.56	50.54	50.57					50.57	
	Nov/98 storm	flow, m^3/s		3.52							
		flood elev., m		50.60							

Note:

- Recommended Alternative includes Highwood detention pond improvements and storm water facilities in the Regional District.
- Water level which exceeds road elevation is denoted by an asterisk (*).
- The control structure at Crown Isle is assumed to be working as designed (ie. limiting discharge to 0.75 m^3/s for events < 100 year return period).

LOCATION / DESCRIPTION	RETURN PERIOD					ALTERNATIVES (10 yr future cond.)				RECOMMENDED ALTERNATIVE	RECOMMENDED IMPROVEMENTS
			PRE-DEV	EXISTING	FUTURE	# 1	#2	#3	#4		
6. Anderton Road culvert 1600 x 920 mm arch approximated road elev. = 47.35 m	5	flow, m^3/s	2.11	1.89	2.32					1.96	Upgrade to 1830 mm by 970 mm arch culvert with flush headwalls and wing walls.
		head loss, m	.26	.21	.33					.22	
		water elevation, m	46.64	46.68	46.89					46.66	
	10	flow, m^3/s	2.38	2.15	2.55	2.18	2.18	2.18	2.18	2.17	
		head loss, m	.33	.27	.39	.27	.27	.27	.27	.19	
		water elevation, m	46.76	46.84	47.04	46.81	46.81	46.81	46.81	46.70	
	100	flow, m^3/s	2.92	2.71	2.23					2.80	
		head loss, m	.50	.44	.54					.31	
		water elevation, m	47.23	47.08	47.47*					47.09	
	Nov/98 storm	flow, m^3/s		3.83							
		head loss, m		.57							
		water elevation, m		47.61*							
7. Roadside Ditch North of Anderton Road Culvert (downstream from proposed detention pond)	5	flow, m^3/s	1.39	1.31	1.39					.79	None
		flood elev., m	46.58	46.53	46.58					46.40	
	10	flow, m^3/s	1.17	1.63	1.70	.94	.93	.94	.93	.93	
		flood elev., m	46.46	46.59	46.66	46.48	46.48	46.48	46.48	46.48	
	100	flow, m^3/s	2.27	.80	2.73					1.64	
		flood elev., m	46.82	46.66	46.99					46.73	
8. Roadside Ditch South of Anderton Road Culvert (downstream from proposed detention pond)	5	flow, m^3/s	.59	1.02	1.24					.59	None
		flood elev., m	46.36	46.52	46.57					46.40	
	10	flow, m^3/s	.69	1.13	1.34	.66	.66	.66	.66	.66	
		flood elev., m	46.46	46.58	46.66	46.48	46.48	46.48	46.48	46.48	
	100	flow, m^3/s	1.42	4.85	2.15					1.00	
		flood elev., m	46.82	46.68	46.98					46.72	

Note:

- Recommended Alternative includes Highwood detention pond improvements and storm water facilities in the Regional District.
- Water level which exceeds road elevation is denoted by an asterisk (*).
- The control structure at Crown Isle is assumed to be working as designed (ie. limiting discharge to 0.75 m^3/s for events < 100 year return period).

LOCATION / DESCRIPTION	RETURN PERIOD					ALTERNATIVES (10 yr future cond.)				RECOMMENDED ALTERNATIVE	RECOMMENDED IMPROVEMENTS
			PRE-DEV	EXISTING	FUTURE	# 1	#2	#3	#4		
9. Detention Pond on east border of Birkdale Farms	5	flood elev., m		37.84	37.96					37.81	Increase berm height to a minimum of 0.56 m with 2H:1V side slopes.
	10	flood elev., m		37.99	38.12	38.34	38.34	38.34	38.34	37.91	
	100	flood elev., m		38.27	38.38					38.47	
	Nov/98 storm	flood elev., m		38.79							
10. Ponding upstream of Guthrie Road culvert estimated field elev. = 37.03 m	5	flood elev., m	37.72	37.83	37.95					37.70	None
		duration, hrs	10	14	18					12	
	10	flood elev., m	37.92	37.98	38.12	37.71	38.04	37.65	37.94	37.83	
		duration, hrs	12	18	24	12	18	10	24	12	
	100	flood elev., m	38.31	38.26	38.40					38.19	
		duration, hrs	12	30	30					24	
	Nov/98 storm	flood elev., m		38.79							
		duration, hrs		32							
11. Guthrie Road culvert 1750 x 1000 mm elliptical road elev. =39.14 m	5	flow, m^3/s	2.41	2.61	2.84					3.23	Upgrade to 1650 mm diameter concrete culvert with flush headwalls and wing walls.
		head loss, m	.44	.52	.59					.38	
		water elevation, m	37.72	37.83	37.95					37.70	
	10	flow, m^3/s	2.78	2.89	3.09	4.13	3.10	4.20	2.82	3.65	
		head loss, m	.58	.62	.70	.26	.75	.30	.59	.45	
		water elevation, m	37.92	37.98	38.11	37.71	38.04	37.66	37.94	37.83	
	100	flow, m^3/s	3.41	3.32	3.54					4.61	
		head loss, m	.85	.80	.90					.72	
		water elevation, m	38.31	38.26	38.40					38.19	
	Nov/98 storm	flow, m^3/s		4.09							
		head loss, m		1.19							
		water elevation, m		38.79							

Note:

- Recommended Alternative includes Highwood detention pond improvements and storm water facilities in the Regional District.
- Water level which exceeds road elevation is denoted by an asterisk (*).
- The control structure at Crown Isle is assumed to be working as designed (ie. limiting discharge to 0.75 m^3/s for events < 100 year return period).

LOCATION / DESCRIPTION	RETURN PERIOD		PRE-DEV	EXISTING	FUTURE	ALTERNATIVES (10 yr future cond.) # 1	#2	#3	#4	RECOMMENDED ALTERNATIVE	RECOMMENDED IMPROVEMENTS
12. Downstream of Guthrie Road culvert bank elev. = 36.80 m	5	flow, m^3/s	2.41	2.61	2.83					3.22	Remove gravel bar, large debris, and channel vegetation. Channel section of 3.9 m base width and 2H:1V side slopes.
		flood elev., m	37.21	37.24	37.27					37.23	
	10	flow, m^3/s	2.78	2.88	3.09	4.13	3.09	4.20	2.81	3.65	
		flood elev., m	37.26	37.27	37.32	37.38	37.17	37.28	37.27	37.27	
	100	flow, m^3/s	3.41	3.32	3.54					4.61	
		flood elev., m	37.36	37.35	37.38					37.35	
	Nov/98 storm	flow, m^3/s		4.09							
		flood elev., m		37.46							
13. Salish Street culvert 1800 x 1150 mm pipe arch road elev. = 35.74 m	5	flow, m^3/s	2.38	2.66	2.85					3.20	Upgrade to 1650 mm diameter concrete culvert with flush head walls and wing walls. Erosion protection at inlet and outlet.
		head loss, m	.34	.38	.42					.26	
		water elevation, m	34.70	34.83	34.94					34.60	
	10	flow, m^3/s	2.73	2.90	3.09	3.99	3.10	4.05	2.84	3.61	
		head loss, m	.39	.43	.48	.32	.49	.32	.42	.29	
		water elevation, m	34.87	34.98	35.10	34.76	34.95	34.77	34.93	34.70	
	100	flow, m^3/s	3.35	3.35	3.57					4.65	
		head loss, m	.54	.54	.58					.41	
		water elevation, m	35.28	35.28	35.47					34.96	
	Nov/98 storm	flow, m^3/s		4.07							
		head loss, m		.71							
		water elevation, m		35.79*							

Note:

- Recommended Alternative includes Highwood detention pond improvements and storm water facilities in the Regional District.
- Water level which exceeds road elevation is denoted by an asterisk (*).
- The control structure at Crown Isle is assumed to be working as designed (ie. limiting discharge to 0.75 m^3/s for events < 100 year return period).

LOCATION / DESCRIPTION	RETURN PERIOD					ALTERNATIVES (10 yr future cond.)				RECOMMENDED ALTERNATIVE	RECOMMENDED IMPROVEMENTS
			PRE-DEV	EXISTING	FUTURE	# 1	#2	#3	#4		
14. Between Salish Street and Pritchard Road bank elev. = 34.39 m	5	flow, m^3/s	2.37	2.63	2.82					3.20	Implement erosion protection where needed.
		flood elev., m	34.08	34.19	34.28					34.05	
	10	flow, m^3/s	2.70	2.87	3.05	3.98	3.07	4.03	2.81	3.61	
		flood elev., m	34.22	34.31	34.42	34.21	34.36	34.22	34.25	34.10	
	100	flow, m^3/s	3.31	3.31	3.53					4.64	
		flood elev., m	34.54	34.56	34.66					34.24	
	Nov/98 storm	flow, m^3/s		4.05							
		flood elev., m		34.82							
15. Pritchard Road culvert 1700 x 1150 mm pipe arch road elev. = 34.61 m	5	flow, m^3/s	2.36	2.63	2.82					3.20	Upgrade to a 2400 mm by 1500 mm concrete box culvert with flush headwalls and wing walls.
		head loss, m	.37	.42	.48					.12	
		water elevation, m	34.03	34.15	34.25					33.69	
	10	flow, m^3/s	2.70	2.87	3.06	3.99	3.08	4.03	2.81	3.62	
		head loss, m	.44	.50	.57	.31	.55	.31	.48	.13	
		water elevation, m	34.18	34.29	34.40	34.11	34.27	34.13	34.25	33.77	
	100	flow, m^3/s	3.31	3.31	3.54					4.65	
		head loss, m	.65	.65	.71					.12	
		water elevation, m	34.53	34.53	34.65*					34.12	
	Nov/98 storm	flow, m^3/s		4.06							
		head loss, m		.79							
		water elevation, m		34.82*							

Note:

- Recommended Alternative includes Highwood detention pond improvements and storm water facilities in the Regional District.
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- The control structure at Crown Isle is assumed to be working as designed (ie. limiting discharge to 0.75 m^3/s for events < 100 year return period).

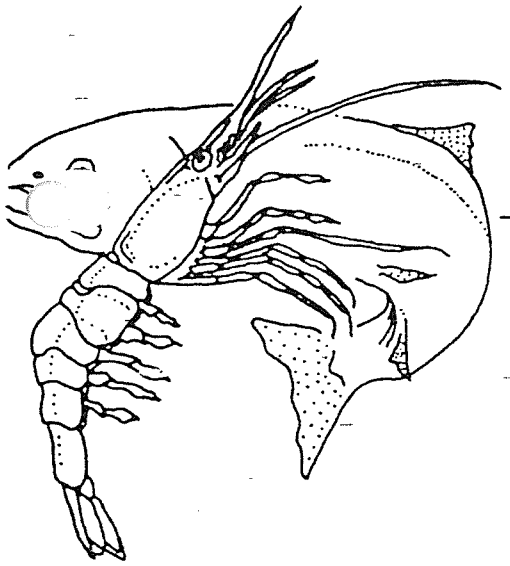
LOCATION / DESCRIPTION	RETURN PERIOD					ALTERNATIVES (10 yr future cond.)				RECOMMENDED ALTERNATIVE	RECOMMENDED IMPROVEMENTS
			PRE-DEV	EXISTING	FUTURE	# 1	#2	#3	#4		
16. Noel Avenue culverts (2 culvert crossing)	5	flow, m^3/s	1.12	1.38	1.52						Upgrade to a 2400 mm by 1500 mm concrete box culvert with flush headwalls and wing walls. Erosion protection is needed at the inlet.
		head loss, m	.50	.56	.58						
		water elevation, m	30.87	30.97	31.01						
a) 1500 x 1000 mm elliptical	10	flow, m^3/s	1.38	1.55	1.69		1.48		1.50		
		head loss, m	.56	.59	.61		.56		.58		
east culvert		water elevation, m	30.97	31.02	31.07		30.99		31.00		
road elev. = 32.06 m	100	flow, m^3/s	1.85	1.99	2.11						
		head loss, m	.64	.65	.68						
		water elevation, m	31.13	31.16	31.21						
	Nov/98 storm	flow, m^3/s		2.54							
		head loss, m		.70							
		water elevation, m		31.36							
b) 900 mm CSP	5	flow, m^3/s	1.26	1.33	1.38					3.29	
west culvert		head loss, m	.46	.47	.49					.32	
road elev. = 32.06 m		water elevation, m	30.87	30.97	31.01					30.44	
	10	flow, m^3/s	1.33	1.39	1.44	4.09	1.66	4.14	1.37	3.71	
		head loss, m	.48	.49	.51	.72	.69	.72	.49	.42	
		water elevation, m	30.97	31.02	31.07	31.02	30.99	31.03	31.00	30.61	
	100	flow, m^3/s	1.48	1.49	1.51					4.77	
		head loss, m	.53	.53	.56					.45	
		water elevation, m	31.13	31.16	31.21					30.73	
	Nov/98 storm	flow, m^3/s		1.58							
		head loss, m		.61							
		water elevation, m		31.36							

Note:

- Recommended Alternative includes Highwood detention pond improvements and storm water facilities in the Regional District.
- Water level which exceeds road elevation is denoted by an asterisk (*).
- The control structure at Crown Isle is assumed to be working as designed (ie. limiting discharge to 0.75 m^3/s for events < 100 year return period).

FISHERIES RESOURCE, HABITAT, AND DEVELOPMENT IMPACT ASSESSMENT

APPENDIX C



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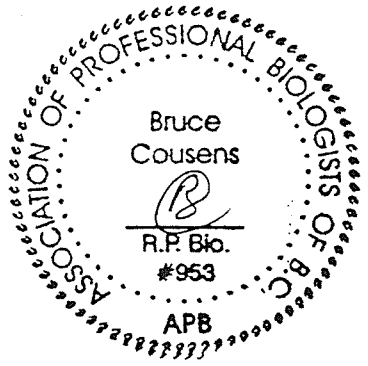
Preliminary Fisheries Resource, Habitat and Development Impact Assessment of Brooklyn Creek in Comox-Courtenay, BC

by

Bruce Cousens and Charlene Lee

April 12, 1999



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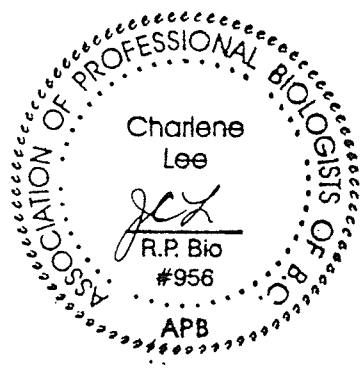
On behalf of: *The Town of Comox*
The City of Courtenay
The Regional District of Comox-Strathcona



1.0 Introduction

J.C. Lee & Associates Ltd. (Nanaimo) was requested by *Associated Engineering Ltd.* (Vancouver) to provide a fisheries resource and habitat assessment of Brooklyn Creek as part of the process of developing a Watershed Management Plan for the three jurisdictions occupying the Brooklyn Creek watershed (the Town of Comox, the City of Courtenay and the Regional District of Comox-Strathcona). We were also asked to provide advice and recommendations concerning in-stream work procedures and avoidance or mitigation of impacts to fish habitat during the course of any necessary operations in or around the channel to alleviate recent increased flooding problems. It was recognized that since Brooklyn Creek is known to support a coho salmon population and has already been the target of several salmonid enhancement projects, protection and improvement of salmonid habitat should be an integral part of further works involving stormwater management and flood control in the watershed.

Since initial logging, the Brooklyn Creek watershed has had a long history of rural/agricultural development and more recently, rapidly expanding urban development, with over a century of accumulated land use impacts to the stream channel and riparian area. These impacts have had a cumulative effect in degradation and loss of fish habitat, which was neither recognized nor of wide public concern for most of this period. However, the same impacts and lack of concern that have resulted in habitat degradation are now beginning to cause urban flooding and property damage. Recognition and gradual restoration of this habitat loss and degradation are consistent with administrative objectives of preventing flooding, erosion and property damage, and a necessary component of overall watershed management for salmon stocks to survive.

2.0 Methods

2.1 *Review of background information*

Available documentation was reviewed for data relevant to this study, including the appropriate Fish Habitat Inventory and Information Program (FHIIP) Stream Summary Catalogue for Fisheries Subdistrict 14N, prepared by Dept. of Fisheries and Oceans (DFO) and Min. of Environment, Lands and Parks (MELP); the Comox-Strathcona Sensitive Habitat Atlas; previous reports concerning sediment deposition and control of flooding in the Birkdale Farm - Guthrie Rd. area by R. Kellerhals, P.Eng., Calvin Cheng (DFO engineering and enhancement staff) and others; and other available background information on Brooklyn Creek. Fisheries resources, stock history, habitat concerns and previous enhancement projects in this system were discussed with Brian Allen and Chris Hilliar of the DFO office in Comox.

The MELP Conservation Data Centre in Victoria was also contacted to obtain any information in their database documenting records of occurrence of rare or endangered animals or plants within the watershed, as well as environmentally sensitive areas (ESAs) identified within the watershed during the recent joint MELP/Canadian Wildlife Service (CWS) East Vancouver Island Sensitive Ecosystem Inventory.

2.2 *Field inspection*

Brooklyn Creek was inspected on a number of occasions during the winter and spring of 1998-99, over a range of discharge conditions from winter storm peak flows (late Nov.-Jan.) to spring base flows (March), and observations were made of flooding, sediment loading; debris accumulations and backwatering; bank erosion and sediment deposition; streambank and streambed material, condition and past disturbance;

presence of in-stream stable large woody debris important for channel stability, gravel retention and cover; riparian vegetation type, abundance and cover; presence and abundance of benthic invertebrates important as food for fish; and visible fish presence.

Sampling effort to document presence, distribution and relative abundance of juvenile salmonids was not undertaken and was not considered necessary, given existing documentation and anecdotal reports, previous enhancement projects, visible presence of adult coho spawners throughout the system in Nov.-Dec. '98, and high flow conditions over most of the study period.

3.3 *Water quality assessment*

The timing of this initial phase of the study during winter high flows (and in a year with unusually high winter rainfall) precluded water quality sampling to date. Little useful water quality information (other than sediment loading) can be collected during winter high flows, due to the constant high rate of flushing. Of particular interest for water quality determination in an urban and rural agricultural area are samples collected during spring base flows as rainfall subsides (baseline contaminant levels), summer low flows (minimum dilution and flushing, maximum residence time and water temperature) and late summer or early fall "first flush" conditions (peak contaminant levels with initial flushing of any accumulations over a prolonged dry period). These samples will be collected at appropriate times during the 1999 spring-fall period. Several additional samples will be collected if necessary to determine winter peak flow sediment loading. Samples will be collected at the following 3 locations:

(i) Parry Place, downstream of Longlands and Crown Isle golf courses and residential development;
(ii) Guthrie Rd., downstream of the urban-agricultural area but upstream of the urban area;
(iii) in Mack Laing Park off Comox Ave., downstream of the urban area but upstream of tidal influence.

This 3-point sampling approach at significant watershed development and land use type boundaries will help in localizing the source of any contaminant levels of concern that may be identified.

3.0 Results and Discussion

3.1 *Presence and distribution of salmonids*

Brooklyn Creek is well known to be a salmonid bearing stream, as documented by the DFO/MELP Fish Habitat Inventory and Information Program (FHIIP, 1991) and has been the target of a number of salmon habitat enhancement projects in the past two decades (B. Allen, pers. comm.). The system supports primarily coho (*Oncorhynchus kisutch*) and coastal cutthroat trout (*O. clarki*) with a few chum (*O. keta*) and pink (*O. gorbuscha*) salmon utilizing the lower reaches, between the mouth and the Balmoral Ave. fishway in Mack Laing Park. Small numbers of salmon returning to the stream to spawn have not been closely monitored in recent years, and coho returns are particularly difficult to estimate because they arrive and spawn during winter high flow conditions when visibility is poor, but returns of up to 60 spawners were reported during the 1980's.

Construction of the fishway downstream of Balmoral Ave. in the 1980s restored anadromous salmonid access to areas upstream of a hanging culvert under the road that had previously formed a complete barrier to fish passage for many years, isolating all but the lower 500m of the channel. The coho stock was

enhanced (or possibly re-introduced) with transfer and release into Brooklyn Creek of 50 adult coho spawners from the Puntledge Hatchery in 1989.

The entire system to Parry Place is accessible at high flows during fall and winter to adult coho spawners (Oct.-Dec.). After the Nov. 23/98 >1:100 yr storm coho were observed by the survey crew and DFO staff and reported by others throughout the system almost to Parry Place, and there was one report of dog (chum) salmon in the Guthrie Rd. - Birkdale Farm area, though most of the habitat with gravel suitable for spawning is in the lower reaches below Noel Ave. The entire system to at least Parry Place is accessible at most flow levels to coho fry and juveniles (which spend their first year in the river after emergence from the gravel in spring and readily move upstream into any available suitable rearing habitat), as well as anadromous and fresh water-resident cutthroat trout.

Sampling effort to further document presence and distribution of adult and/or juvenile salmonids was considered unnecessary, given the FHIIP documentation, past enhancement work, the presence of adult coho spawners throughout the system in Nov.-Dec., 1998, and past reports of coho fry at the outflow of the Crown Isle culvert at Parry Place, combined with the timing of the study during the winter high rainfall period and limited field budget. The system appears capable of supporting and is considered to support juvenile coho salmon and cutthroat trout year-round downstream of Parry Place (where low summer flows permit), with as yet undetermined distribution and abundance. This area is also accessible throughout for coho and cutthroat spawning where suitable gravels permit during winter high flows, though most suitable gravel and likely most coho spawning occurs downstream of Noel Ave.

3.2 *Assessment of salmonid habitat*

Without engaging in a detailed reach-by-reach stream assessment process that is beyond the scope and budget of this study (but a desirable starting point for a community stream stewardship group), it is possible to subdivide the watershed into three major sections on the basis of general land use type, with a more general habitat evaluation within these sections, as follows:

(i) the Crown Isle golf course and residential development, Longlands Golf Course and adjacent headwaters area upstream of Parry Place;

(ii) the rural-agricultural section between Parry Place and Guthrie Rd. (which may be further subdivided into a mainly rural component upstream of Anderton Rd. and a mainly agricultural component downstream of Anderton Rd.);

(iii) the heavily urbanized residential section downstream of Guthrie Rd., within the Town of Comox.

The headwaters section upstream of Parry Place is reportedly inaccessible to fish, with a ~300m steel culvert and impassable manhole intake structure separating the open channel at Parry Place and the final stormwater detention pond ("Pond #20") at the downstream end of the Crown Isle development. Other culverts entering the channel at Parry Place are not passable to adult salmon except perhaps for brief periods during extreme flows, do not provide access to spawning habitat, and while likely passable to juvenile salmon at high flows, are dry much of the year and do not provide access to rearing habitat.

However, all of these areas drain directly into fish habitat downstream, so water quality and quantity (peak winter flow and low summer flow) concerns are significant for habitat quality, fish health, egg-to-fry survival in downstream spawning areas and juvenile survival through the in-stream rearing stage. Any excessive peak flows that may arise from these areas will cause additional channel scouring and bank erosion, with sediment deposition and possible flooding impacts downstream. Lack of summer flow to

supply the channel downstream is a particular concern, though there is little available surface or in-ground storage capacity in this area at present to augment summer flows. While storm water detention may effectively control most peak storm flows, temporarily retained water must be released before the next winter storm, offering no benefit to low summer flows. Increased storage capacity for slow summer release and/or artesian well supplies are enhancement possibilities to consider.

The rural-agricultural area between Parry Place and Guthrie Rd. is accessible to adult spawners at high flows, though gravel suitable for spawning is very limited, and provides rearing habitat for juvenile salmonids year-round or as long as low summer flow persists. The low-gradient ditched artificial channel parallelling property lines downstream of Parry Place has a clay/till streambed with small shallow patches of gravel, no in-stream debris cover, negligible pool-riffle complexing, near vertical banks subject to erosion at high flows, limited shrub cover along the streambank and no crown (tree or tall shrub) cover to shade the stream. Without enhancement and restoration work to address these deficiencies this area of the channel provides negligible spawning habitat and poor quality winter rearing habitat which likely dries in summer.

The channel section immediately downstream, above Idiens Way, is wider and more shallow with a slightly steeper gradient, and has some patches of shallow gravel, limited in-stream pool-riffle structure and both streambank shrub cover and forest crown cover. This area also provides little spawning habitat, but contains some moderately good quality rearing habitat for as long as stream flow persists. The section downstream of Idiens Way to Anderton Rd. is similar in gradient and structure, but lacks in-stream debris cover, bank cover and crown cover, so rearing habitat quality is degraded without enhancement to address these deficiencies.

Downstream of Anderton Rd. to Guthrie Rd. the stream flows through agricultural fields, including Birkdale Farm. The channel has been excavated to increase capacity in some areas and the streambed lies on clay/till with patches of cobble, gravel and (near Guthrie Rd.) deposits of fine gravel and sand. In-stream woody debris cover is absent and pool-riffle structure is minimal or absent due to ditching, scour at high flows and sediment deposition. Banks are often steep, un-vegetated and subject to erosion (and on the outer radius of curves have rip-rap to retard erosion). Shrubby riparian vegetation is present in some areas (particularly on the south bank) and lacking in others, and crown cover is entirely lacking. This section provides little or no suitable salmon spawning habitat (but may be suitable for trout spawning) and likely provides poor to moderate juvenile rearing habitat while summer flows persist. There is also the potential here (and elsewhere) for fry to become trapped in shallow pools as summer flows subside, where they are unlikely to survive due to high water temperatures, predation and further drying.

Downstream of Guthrie Rd. the stream flows through Salish Park for about 500m, then through a heavily urbanized portion of the Town of Comox. Within the upstream portion of Salish Park the channel contains a large wedge-shaped deposit of mostly fine gravels, sand and silt, some of which is exposed during low summer flows and has been invaded by shrubby streambank vegetation (willow and ninebark). This in-channel shrub vegetation traps additional sediment and floating debris, including vegetation from eroding banks, forming debris jams which retard flow and accelerate further sediment deposition, shallowing of the channel and bank erosion as the stream cuts new channels around these obstructions. This portion of the channel provides potentially excellent coho rearing habitat with good bank and crown vegetation cover, but has been severely degraded by high flows, large debris removal and sediment deposition. Any spawning habitat that may have once existed here has been buried in fine sediments and most stable in-stream cover and insect fish food production capacity has been lost. Loss of stable large woody debris and

pool-riffle structure may have occurred as a result of high flows, but likely began long before while the surrounding land was used for agriculture. The shortage of large older trees in the narrow vegetated riparian area bordering the channel severely limits the available supply of large woody debris (although a number of recently felled large and still mostly intact conifers in this area present a habitat enhancement opportunity if used correctly and not cut up for firewood).

Downstream of Salish Park the stream flows through or between urban back yards, often with clearing and landscaping to the streambank, attempts at channel and bank stabilization, a channelized section adjacent to the school grounds downstream of Noel Ave., and a variety of other impacts of urbanization and human use. Little spawning habitat for coho is present due to either deposition of sand and fine gravels (though some of the latter may provide suitable spawning substrate for cutthroat), or a streambed of cobble or bare till in channelized areas with scouring at high flows. In-stream debris cover is lacking, bank and crown cover are variable and bank erosion is occurring at some points, particularly where the channel is confined by the till layer and can only erode laterally at high flows. Intrusion of grasses and rushes into shallow portions of the channel on sediment deposits indicates these areas are exposed at low summer flows with inadequate shade cover, and presence of this vegetation promotes additional fine sediment accumulation. This section of the stream thus provides moderate to poor quality rearing habitat for juvenile salmon, and enhancement opportunities are numerous.

Further downstream the channel becomes increasingly incised into deeper surface soils over the clay/till layer, and downstream of Dogwood Rd. lies on the floor of a 3-8m deep ravine which extends almost to the mouth. Most suitable spawning gravel in the system occurs within this lower urban section, but has been degraded by clogging with fine sediments from upland sources, transport of in-stream deposits and ongoing bank erosion upstream. This is a continuous process, since spawning salmon clean the gravel in which they deposit and bury their eggs, but subsequent sediment loading re-clogs the gravel with fine sediment after each storm event, suffocating the eggs and greatly reducing egg-to-fry survival.

This lower section of the stream, largely within forested Mack Laing Park, has moderate to good crown cover and some bank cover, so is relatively well shaded, and has limited pool-riffle structure in many areas, though this has been reduced by channel scouring at high flows and lack of large woody debris embedded in the channel. Despite forest cover, very little stable large woody debris is present due to a combination of flushing at high flows and ongoing disturbance and cutting of large branches and trees that fall into or across the stream, likely by park maintenance staff and/or private individuals concerned that this windfall material will initiate a debris jam and cause erosion and channel relocation. Some of this cut material may be removed for firewood, but the rest is left to wash downstream with the next freshet. Occasional minor accumulations of small woody debris occur, but these provide minimal in-stream cover and are unstable over time, so contribute little to long-term channel and streambed structure and stability. As a result, potentially excellent salmonid rearing habitat in this section is also considerably degraded, and juvenile survival and smolt production are likely quite low. Again, enhancement opportunities are numerous.

Throughout the entire system production of streambed insect larvae and other invertebrates important as food sources for fish is extremely limited, due to both the very limited supply of suitable coarse gravel substrate in the upper reaches, upstream of Guthrie Rd., and the clogging of suitable gravels throughout the system by fine sediments from upland exposed soil surface and bank erosion. In many locations submerged gravels and other surfaces had a covering of algal (likely diatom) film, but the expected benthic invertebrate community which feeds on this material and provides food for fish was almost entirely absent, though some recovery may occur during summer months. In summer a supply of drift insects that have

fallen into the stream from riparian shrubs and trees should be available as food (where summer flows persist), but in fall, winter and early spring this food supply is also absent. Autumn leaf and litter fall is a major energy and nutrient supply to small coastal streams, passed on to fish through the benthic invertebrate community that feeds on this material. In this system, because of the lack of a healthy benthic invertebrate community, most of this material is likely flushed from the system at high flows or buried in sediments with little benefit to the fish population.

3.2 *Soils, sediments and surface runoff and erosion*

Surface soils in much of the watershed are primarily poorly drained and highly erodible silts or silty sands, likely of glaciofluvial and possibly (in the lower watershed) post-glacial marine origin, with rich organic (peat) soils, likely from a previous wetland, in the Birkdale Farm area and a deposit of sands and fine gravels in the adjacent Highwood Subdivision area north of Guthrie Rd. The silts allow surface water from rainfall to penetrate slowly and promote surface pooling and sheet flow runoff without well defined channels in low relief areas. Removal of forest cover and the long history of agricultural use adds to the fine texture and slow drainage qualities of these soils after they become compacted when no longer worked for farming, partly due to breakdown and loss of porous organic humus materials, without replacement.

The surface soil layers are underlain by clay or clay/glacial till ("hardpan"), often within 20-30 cm of the surface in parts of the upper watershed and on or underlying the streambed. This material erodes slowly and is essentially impermeable to water, confining rainfall penetration to the shallow surface soil layers. A thin gravel layer is present between the surface soils and clay/till in some areas, mainly in the lower watershed, likely allowing some increased lateral movement of sub-surface water into the channel in these areas.

Beneath the till layer in much of the watershed is an interglacial sand/gravel deposit known geologically as the Quadra Sands (Kellerhals, 1996), which contains an aquifer accessible via shallow wells in rural-agricultural areas. Guy Sim of Birkdale Farm reports that well supply capacity from this aquifer has declined substantially in recent years, and suggests this may be a result of land use and development changes that have increased surface runoff and retarded aquifer recharge from infiltration of winter rainfall.

In the upper portions of the watershed, upstream of Guthrie Rd. and particularly upstream of Idiens Way, the stream channel has been enlarged by ditching and in some areas has been artificially created by ditching parallel to property lines to increase channel capacity and/or intercept and rapidly dispose of surface pooling and sheet flow runoff. In these areas the streambed has been excavated or scoured to or below the surface of the clay/till layer, and any streambed gravels from upstream bank erosion accumulate at deposition points to form a very shallow layer over the impermeable clay/till base. As a result, ground infiltration of water from the channel is minimal and gravel deposits suitable for salmonid spawning are shallow and extremely limited in area.

Significant sediment accumulation (mainly silt, sand and fine gravels) begins in the downstream portion of the channel through Birkdale Farm, where ponding of runoff and flooding has occurred in recent years, with sediment deposition for at least 100m upstream and 2-300m downstream of the culvert at Guthrie Rd. Much of this material has been deposited as a sediment bar or wedge downstream of the culvert. Some of this material may have originated from bank erosion further upstream, but most of it likely originated from the Highwood Subdivision area immediately upstream of Guthrie Rd., during the initial site clearing

and development stages. Neither an exposed source of this type of material nor significant erosion and sediment entry points (or similar major deposition points) were observed further upstream.

Increased peak flows during early phases of clearing and development of the Crown Isle property in the headwaters of Brooklyn Creek may have contributed to bank erosion and/or sediment transport in downstream reaches for a time, but there is no clear evidence of this occurring, and no indication that either elevated post-development flows or increased bank and channel erosion upstream of Anderton Rd. are occurring at present. Anecdotal reports of property owners encountered during the field survey indicate significantly elevated flows, high flood levels (e.g. over Pritchard Rd.) and sediment deposition during development of the Highwood property (now close to build-out), but not during development of the Crown Isle property (cleared, with a golf course, and at about 12% of the planned residential development), though these reports are not adjusted for possible variation in rainfall amounts.

3.3 *Land use and development impacts to fish habitat*

Like many other east Vancouver Island streams (Reid *et al*, 1999), Brooklyn Creek has a long history of land use and development impacts, which have had a large cumulative effect on the current condition of the channel and the quality of fish habitat therein. Most of these impacts have been negative, including:

- increased runoff and peak flows after logging, land clearing and agricultural and urban development without stormwater retention features to mitigate these impacts;
- loss of crown (tree/shrub) and bank (low shrub, root and stable undercut) cover in agricultural and urban areas, often due to ditching, channel enlargement and clearing to the stream bank;
- increased bank and channel erosion and sediment deposition and loss of stable large woody debris (in-stream cover) with increased peak flows and disturbance of the channel and banks;
- resulting changes in channel morphology, particularly widening and shallowing of the channel, filling and loss of pool areas, and much reduced wetted area with dry gravel benches at non-peak flows;
- clogging of streambed gravels with fine sediments from erosion upstream, which suffocate fish eggs and many insect larvae and other invertebrates that form important food resources for fish;
- "critically low" summer flows (FHIIP, 1991), likely with increased water temperatures and reduced oxygen levels detrimental to fish.

Throughout most of the past century the stream has served primarily as a disposal conduit for ever increasing post-agricultural and urban development runoff volume with little appreciation or concern for the cumulative long-term effects on fish habitat. As a result, salmonid habitat throughout most of the stream is now moderately to severely degraded and the salmonid production capacity is likely severely depressed.

A noticeable coho return was observed by streamside residents after floods in late November, 1998, "for the first time in at least five years", possibly as a result of the much-restricted coho fishery. With minimal harvest, virtually the entire Brooklyn Creek adult coho return from sea should have survived to spawn, giving an indication of the remaining stock size. Unfortunately, there is ample cause for concern that the degraded in-stream spawning and rearing habitat can only support a small proportion of the potential production capacity of the stream, seriously limiting the benefit of increased adult returns.

During the spring field survey in late March, when winter high flows and high turbidity had sufficiently declined to allow fish visibility, but fry from the fall 1998 spawning had presumably not yet emerged from the streambed gravels, small numbers of juvenile salmonids (probably coho parr produced from the 1997

adult return and young cutthroat trout) were observed in pools only in the downstream portion of Mack Laing Park, a short distance from the mouth. None were observed upstream, though some were likely present in the very limited available debris and bank cover areas, mainly downstream of Dogwood Ave. No fry were observed.

Visual examination of streambed gravels at a number of points in reaches downstream of Salish Park to the mouth indicated clogging with fine sediments sufficient to suffocate salmonid eggs, and very low numbers of overwintering aquatic insect larvae, which occupy small spaces in unclogged gravel and are important as food for fish. In-stream cover was also nearly absent. Salmonid egg-to-fry survival and juvenile rearing capacity in these areas thus appear to be significantly degraded.

Any streambed gravels that may have originally been present in the Salish Park - Guthrie Rd. area (after reported lowering of the culvert and cleaning of the adjacent channel circa 1982) have since been completely buried in fine sediments for about 100m upstream and 2-300m downstream of the Guthrie Rd. culvert, so that any former spawning capacity and/or streambed insect food production capacity have been lost. A wide shallow channel cross-section has developed, with vegetation and small debris obstructions but negligible large stable woody debris, promoting further bank erosion and deposition of fine sediments, rather than scouring and flushing with retention of coarser gravels and development of pool-riffle structure.

Upstream of Guthrie Rd., wetted streambed gravel-cobble area is very limited due to a trapezoidal channel cross-section ditched onto or into clay/till, scouring at high flows, lack of gravel retention structures (e.g. stable large debris) and limited gravel supply. Some clogging of available gravels with fine sediments was evident in these areas as well, likely as a result of bank erosion after channel ditching. Banks are stabilized with rip-rap at scour points in some areas to minimize further erosion.

In nature, sediment-clogged streambed gravels may be cleaned by two processes: *(i)* scouring during peak flows, and *(ii)* redd (nest)-digging by salmon during spawning, particularly where large numbers are present. Both of these processes are defeated if continued fine sediment loading is sufficient to re-clog gravels as peak flows subside.

3.4 *Environmentally sensitive areas (ESAs) within the watershed*

An inquiry to the Min. of Environment, Lands and Parks' (MELP) Conservation Data Centre (CDC) in Victoria listed several ESAs within the watershed, designated in the course of the recent joint MELP/Canadian Wildlife Service *East Vancouver Island Sensitive Ecosystem Inventory*, and also indicated in the *Comox-Strathcona Sensitive Habitat Atlas*. These include the older forest area bordering lower Brooklyn Creek within and adjacent to Mack Laing Park, and three small wetlands all located well off-channel east of the creek and Comox east town boundary and south of Noel Ave. The latter lie at or just outside the lower watershed boundary, and are not likely to be effected by flood control or salmonid enhancement works on the creek. The Mack Laing Park area is a valuable and popular community asset and is hopefully not subject to further significant disturbance. It should not suffer any negative impacts from flood control or salmonid enhancement works suggested or discussed herein.

Although not listed by the CDC as an ESA, likely due to recent creation and disturbance that may have been in progress during the inventory survey, the "duck pond" that provides minimal stormwater detention capacity for the Highwood Subdivision, north of Guthrie Rd., is both significant wetland wildlife habitat and a significant community recreational asset, though it may or may not (yet) provide effective salmonid

winter habitat. Increase of stormwater detention capacity in this area, if found to be desirable, should respect and at least maintain the wildlife habitat and recreational values of this site (most vegetation species present are tolerant of short duration winter flooding), and should also employ necessary measures to prevent the detention area from becoming a trap for overwintering salmonids, which cannot escape after peak flows decline. Salmonid access should either be prevented, or the expanded detention pond should be designed to provide wetland winter habitat, with an escape route for downstream migrants in spring.

No occurrences of rare or endangered plants or animals within the watershed are recorded by the CDC.

(During stream survey work in Mack Laing Park two Bald Eagle nests in an occupied territory were observed, one currently in use in a tall old Sitka spruce immediately south of the access to the park off the end of Comox Ave., and the other in an unidentified tall old tree, possibly a Douglas fir, near the creek mouth and shoreline. These nests are documented and protected from disturbance or removal under Section 34 of the BC Wildlife Act, and are not at risk or of concern for the purposes of this study.)

4.0 Conclusions and Recommendations

- It is clear from the field study and available historical information that:

(i) salmonid habitat has been severely degraded by impacts of historic land use and stormwater management practices, though fish access to habitat upstream of Balmoral Ave. has been restored and residual (possibly re-introduced) coho and likely cutthroat trout stocks are still present in the watershed; with sufficient recovery and enhancement effort these stocks can presumably be re-built;

(ii) a considerable sediment volume has been deposited in the channel in the vicinity of the Guthrie Rd. culvert since previous work to improve channel capacity in this area circa 1982, and streambed gravels have been clogged with fine sediments throughout reaches further downstream;

(iii) the accumulation of sediment and debris in the Guthrie Rd.- Salish Park area has been shown in three separate studies of varying scope (including a localized DFO study and this watershed management study) to be a major contributing factor to recent increasing flooding problems upstream at Birkdale Farm and in the adjacent residential area;

(iv) removal of at least a major portion of these materials from the channel in an environmentally acceptable manner that does not unnecessarily impact fish or fish habitat (with appropriate mitigation) will be necessary to prevent further property damage;

(v) numerous salmonid habitat restoration and enhancement opportunities exist throughout the watershed, but the success of these measures will depend on:

- reduction of current peak flow volumes, likely with additional stormwater retention capacity in the Guthrie Rd. area, to minimize further downstream channel erosion and sediment transport, combined with inclusion of adequate off-channel stormwater retention capacity in all future land use and development planning in the watershed;
(*if feasible*, it may also be beneficial to temporarily lower controlled peak flows from the Crown Isle stormwater detention facility and extend the detention period, as existing

storage capacity permits, at least during early residential development stages until additional off-channel detention capacity downstream is developed);
- control of soil surface erosion and prevention of sediment transport into the stream during all land development or disturbance, to greatly reduce or eliminate sediment loading;
- removal by acceptable methods of current large deposits of sediment from the stream channel adjacent to the Guthrie Rd. culvert (which will otherwise continue to move downstream and continue to clog spawning gravels and smother fish eggs and benthic invertebrates)
- eventual removal of fine sediments from clogged streambed gravels downstream to restore streambed in-gravel flow and invertebrate communities important in the fish food web;
- re-introduction of stable large woody debris and boulders to provide in-stream structure and cover, promote gravel retention and controlled fine sediment scouring, and help restore complex channel morphology and increase aquatic habitat diversity;
- provision of adequate summer flows to maintain functional fish habitat in the stream;

There is obviously little point in engaging considerable community effort and (hopefully) funding support in major habitat restoration and enhancement measures if these underlying causes of ongoing salmon habitat degradation are not addressed simultaneously, and it is unlikely that significant in-stream works to address flooding and erosion related issues will be approved unless salmon habitat restoration is a key component of the proposed work and the overall Brooklyn Creek Watershed Management Plan.

These issues can be resolved into the following critical processes:

(i) removal (with mitigation) of debris and sediment accumulations causing flooding and bank erosion;
(ii) reduction and control of peak flows throughout the system, likely by off-channel stormwater detention;
(iii) control of soil surface and bank erosion and elimination of sediment input from upland sources, with sediment trapping and removal as a design component of stormwater detention facilities;
(iv) restoration and enhancement of severely degraded salmonid habitat throughout the system;
(v) future augmentation of low summer flows to maintain and increase salmonid summer rearing habitat.

Given that *(i)*a hydraulic model of the Brooklyn Creek system has now been developed and there are still some uncertainties that remain to be evaluated in relation to this model; *(ii)* major environmental impacts and mitigation will be involved in significant in-stream work other than localized culvert maintenance; and *(iii)* time is short for project planning and submission of B.C. Water Act Section 9 Approvals and Notifications for in-stream work during the summer 1999 fisheries "in-stream work window", as well as for obtaining MELP and DFO approvals, a phased multi-year approach is recommended that focuses on the most significant, immediate and easily addressed problems initially. Specific recommendations and suggested staging include:

- Hand clearing of jams of small floating debris and clumps of in-stream vegetation which are trapping debris downstream of the Guthrie Rd. culvert in Salish Park. These are obstructing the channel, causing flooding upstream and promoting further sediment accumulation and bank erosion. Hand clearing will have minimal negative impact to fish and fish habitat on site or downstream, will help to alleviate the flooding problems by increasing channel capacity and reducing culvert backwatering, but should not increase peak flow volume so much that new flooding and erosion problems will be initiated downstream before more stormwater detention capacity is developed. **(Complete in 1999)**

- In the short term, hand clearing of debris will likely cause some of the accumulated sediment to be transported downstream during subsequent high flows (as will occur anyway) and ideally be flushed from the system, reducing the extent of future removal to restore a gravel streambed. This will at least continue if not temporarily increase the sediment impacts to downstream areas. These impacts may be reduced by upstream stormwater detention to reduce peak flows, possible temporary off-channel sediment trapping facilities constructed in the Salish Park area, and incubation of salmon eggs from returning spawners in suitable artificial structures, to avoid suffocation in the streambed by fine sediments and likely greatly increase egg-to-fry survival. **The latter is a key enhancement measure that is highly recommended and long overdue in this system.) (Initiate in 1999)**

- Removal of the heaviest accumulation of sediment immediately downstream of the Guthrie Rd. culvert by excavator or suction dredge, with appropriate downstream impact mitigation precautions and environmental monitoring. There is no other practical means of removing this volume of material and it can be done from the west bank with little impact to native riparian vegetation, here mostly introduced Scotch broom, Himalayan blackberry and reed canary grass in a recently disturbed area. (These invasive species should be removed and replaced with alder and other native riparian species on completion of the work.) **(Complete in 1999)**

- It may be possible to extract some of the fine sediment accumulated in the channel further downstream with a small portable suction dredge (practicality still being explored), avoiding significant impact to established riparian vegetation in Salish Park that is the most valuable and least degraded component of salmonid habitat remaining in this area. (Initiate after 1999)

- Following removal of accumulated fine sediments and control of upstream sediment sources, eroding streambank sections should be stabilized and a gravel streambed should be restored throughout this area, if necessary by adding appropriate clean (washed) material where it is lacking. Stable (anchored) large woody debris and large boulders should be added where appropriate for bank stabilization and habitat complexing, to help develop pool-riffle structure. (Initiate after 1999)

- Implement sediment and erosion control guidelines for all land development and disturbance in the watershed, to at least the standards described in *Land Development Guidelines for Protection of Aquatic Habitat* (Chillibeck *et al*, 1993), to prevent or minimize surface soil erosion and sediment transport into the watercourse from disturbed upland areas. (The City of Nanaimo has recently produced comprehensive guidelines on this topic that may be of use.) **(Initiate immediately)**

- Incorporate off-channel stormwater detention and sediment trapping facilities upstream of Guthrie Rd. to receive both upstream peak flows and discharge from the Highwood subdivision, and designed to limit downstream peak flows to levels that will preclude existing or predicted flooding and downstream bank erosion and sediment transport problems. A temporary reduction in controlled peak flows from the Crown Isle system may also be possible. In our view, any significant increase in peak flow volumes downstream of Guthrie Rd. (as could occur with increased channel capacity without stormwater detention) may lead to further bank erosion and property damage in residential areas, with additional sediment transport and further degradation of downstream salmon habitat. (R. Kellerhals, P.Eng., expressed similar concerns in his letter to DFO dated March 6, 1996, evaluating flooding problems in this area and possible solutions.) **(Initiate expansion of Highwood detention pond in 1999**; planning, design and implementation of an off-channel

detention pond to intercept Brooklyn Creek upstream peak flows and sediment is likely a longer-term project.)

- If the porous sandy surface soils in the Highwood subdivision area originally drained by infiltration to the underlying Quadra Sands aquifer (an unconfirmed possibility) there may be some potential in this area for both in-line stormwater retention and aquifer recharge via an infiltration gallery, if available undeveloped land exists. (Initiate only as a possible option to explore)

- It is recommended that periodic flow monitoring (especially of peak and low flows) be conducted at several points within the system (e.g. Parry Place, Guthrie Rd. and Balmoral Ave.) for a period of at least a year, both as a "reality check" for fine calibration of the hydraulic model and as a basis for evaluating adequacy of existing stormwater detention facilities and future detention requirements to maintain desirable peak flow levels which minimize erosion and sediment transport, as well as flooding risks. It is possible, even likely, that peak flows that will minimize further erosion and sedimentation and thus allow maintenance and restoration of salmon habitat are somewhat lower than those that can be accommodated without flooding problems. (**Initiate immediately**)

- It is strongly recommended that an active and well informed community watershed stewardship group for the Brooklyn Creek watershed be developed and encouraged as a focal point for proposed salmonid habitat restoration and enhancement projects. These projects are often long term labour intensive undertakings, particularly in systems with as much habitat degradation and required repair work as Brooklyn Creek, and it is essential that these projects have a strong base of public support and commitment within the local community to be sustained and successful. In addition, most of the funds available to assist with the costs of this work (using volunteer labour) are only available to non-profit organizations working in partnership with municipalities, businesses and other agencies. (**Initiate immediately**)

Given the degree of fish habitat degradation that has already occurred and the need to resolve flooding problems, reduce peak flows, restore salmonid habitat and avoid further habitat loss and negative impacts to fish or fish habitat downstream of restored areas, this process will be complex, gradual and possibly challenging at times, but ultimately will be a rewarding long term endeavour.

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