Chapter 3

Ecologically Sensitive Channel Design for Urban Receivers: Case Studies

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Historically, engineering practice for managing urban runoff in natural watercourses related to the provision of flood and erosion protection, with typically a minimal regard for the existing or potential aquatic habitat. Engineers were concerned with conveying storm runoff in a safe and efficient manner, which would use a minimal amount of “developable” lands. Short and long-term maintenance costs, and accessibility, were also strong guiding principles in the design.

During the 1960’s and 1970’s aquatic biologists began to examine the impacts of channel alterations on aquatic ecosystems. The knowledge gained, combined with increased public environmental awareness in the late 1980’s and 1990’s, has led to stricter agency enforcement of environmental protection legislation. Engineers, along with development proponents, have been able to “rethink” their approach to managing urban runoff. No longer is it satisfactory to provide flood and erosion control at the expense of the environment. Rather, the existing and potential aquatic habitat associated with urban receivers has

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become an elemental design constraint. The fisheries biologist has become a member of the design team, which focusses on maintaining or enhancing aquatic habitat while meeting other water management objectives.

This paper focuses on a series of case studies involving the application of eco-restoration to Southern Ontario stream systems. Successes and failures alike are reviewed, based on documented field evidence highlighting potential future design enhancements.

3.1 Preamble

Traditionally, engineers have taken great care in focussing on means of treating storm runoff at its source. Extensive research and development has taken place, predominantly in the last 20 years, concentrating on enhancements to analysis techniques, modelling of quantity and quality, and innovations to best management practices. Less attention though, has been afforded to the urban runoff receiver; for the most part, channel design, for the purpose of erosion and flood control, has progressed minimally during this same period.

The impacts of urbanization and channelization on aquatic ecosystems within natural streams has long been understood to cause environmental degradation. Although urbanization typically leads to changes in water quality and quantity, the physical characteristics of channels also has a major effect on stream biota. Recognition of this fact, combined with strengthened legislation and an overall shift in public environmental awareness, has allowed us to look at new and innovative ways of treating the urban runoff receiver. By monitoring the impacts on aquatic habitat, and understanding the processes associated with fluvial geomorphology, we are able to not only assess potential impacts associated with modified channels, but also develop appropriate means of mitigation.

The basic problem relates to the fact that this is a burgeoning science, with a short history. Conventional channel design is well-understood in terms of its construction cost, long term integrity and maintenance requirements. Naturalized channel design, is comparatively new.

The management of stormwater, even to the present day, through the respective policies of municipalities and provincial agencies, normally focusses on the discharge point with respect to quantity and/or quality, with less attention afforded to the receiving system and its physical characteristics. This paper reviews historical practice with respect to traditional flood and erosion control, and outlines the potential impacts of channel alterations on aquatic ecosystems.

Three Southern Ontario examples are presented; each site's unique problems are described, along with the distinctive analysis approach required to develop an ecologically-sensitive channel design. In addition, as each design has been implemented within the last two years, a "design retrospective" is given, outlining the positive and negative aspects of implementation.

3.2 Introduction

Historically, urban runoff has been managed in natural watercourses by providing flood and erosion control related to conveyance improvements. This practice is evidenced by the implementation of straight, deep, and hard-lined systems, such as concrete, gabion, and concrete block channels. This form of channelization was, and is, considered extremely effective in managing runoff from both a flood and erosion perspective in urban settings. Minimal amounts of land are consumed by the works, and typically, the construction can be coordinated with new development in order to maximize the usage of tablelands, while providing satisfactory depth for storm sewer outlets.

The traditional channel, though, is implemented at relatively high cost, both from an economic and environmental perspective. While general “day-to-day” maintenance is infrequent and relatively inexpensive, long term costs are typically high, as they relate to capital maintenance of these systems.

The “conveyance improvement philosophy” is related to the principle of providing larger and larger conveyance systems, which discharge storm flows to receivers of ever-increasing size. As the cost of implementing these systems increased proportionately, along with associated maintenance costs, stormwater management for the purpose of quantity control became prevalent (circa. 1970 to mid 1980’s).

The “quantity control philosophy” typically sought to reduce runoff from new developments at their source, in advance of flow entering into receiving streams, thereby either reducing the amount of channelization/alteration necessary to the receiver, or removing the need for any alteration altogether. While this approach had, and still has, considerable merit in flood control, its impact on stream morphology and associated aquatic habitat is often severe, based on changes in runoff volume, duration and quality.

Watershed management techniques being supported by lead agencies and consulting engineers since the mid-1980’s, now include a multi-objective planning approach. Runoff quality and quantity, along with environmental ecosystems are now proposed to be managed in a comprehensive manner, whereby the treatment of urban receivers is complementary to source control from typical urban development.

3.3 Impacts of Channel Alterations on Aquatic Ecosystems

One of the most obvious impacts of channelization has been a reduction in the length of stream habitat. The relative magnitude of this reduction depends upon the sinuosity of the natural channel, and it is not uncommon to find that stream length has been reduced by more than 50%, simply due to channel

straightening.

Channelization also alters the quality of aquatic habitats. In the most extreme cases, concrete channels support little more than thin films of algae and bacteria, but less severe channel treatments can also lead to reductions in biotic diversity and biomass. Most natural channels are sinuous, and have an undulating profile. This results in variations in depth, water velocity, and substrate on a meso-scale. Aquatic biota have evolved in these spatially, and in many cases temporally, heterogenous systems. It is therefore not surprising that habitat requirements differ between fish species, and often differ between life history stages, or seasonally, for a single species.

Channelized streams are more homogenous. They flow in straight lines, with homogenous substrates, constant slopes, and consistent cross-sections. This "simplification" of habitat leads to a reduction in biotic diversity. The elimination of one critical habitat, for example spawning habitat, can lead to the elimination of a fish species.

Changes in channel depth also have a dramatic effect on the biomass of fish present in streams. The deeper pools, typically found on the outside of meanders in natural streams, are absent in channelized streams. In warmwater streams in southern Ontario, where large predatory species are absent, fish biomass is approximately proportional to the square of mean depth, $B=2.56D^{2.05}$. Thus, the elimination of deep habitats, even though they may constitute a small proportion of the total habitat area, results in substantial reductions in fish biomass. Other factors which can lead to reduced fish abundance and diversity include the elimination of cover along the banks, where overhanging vegetation no longer grows, and the construction of drop structures which prevent fish migration. Finally, in highly efficient channels, the detritus which provides the energy source for a large proportion of the food chain in natural streams is transported quickly through the system. This not only reduces the energy available to stream communities, but increases nutrient loading at the final receiver.

As fisheries science has matured, it has become generally accepted that the protection of habitat is a critical component of any management strategy. At the same time the public has become increasingly concerned with the preservation of natural ecosystems, even when those ecosystems do not provide a resource which is exploited in the traditional sense. In response to these facts the Department of Fisheries and Oceans developed its "net gain/no net loss" policy, which was introduced in 1986. Briefly, this policy states that the long-term objective of the Department of Fisheries and Oceans is to achieve a net gain of the productive capacity of fish habitats. Three goals have been identified in this policy: fish habitat conservation (no net loss of productive capacity), fish habitat restoration, and fish habitat development. The Fisheries Act is the federal legislation under which this policy is applied. Under the Fisheries Act, the Minister of Fisheries and Oceans has "the authority to modify, restrict, or

prohibit any work or undertaking which is likely to result in the harmful alteration, disruption or destruction of fish habitat”.

While protection of natural ecosystems is a priority, there are legitimate reasons for many of the drainage projects which are undertaken. A new approach is necessary which will allow the engineering objectives, which are usually related to land use, to be achieved while meeting the objectives of no net loss of fish productive capacity. In the following sections we discuss three projects where we have attempted to employ such an approach.

3.4 Case Studies

Global Objectives

1. Restore/recreate physical habitat on-site.
2. Accomplish engineering objectives related to hydrology and hydraulics.
3. Minimize impacts upstream and downstream of restoration.

Tuck Creek, City of Burlington

Problem Description

Approximately 500 m of Tuck Creek upstream of Headon Road in the City of Burlington has undergone extensive erosion, particularly during the 1980's, due primarily to considerable upstream residential development. The erosion has been characterized by deeply scoured banks, widening creek sections, and increased sediment deposition, both along this reach and downstream. In addition, a steeply sloped bank, some 4 m high, adjacent to a proposed development area, has been undermined and exposed to a point of potential instability.

Analysis Approach

The creek and flood plain was surveyed at a high resolution (maximum cross-sectional spacing 15 m). In addition to the topographic survey, a comparison of previous survey information compiled by the municipality, some three years earlier was reviewed along with historical aerial photography. A photographic reconnaissance was completed and compared with previous photographic record.

Hydrologic information relating to post-development peak flow discharge was provided by the municipality. Peak flows were computed using OTTHYMO83, based on single event analysis using City of Burlington design storms.

The reach under analysis extends approximately 680 m upstream of Headon Road. The previously developed HEC-2 hydraulic model used to define the flood plain limit comprised 6 flood plain cross-sections, which were replaced by 52 new field cross-sections.

Based on a detailed assessment of “bank-full” conditions, less than 10% of the cross-sections would have the ability to convey the future landuse 2-year event within the existing channel banks. Channel velocities for the reach ranged between 1.15 and 2.81 m/s (1.85 m/s average) for the 2 year event, and 1.22 and 3.00 m/s (1.92 m/s average) for the 5-year event. Average velocity in this location generally range between 1.22 and 1.46 m/s.

Two common minnow species, creek chub (*Semotilus atromaculatus*) and blacknose dace (*Rhinichthys atratulus*) were abundant in the stream, and white sucker (*Catostomus commersoni*) were also present. The channel, although experiencing bank erosion, contained a variety of habitats, including several deep pools. None of these species are considered game species, in fact all three are commonly used as bait, however during the course of the field investigation we became aware that local children enjoyed fishing in the stream for creek chub.

Recommended Solution

In light of the technical and environmental conditions constraining the site, a design was developed which would:

1. minimize disruption to the substrate,
2. protect outside bends with natural materials,
3. promote and/or maintain the pool/riffle sequence, and
4. minimize disruption to natural vegetation.

The total length of the creek system would need to be maintained or lengthened, hence in locations where a new alignment would be required, an on-site “walk-through” was conducted in order to stake an alignment which would have the least impact on existing vegetation, while facilitating construction access. Actual angular geometry of the meanders was determined based on an assessment of pre-construction meanders both upstream and downstream of the site (see Figure 3.1 a, b).

The channel cross-section in the areas proposed to have a new vertical and horizontal alignment, was designed with symmetric and asymmetric configurations such that the pool/riffle sequence would be promoted. The substrate was specified to be a washed, well-graded granular material, complementing existing habitat (see Figure 3.2).

In areas where the horizontal alignment was proposed to be unchanged, armour stone lining of outside banks was recommended, while the inside banks

Figure 3.1a
Proposed realignment, Tuck Creek, City of Burlington.

TYPICAL ARMOUR STONE TREATMENT
PLAN

TYPICAL ARMOUR STONE TREATMENT
SECTION

Figure 3.1b
Proposed realignment, Tuck Creek, City of Burlington.

Figure 3.2
Proposed asymmetric/symmetric sections, Tuck Creek, City of Burlington.

were proposed to be cut back to a 3:1 slope or flatter and stabilized with vegetation. Careful attention was required in the field in order to avoid off-bank erosion due to the deflection of bank-full flows.

Design Retrospective

The project was constructed during the late fall (November and December) of 1991, and consequently revegetation could not occur until the spring of 1992. While it would normally be considered undesirable to leave the adjacent area unvegetated during the winter, the soils were cohesive, and there was little evidence of erosion having occurred.

The use of HL8 as a bed material has been effective. The material has been moved about extensively during high flows. There have been several major storm events during the first year. As anticipated, the pool riffle sequence is well developed, with deep pools, scoured to the underlying shale, forming on the outside of the bends, and riffles and raceways forming in the straight sections. The pools which most closely resemble natural pools in cross-section have developed where armour stone was applied to the outside of the bends. These pools, however, lack fish cover, and in the future we would endeavour to remedy this, perhaps by the introduction of vegetation.

Vegetation has been slow to establish on the point bars which have formed within the channel. This may be due to the unstable nature of this material, which has been compounded by the unusually high flows experienced during 1992. Future monitoring will determine if planting is necessary to stabilize these features.

No quantitative assessment of fish utilization has been conducted, but creek chub were observed spawning on the HL8 material in the spring of 1992, and schools of minnows are always observed in the pools.

West Hager Creek, City of Burlington

Problem Description

The construction of Highway 403 through north Burlington, requires that a stormwater management system be implemented, part of which is an on-line stormwater management detention facility on the West Hager Creek, upstream of the North Service Road. Located in an existing natural valley, this site needed to be lowered for storage volume and stabilized against future erosion. Given the foregoing, the existing creek system which traversed the natural valley would be entirely eliminated in its natural form. It became the objective of the design team to "recreate" a natural stream system which would also be sufficiently stable, in order to avoid any future erosion problems associated with the steep banks adjacent to the facility, and top-of-bank development.

Analysis Approach

The proposed creek system would essentially serve as the low flow conveyor within the stormwater management facility, hence flood control would not be the primary objective in design. Rather the flow criteria for the thalweg and low flow channel were to complement existing in-field conditions. (NOTE: The low flow capacity approximated a 2 to 5 year capacity.) For events less frequent than these criteria, the stormwater management embankment would initiate an upstream backwater, and the facility would eventually fill. The design analysis necessitated an assessment of alternative channel configurations in order to establish the target storage volume. Given the volumetric and flow criteria, a system of conveyance, cognizant of the environmental requirements, was developed.

Only creek chub were captured in this reach of stream, and their abundance was low. This appeared to be due in part to the absence of pool habitats. A sanitary sewer had been constructed through the valley in the late 1970's. The channel was straightened at that time, and only one significant pool had developed since, where a gabion had been undermined and fallen into the channel.

Recommended Solution

A survey of the valley prior to the construction of the sanitary sewer and re-alignment of the creek provided information on the sinuosity of the original channel. A new channel alignment was designed to meet or exceed this sinuosity in the bottom of the detention facility (see Figure 3.3). Since the floor of the valley was being lowered, the gradient in the upstream portions of the channel would increase. A series of rip-rap saddles was designed which provided grade control, while permitting fish to migrate freely (see Figure 3.4).

In order to promote more natural bank conditions in the longer term, rip-rap was not employed to stabilize the banks of the low-flow channel. It was hoped that little bank erosion would occur at normal flows due to the low gradient through the reach. The banks of the high-flow channel were stabilized with rip-rap on the outside of the bends, to ensure that channel migration could not eventually bring the channel into contact with the valley wall.

It was originally intended to use shale which had to be excavated within the valley during the re-alignment of the existing sanitary sewer, to line the channel bottom. During construction it was found that the shale became too friable for this purpose after even brief exposure to the air. Consequently 50 mm cobble was used.

The 'soft' bank treatment required that vegetation be re-established as quickly as possible following construction. The bank-full channel was seeded with a mixture which included a large proportion of annual rye, as soon as the

Figure 3.3
Plan and profile, West Hager Creek, City of Burlington.

NOTE:
SEED MIXTURE FOR CREEK SECTIONS
TO CONFORM TO THAT LISTED IN
CONTRACT DOCUMENT.

Figure 3.4
Proposed channel sections, West Hager Creek, City of Burlington.

channel was completed. Construction continued outside this area for some time, however seeding was carried out as soon as possible. Shrubs were planted on the outside of meanders. The native topsoil was re-used here, and it is expected that the seed bank which it contains will lead to rapid naturalization.

Design Retrospective

The friability of the native shale was unanticipated, and the 50 mm cobble which was substituted was not sufficiently large to stabilize the outside of the meanders. This is not expected to be a long-term problem, as vegetation becomes established and the soils are stabilized by roots. A trade-off exists here, between using large material, which does not permit vegetation to develop in a natural manner along the banks, and using material which permits vegetation to flourish but does not provide the stability required immediately after construction. In the future, we suggest that shrub material be planted in the 2 to 5 year channel, adjacent to the low-flow channel, to increase the stability of the low-flow banks.

The meanders in the 2 to 5 year channel mimic those in the low flow channel. This is unnecessary and probably detrimental, since it increases the slope on the inside of the meanders, and thus increases the erosive forces on the opposite sides. In the future we recommend that the width of the high-flow channel be maintained, constructing more gradual slopes from the edge of the point bars. The rock saddles which were constructed to allow a decrease in elevation, were tied well back into the sides of the channel. They have performed well to date, from the stand-point of stability, and pose no barrier to fish migration over a wide range of flows.

Fairchild Creek Tributary, St. George

Problem Description

The Ministry of Natural Resources and the Grand River Conservation Authority had several concerns with respect to the impacts on local streams, associated with the development of a local Golf and Country Club. These concerns related primarily to two tributaries of the Fairchild Creek, which were modified as part of the golf course construction.

The first watercourse, flowing through the eighteenth fairway, had been shortened and steepened as part of the implementation of the golf course. Agency concerns related to impacts on fisheries, erosion, and overall stability.

The second watercourse, on the western side of the twelfth fairway, had been partially enclosed and concerns related to the potential barrier which the enclosure created, as well as the "shortened" overall length of the system (i.e. reduced habitat).

Analysis Approach

The Grand River Conservation Authority had developed a calibrated GAWSER model of Fairchild Creek watershed which drains to the Grand River. This calibrated model was further discretized in order to develop associated design flows at various locations within the study area. An excellent correlation was achieved with the calibrated Grand River Conservation Authority model and the disaggregated Philips Planning and Engineering Limited model for this study area.

A detailed HEC-2 hydraulic model was generated for the main watercourse flowing adjacent to the eighteenth fairway, under both sub- and supercritical flow regimes. The combination of these analyses defined the reaches most susceptible to erosion.

Channel velocities generally fluctuated, as did the flow regime, with annual frequency velocities approaching 2.4 m/s and averaging 1.5 m/s over the entire reach.

Field reconnaissance also revealed several scour holes, which were evident in the streambed along with severe bank sloughing, particularly evident in the vicinity of localized hydraulic jumps.

Agency fish collections, and those which we conducted, determined that there were no game species present. There was an existing dam, which created a barrier to fish migration, located on private property immediately downstream from the course. Upstream from this dam only two minnow species, creek chub and blacknose dace were present. Downstream from this dam five additional fish species were present. Since extensive channel alterations had already occurred, it was not possible to evaluate the pre-construction habitat.

Recommended Solutions

The disturbed watercourse reach along the Eighteenth hole, was designed in order to be re-instated and stabilized, complementary with the local fisheries and habitat requirements, while maintaining overall golf course functionality (see Figure 3.5 a, b).

The design team proposed the following:

1. Lengthen the channel.
2. Flatten the channel gradient.
3. Promote a pool/riffle sequence.
4. Stabilize with rip rap/granular mixture.
5. Restore or enhance the sinuosity.

A small diameter ($d_{50} = 100$ mm) rip rap lining was proposed since rip rap:

Figure 3.5a
Plan and profile, 18th hole, Fairchild Creek Tributary, St. George.

Figure 3.5b
Plan and profile, 18th hole, Fairchild Creek Tributary, St. George.

1. is flexible and is not weakened by bank movements,
2. is easy to construct and maintain,
3. provides a natural appearance,
4. is stable given degradation properties, and
5. allows the establishment of vegetation between stones providing cover and additional stability.

A trapezoidal configuration with a “V-shaped” bottom had been selected to be the most effective design in satisfying all of the objectives. Similar to the Tuck Creek, both symmetric and asymmetric sections were proposed in order to promote the natural formation of pools and riffles. The overall vertical alignment was reduced from a maximum slope of up to 3% to an overall average of 0.4%. It should be noted that typically slopes of 0.5 to 1% are considered the upper limit for natural channels in order to maintain their pool/riffle stability and equilibrium. An overbank setback area was proposed to serve as a natural buffer strip of a minimum of 15 m which is to be maintained, unmown, on both sides of the stream.

On the twelfth hole, the watercourse was initially enclosed to allow for a landing area from the tee. Discussion with the golf course designer indicated that, without a major golf course redesign, a portion of the watercourse would need to be enclosed. In an effort to compromise, given the localized fisheries potential, it was proposed to reduce the length of the enclosure, and recreate additional open channel both upstream and downstream of the enclosure to compensate for the enclosed length. The enclosure would then be oversized and embedded in order that the substrate through the culvert would be as natural as possible (see Figure 3.6).

Design Retrospective

Construction was carried out during March of 1992, and temperatures were below freezing most of the time. This was almost essential in order to carry out construction in some of the areas, where soils were extremely unstable. The lead agency responsible for protection of fisheries agreed to permit the end of the construction period to be determined on the basis of water temperature. Maximum water temperature was monitored daily, with the agreement that in-stream activity would cease if temperatures approached those which trigger spawning in the fish species which spawn earliest in the spring. This permitted construction to continue beyond the date on which it is normally required to terminate. We believe that winter construction greatly reduced the amount of sediment which entered the stream.

At the site which required the most extensive channel re-construction, the stream was de-watered by creating a temporary coffer dam and then pumping the water to ponds adjacent to the channel. The water flowed through these ponds

Figure 3.6
Plan of 12th hole, Fairchild Creek Tributary, St. George.

and eventually re-entered the stream via an overflow from the pond which was furthest downstream. This proved a highly effective and economical means of de-watering.

Following construction, much of the gravel, which was placed in one of the culverts to create fish and benthic invertebrate habitat, had been washed downstream. The HEC-2 model, which was used to determine the size of this material did not accurately predict field conditions. The introduction of such material is costly, particularly in terms of the labour involved, and the benefits are not realized if the substrate does not remain in place. Improved prediction of shear stress within the culverts is required in order to size material appropriately.

The silt fences employed to prevent sediment from being transported into the stream from adjacent areas of exposed soil, were effective. In some locations, however, they confined the peak flows, resulting in higher velocities and increased erosion within the channel. Stabilization of surrounding soils as quickly as possible following construction, permitting timely removal of silt fences, is an important requirement for habitat protection.

Filter fabric (geotextile) was placed under the channel at two locations. At one location this was considered essential, as the native soils were so unstable that the rip-rap used to line the channel would otherwise sink below ground. In

Table 3.1
Number of fish captured by electrofishing 50 m long reaches of stream at seven locations on september 9, 1992. Capture data from 1991 are also provided where available, but do not pertain to 50m long reaches

Species	E1		E2		E3		E4		E5		E6		E7
	1992	1991	1992	1991	1992	1991	1992	1992	1991	1992	1991	1992	1992
white sucker										4	7		
finescale dace	1		1										
brassy minnow										2			
common shiner										8	11		
blacknose shiner										2			
bluntnose minnow	1		1										
fathead minnow										1	1	1	
blacknose dace	40	10	13	3	11	23	7	17	7	7	23	43	
creek chub	151	13	31	4	17	11	11	16	3	37	37	72	
brook stickleback			1					2					
largemouth bass											1		
johnny darter											32		
Number of species	4	2	5	2	2	2	2	3	2	8	7	3	

the other location the primary purpose of the geotextile was to prevent the erosion of the channel bottom. At the latter location the geotextile has been exposed due to erosion of the overlying material. This has created a chain reaction, with the current lifting more of the geotextile. In the future the use of geotextile within the channels will be minimized.

Construction was completed in the summer of 1992, and banks were still stabilizing when post-construction monitoring was conducted (see Table 3.1). At that time more fish were present in the largest of the re-aligned channels than were present in portions of this channel upstream which had not been altered. Continued monitoring will determine if this condition persists over time.

3.5 Conclusions

Research has shown that traditional channelization can dramatically reduce fish production in streams, and that channel morphometry plays a significant role in this reduction. Channel designs which incorporate fundamental features of natural channels, such as meanders and asymmetric cross-sections, should help to meet the goal of maintaining fish productivity. As this approach to channel design is developed, it is essential that monitoring of both biological and functional performance be carried out. Co-operation among the public and private sectors is required in order to develop optimal solutions which will meet both the physical and social environmental objectives.

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