Evaluating the Effectiveness of 'Natural' Channel Design Projects:

A Protocol for Monitoring New Sites

Prepared by:
The Toronto and Region Conservation Authority
Geomorphic Solutions, Sernas Group Inc.
LGL Limited

Final Report 2009

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PROVISO

This protocol document was prepared by the Toronto and Region Conservation Authority (TRCA), with the support of Fisheries and Oceans Canada (DFO) and the municipalities of York, Peel and Toronto, as part of a larger initiative to assess and improve the performance of 'natural' channel design projects. The protocol describes a process for monitoring new 'natural' channel design projects to satisfy conditions of TRCA permit approval. While the approach described herein also addresses DFO monitoring requirements for authorization of such projects, the full scope of monitoring activities may not necessarily be required for projects outside of the TRCA jurisdiction. In these instances, this protocol will be applied by DFO as a guideline to project proponents for the development of monitoring programs to satisfy conditions of authorization. The full extent of monitoring described in the protocol will be required only for large-scale projects and/or where important fish habitat is affected, with an appropriately reduced scope of monitoring for smaller projects. DFO should be contacted as soon as possible after project initiation to establish specific monitoring requirements. It is also the responsibility of the proponent to identify and address the monitoring requirements of other regulatory agencies.

While this document provides detailed instruction on the preparation of a monitoring program for a 'natural' channel design project, the final design and execution of the monitoring plan must be undertaken by qualified professionals. Expert knowledge is essential in the elucidation of design objectives, the determination of monitoring locations and in the interpretation of results. In most cases it will be most effective for the 'natural' channel project design team of geomorphologists, engineers, ecologists, and landscape architects to prepare the monitoring plan.

The monitoring protocol is intended to be a 'living' document in that it will be updated as input is received from proponents and practitioners involved in conducting monitoring on 'natural' channel design projects. The protocol will be updated as required to address user feedback with full documentation of version changes.

NOTICE

PUBLICATION INFORMATION

Reports conducted under the Sustainable Technologies Evaluation Program (STEP) are available at www.sustainabletechnologies.ca. For more information about this report and other STEP studies, please contact:

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THE SUSTAINABLE TECHNOLOGIES EVALUATION PROGRAM

The Sustainable Technologies Evaluation Program (STEP) is a multi-agency program, led by the Toronto and Region Conservation Authority (TRCA). The program was developed to provide the data and analytical tools necessary to support broader implementation of sustainable technologies and practices within a Canadian context. The main program objectives are to:

- monitor and evaluate clean water, air and energy technologies;
- assess barriers and opportunities to implementing technologies;
- develop tools, guidelines and policies, and
- promote broader use of effective technologies through research, education and advocacy.

Technologies evaluated under STEP are not limited to physical structures; they may also include preventative measures, alternative urban site designs, and other innovative practices that help create more sustainable and liveable communities.

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1.0 INTRODUCTION

Monitoring and evaluating the effectiveness of ‘Natural’ Channel Design (NCD) is an important part of an adaptive management process, whereby monitoring results are used to review the design goals and objectives, evaluate project implementation, and assess the final on-the-ground results. By compiling and reviewing this monitoring information, immediate problems can be identified, corrective measures can be taken where necessary, and modifications can be made to design specifications to improve future projects, and the potential for reaching restoration goals. Despite this, detailed monitoring to evaluate project success and effectiveness of stream restoration techniques is rarely undertaken. In southern Ontario and specifically the Greater Toronto Area (GTA), monitoring is typically included as a regulatory permitting requirement, however the scope and duration of the monitoring that currently takes place is not sufficient to support the adaptive management process. Moreover, there is no single standardized approach to monitoring NCD projects.

To address the current absence of monitoring and the lack of monitoring data, the Toronto and Region Conservation Authority (TRCA) initiated a project to develop an NCD monitoring program for its jurisdiction that could ultimately be applied to the GTA and other areas. Part of that program involved the creation of a monitoring protocol, which is the subject of this report. The monitoring protocol was developed based on a literature review and preliminary assessment of sites in the TRCA jurisdiction, which is published as a separate report in this series.

For the purposes of this protocol, NCD projects are defined as those that involve reconstruction of a watercourse channel bed or banks, either in-situ or as a result of realignment, with the primary goal of preserving or restoring the geomorphic function of the channel. While there may be secondary objectives related ecosystem restoration, true NCD relies on the achievement of geomorphic equilibrium within the restored corridor to create forms and features that sustain aquatic and riparian ecosystems. As such, the channels in NCD projects are generally constructed of native or natural materials that preserve the ability of the channel boundary to erode and adjust in response to prevailing conditions of flow and sediment transport. However, for many projects there are practical constraints that cause designers to artificially limit the ability of the constructed channel to adjust, for example through the use of large, non-native bed or bank substrate. While these projects are not considered to meet the true definition or intent of NCD, they occur frequently and are often claimed to provide benefits equivalent or similar to NCD, including restoration of channel stability and aquatic habitat. As there is a similar lack of monitoring and adaptive management for these modified NCD initiatives as well as a reduced theoretical basis from which to expect long-term success, this protocol should be applied to evaluate these projects as well.

The protocol does not apply to projects involving the construction or reconstruction of engineered flood or erosion control channels, except in such cases where NCD elements are a major component in the design. Similarly, the protocol does not apply to bank stabilization projects when out of necessity engineered materials must be used and NCD elements are not incorporated. Fish passage and fish habitat improvement projects that rely on the creation of structures or features not native to the subject watercourse are also not consistent with NCD principles. However, the above project types also suffer from a general lack of post-project appraisal as NCD projects; therefore the development of specialized monitoring programs for such work based on the principles outlined in this document is strongly encouraged.

The monitoring protocol is a product of an extensive literature review, a review of existing stream and stream restoration monitoring protocols, and a review of on the current condition of existing NCD projects in the TRCA jurisdiction. Selection of methodologies focused on balancing the collection of quantitative information with realistic time and financial constraints. The protocol includes tools for the assessment of fluvial geomorphology, aquatic habitat, riparian conditions, fish communities, water quality, engineered and bioengineered elements, and social elements that are applied for individual NCD projects.

The monitoring protocol utilizes elements of both the TRCA Regional Monitoring Network (RMN) and the Ontario Stream Assessment Protocol (OSAP), to enhance compatibility and integration with the ongoing RMN and province-wide monitoring activities, while also providing a toolbox of methods for proponent-based NCD project monitoring. Even though monitoring is a fundamental component of stream restoration projects, it is recognized that financial and human resources are sometimes limited in NCD projects, particularly those conducted purely for restoration purposes. Therefore, the methods selected for this protocol represent the best combination of approaches to characterize NCD's while maximizing time and cost efficiencies. Each of the methods follows standard practice where it exists, and is rigorous, practical and simple to implement.

Both qualitative and quantitative methods are included in this protocol. The qualitative methods focus on visual observations that can be standardized among observers and grouped into evaluative categories. This type of monitoring is relatively inexpensive and allows for rapid assessment of large areas. The quantitative monitoring methods provide data that can be numerically analyzed to further evaluate success criteria. This approach provides information on temporal changes and leads to a better understanding of systems and the effectiveness of NCD projects.

This monitoring protocol should be considered as a first iteration towards comprehensive monitoring, to provide data for practitioners and regulatory agencies to evaluate the effectiveness of channel designs. It is not anticipated that this first iteration will necessarily result in definitive determinations of absolute success or failure of a project as there are numerous independent influences on the performance of stream channel works and NCDs. Instead, the monitoring tools will allow an evaluation of overall design effectiveness and to better understand the functional integration of individual design elements. As new data are generated from implementation of this methodology and the value of the collected information in evaluating project performance is assessed this protocol may be revised. The current protocol should therefore be viewed as the first of numerous versions and is expected to change on a regular basis in response to review of monitoring results and input from project proponents. Formal comments on this or future versions are welcome at any time and will be recorded for consideration in preparation of updates.

In the near future all new NCD projects in the TRCA jurisdiction will require a monitoring program to be developed and executed according to this protocol to be permitted by the Authority. It is also hoped that other jurisdictions will utilize the current protocol to define monitoring requirements as they incorporate detailed monitoring into their approval requirements. Therefore, in addition to presenting the monitoring protocol, this document also provides specific guidance on the development of a monitoring program for individual projects including a number of hypothetical case examples and a recommended approach for the preparation of documentation.

Regulatory authority and responsibilities will differ between jurisdictions, and therefore it may not always be possible for regulators to require that monitoring be completed. However regulatory agencies and project proponents should collaborate to ensure that rigorous long-term monitoring is undertaken on every project. While monitoring may require significant additional time and effort, it is invaluable in identifying the need for maintenance and corrective action without which projects may fail to achieve their objectives, negating any benefits of the investment in the project. Monitoring data, when shared, will also serve to improve the practice of NCD as a whole.

2.0 MONITORING PLAN DESIGN AND EXECUTION

Effective monitoring of NCD projects requires activity before, during and after the construction of the project. Monitoring during all of these stages is essential to understanding how the design is functioning relative to project goals, the pre-construction condition, upstream and downstream areas, and a broader ecosystem context. Thus, the intent of any NCD monitoring plan is to measure and evaluate a suite of parameters throughout the project cycle that will provide suitable results for evaluating the performance of the project.

The development and successful completion of a monitoring plan for any environmental restoration initiative requires the following components:

1. Identification of project goals and objectives;
2. Selection of performance criteria;
3. Defining the spatial extent of monitoring;
4. Setting the duration and frequency for monitoring;
5. Selection of monitoring parameters and monitoring methods;
6. Documentation of the monitoring plan;
7. Management of monitoring data
8. Analysis of monitoring results
9. Reporting of monitoring outcomes.

The protocol described in this document provides an approach to undertaking of these tasks for the monitoring of NCD projects. The guidance in the protocol recognizes the goals and objectives inherent to the concept of NCD and presents standard approaches that will promote monitoring that is both comprehensive to and consistent. The desired results are that individual NCD projects will be monitored and maintained more effectively and that a large quantity of high quality data may be obtained from many projects to improve the NCD practice.

The design of the NCD project and of the monitoring program should be concurrent. Most importantly, this provides a mechanism for early and explicit definition of project goals and objectives, and of the criteria that will define the success of the project in achieving these. This increases the likelihood that the project design will incorporate the comprehensive list of interrelated goals and objectives that are inherent to NCD projects, instead of focusing solely or disproportionately on specific conditions or constraints. As effective monitoring also involves a significant pre-construction component, planning for monitoring must begin in the early stages of project conception in order to ensure that pre-construction data collection can take place. This is particularly important for measurement of biological parameters that can only take place in certain seasons.

While the current protocol provides specific guidance on monitoring plan design and monitoring techniques, it is not intended to serve as a substitute for professional expertise and experience in the preparation and execution the monitoring plan. These tasks should always be completed by practitioners that are knowledgeable in the fields of fluvial geomorphology, aquatic biology and terrestrial ecology as well as experienced in the data collection techniques. This will ensure that data is collected and interpreted according to a consistent standard. Where possible, it is recommended that the practitioners responsible for the project design not be involved in the execution monitoring plan to avoid bias in the interpretation of results.

2.1 Identification of Project Goals and Objectives

The elucidation of project goals and objectives is a critical component of monitoring program design. Clear definition of goals and objectives allows identification of the hypotheses or questions that the monitoring program is intended to address and selection of appropriate data gathering activities to answer those questions. For restoration projects of all kinds, it is important to clearly document goals and objectives during the planning and design stages. The goals and objectives should define in detail what the desired future conditions are, and should identify the scale at which restoration effects are anticipated. During this process, project-specific constraints should also be identified, to provide a framework for developing realistic expectations of success. It is critical for project goals to be defined clearly and in terms that are conducive to monitoring measurement and the development of performance criteria. Vague and ambiguous goals such as 'maintain or improve stream health' or 'restore a natural watercourse', without more detailed and specific objectives, make it difficult to establish a monitoring program that will provide useful data regarding the success of the project in meeting design goals.

All NCD projects share the same principal goal, which is to effect the reconstruction of a channel and corridor that mimics the geomorphic forms and processes of an undisturbed watercourse subject to the same watershed-scale influences and local conditions. As stream ecological functions are fundamentally connected to physical processes, a constructed channel that achieves this goal will be expected to support aquatic and riparian ecosystems of the same composition and quality as an undisturbed watercourse in the same setting, subject to the same independent controls. As such, all projects where the intended outcome is a NCD should acknowledge a number of common goals and objectives resulting from this intent, which are listed in Table 2.1.

Table 2.1: Project goals and objectives inherent to all NCD Projects

	GOAL	OBJECTIVES
FLUVIAL GEOMORPHOLOGY	Achieve channel form and rates of channel change that are self-sustaining and in balance with the local hydrology and sediment regime, equivalent to those of an undisturbed stream subject to the same independent influences.	• Maintain or restore a channel geometry consistent with undisturbed conditions. • Maintain or restore self-sustaining rates of bank erosion, planform migration and bedform evolution consistent with undisturbed conditions. • Maintain or restore channel substrate that is consistent with the sediment supply of the watercourse and will maintain sediment transport continuity within the system.
AQUATIC ECOSYSTEM	Create self-sustaining aquatic habitat that supports an aquatic ecosystem with diversity and richness equal to that of an undisturbed stream subject to the same independent influences.	• Maintain or restore self-sustaining physical and hydraulic in-stream habitat consistent with undisturbed conditions. • Maintain or restore species richness and biomass of aquatic flora and fauna consistent with undisturbed conditions. • Maintain or restore continuity of the upstream and downstream movement of organisms and energy with adjacent reaches. • Maintain or improve chemical water quality between upstream and downstream extents of project to a level consistent with undisturbed conditions • Maintain or reduce water temperature or minimize temperature increases from upstream to downstream extent of site to a level consistent undisturbed conditions
RIPARIAN ECOSYSTEM	Create a riparian corridor with native and diverse vegetation that supports terrestrial and aquatic habitat and provides structural channel stability equivalent to those of undisturbed streams subject to the same independent influences.	• Maintain or restore a self-sustaining vegetation community reflective of undisturbed conditions. • Maintain or restore composition and density of bank and channel margin vegetation to a state reflective of undisturbed conditions.

The goals and objectives in Table 2.1 apply to 'true' NCD projects in which it is possible or desirable to construct a channel that reflects the influence of prevailing conditions. While it may be hoped that individual projects may realize success in specific areas such as the creation of various habitat features or increase in numbers of a particular species, it must be remembered that the intent of NCD is to create a channel form that is specific to, and in balance with, the prevailing conditions. Departures from this philosophy to create habitat types or promote species that cannot be maintained in such a channel will negate the self-sustaining benefits of NCD. While in some cases this approach may be warranted, it must be explicitly acknowledged that the outcome will not be a NCD and as a result the constructed features will require human intervention in perpetuity to maintain. This monitoring protocol does not apply to such projects; and while monitoring programs would still be of value they would need to be tailored to the more specific objectives involved.

In many cases, project constraints dictate that the channel cannot be allowed to evolve and migrate at the same rates as undisturbed channels in the same setting. For example, there may be insufficient land to establish a floodplain of appropriate width for channel planform development, infrastructure at risk adjacent to the channel that cannot be moved, or an urban hydrologic regime that cannot sustain a stable watercourse. Experience in the TRCA jurisdiction suggests that a large number of past projects labeled as NCDs have in fact been subject to such constraints and have therefore departed, in whole or in part, from the NCD philosophy of creating natural, self-maintaining channels. To limit channel change in whole or in part, permanent or semi-permanent features such as oversized bed material and bank stabilization works that are not representative of an undisturbed channel condition have been incorporated into these channel designs. However, many of these projects have also maintained sections or features that are intended to change and adjust in response to the prevailing hydrology and sediment regime. Observations of such projects in the TRCA jurisdiction suggest that these opposing objectives often lead to undesirable results such as failure of stabilization structures or the creation of fish barriers. The initial response to such outcomes might be to suggest that such hybrid designs are not appropriate and should not be utilized or approved. However, it is likely that the majority of future watercourse restoration sites in the TRCA jurisdiction will be subject to constraints that do not permit a complete NCD approach and therefore a viable restoration design approach for these conditions should be developed if at all possible as alternatives may be less desirable. As a result, this monitoring protocol will address these hybrid and modified channel designs in the hope that data will be generated which will improve design practices. However, the protocol is not appropriate for projects where constructed channels are intended to be entirely static, regardless of whether the material used is of natural or engineered origin. Such projects should be assessed differently by regulatory agencies given that in most cases the outcome is a channel that will require maintenance in perpetuity, and monitoring initiatives should be focused on ensuring that long-term maintenance is undertaken when required.

While the project goals listed in Table 2.1 are still generally applicable for all individual NCD projects including hybrid or modified NCD designs, the objectives may require modification to reflect project-specific needs and constraints. Additional goals and objectives may also need to be defined to reflect other social or economic aspects of the project intent, such as the protection of property or the creation of aesthetic improvements to satisfy public expectations. For each project, a complete listing of goals and objectives should be prepared by the proponent and the designers based on their understanding and expertise. Table 2.2 provides examples of project goals and objectives that might be defined for typical hybrid or modified NCD channel design in which a true NCD cannot be achieved because of a need to protect adjacent property and infrastructure in some locations, as well as a need to satisfy the aesthetic criteria of adjacent residents. Although this list would apply to many past projects constructed in the TRCA jurisdiction, it is not intended to be complete; each project is expected to have slightly different goals and objectives based on its own particular details.

Once goals and objectives are identified, an appropriate suite of performance criteria and monitoring parameters can be selected, to evaluate the project success in meeting satisfying these aims.

Table 2.2: Example project goals and objectives for typical hybrid/modified NCD Projects

	GOAL	OBJECTIVES
FLUVIAL GEOMORPHOLOGY	Achieve channel form and rates of channel change that are self-sustaining and in balance with the local hydrology and sediment regime, equivalent to those of an undisturbed stream subject to the same independent influences.	• Maintain or restore channel geometry, rates of bank erosion, planform migration, bedform evolution and channel substrate consistent with undisturbed conditions *wherever possible*. • Design permanent/engineered structures intended to limit channel change such that unconstrained sections of channel are not negatively affected in their ability to adjust in response to prevailing conditions.
AQUATIC ECOSYSTEM	Create self-sustaining aquatic habitat that supports an aquatic ecosystem with diversity and richness equal to that of an undisturbed stream subject to the same independent influences.	• Maintain or restore self-sustaining physical and hydraulic in-stream habitat consistent with undisturbed conditions *wherever possible*. • Design permanent/engineered structures intended to limit channel change to provide maximum quality and diversity of aquatic habitat consistent with the non-limited portions of the design. • Ensure that permanent/engineered structures intended to limit channel change do not create barriers to the movement of organisms, food and energy upstream and downstream of the project reach.
RIPARIAN ECOSYSTEM	Create a riparian corridor with native and diverse vegetation that supports terrestrial and aquatic habitat and provides structural channel stability equivalent to those of undisturbed streams subject to the same independent influences.	• Maintain or restore a self-sustaining vegetation community reflective of undisturbed conditions. • Maintain or restore composition and density of bank and channel margin vegetation to a state reflective of undisturbed conditions.
WATER QUALITY	Create a stream corridor that does not contribute negatively to water quality and provides such improvements or inputs as are made by undisturbed streams subject to the same independent influences.	• Maintain or improve chemical water quality between upstream and downstream extents of project to a level consistent with undisturbed conditions. • Maintain or reduce water temperature or minimize temperature increases from upstream to downstream extent of site to a level consistent with undisturbed conditions.
PROPERTY AND INFRASTRUCTURE	Prevent the erosion damage of adjacent property or infrastructure by the constructed stream channel.	• Prevent or limit channel change where adjacent property and infrastructure are at risk . • Create permanent or long-lived structures to limit channel change (where required) that will eliminate or minimize maintenance requirements.
SOCIAL EXPECTATIONS	Maintain or increase the aesthetic value of the affected stream channel and corridor.	• Create a channel configuration and corridor landscape that are aesthetically pleasing to the extent possible within the physical and ecological requirements dictating the design.

2.2 Selection of Performance Criteria

Performance criteria are standards by which the monitored behaviour and outcomes of a project can be evaluated to determine if project goals and objectives are being met. In general terms, performance criteria allow a practitioner to evaluate whether or not the project and/or specific design elements are performing to an acceptable or expected standard. To accomplish this, the criteria must be closely related to the project goals and provide *measurable* means of determining whether the goals and objectives have been achieved. In simple terms, project performance can be classified as acceptable if the criteria are met, or unacceptable if they are not. If the results are unacceptable, the magnitude of the deviation can be used as an indicator of the severity of the deficiency if the threshold is quantitative.

Performance criteria should also be set at the design phase based on the list of project goals and objectives that has been compiled. As described above, many goals and objectives are inherent to all projects and therefore some performance criteria can be standardized. Table 2.3 lists standard performance criteria that correspond with the goals and objectives inherent to NCD as defined in Table 2.1.

Table 2.3: Example performance criteria for typical modified/hybrid NCD projects.

	PROJECT OBJECTIVES	PERFORMANCE CRITERIA
FLUVIAL GEOMORPHOLOGY	Maintain or restore channel geometry consistent with undisturbed conditions.	• Channel cross-section geometry remains consistent with design parameters and reference location(s) or targets* • Channel plan form geometry remains consistent with design parameters and reference location(s) or targets* • Channel longitudinal profile geometry remains consistent with design parameters and reference location(s) or targets*
	Maintain or restore self-sustaining rates of bank erosion, planform migration and bedform evolution.	• Rates of bank erosion and channel cross-section change are consistent with reference location(s) or targets* • Rates and modes of plan form migration are consistent with reference location(s) or targets* • Rates of bedform translation are consistent with reference location(s) or targets*
	Maintain or restore natural channel substrate and sediment transport continuity.	• Channel bed and bank substrate remain consistent with design parameters and reference location(s) or targets* • No long-term sediment accumulation or depletion take place in the constructed channel and corridor unless associated with systemic change affecting entire area*
AQUATIC ECOSYSTEM	Maintain or restore self-sustaining physical and hydraulic habitat.	• Physical habitat features develop and remain present in similar frequency as design targets and to reference location(s) or targets* • Distribution of flow depth and velocity, and hydraulic features remain equivalent to design parameters and reference location(s) or targets*
	Maintain or restore species richness and biomass of aquatic flora and fauna	• Diversity and numbers of fish species remains equivalent to reference location(s)* • Diversity and numbers of benthic macroinvertebrates remains equivalent to reference location(s) or targets* • Diversity and density of aquatic vegetation remains equivalent to reference location(s) or targets*
	Maintain or restore continuity of the upstream and downstream movement of organisms, food and energy	• Barriers to fish movement are eliminated and no new barriers to fish movement are created* • Corridor contributions of nutrients, detritus and terrestrial insects are similar to reference locations(s) or targets*
	Create a stream corridor that does not contribute negatively to water quality and provides natural improvements or inputs	• Water chemistry changes through reach are comparable to reference location(s) or targets* • Water temperature changes through reach are comparable to reference location(s) or targets*
RIPARIAN ECOSYSTEM	Maintain or restore a self-sustaining vegetation community reflective of undisturbed conditions.	• Composition and density of riparian vegetation species approaches that of reference location(s) or targets* • Succession proceeds according to natural patterns; invasive and non-native species are restricted to reference corridor or watershed target values* • Survival rate of planted species meets or exceeds target or warranty values*
	Maintain or restore composition and density of bank and channel margin vegetation	• Composition and density of bank/channel margin vegetation approaches that of reference location(s)*
PROPERTY AND INFRASTRUCTURE	Prevent or limit channel change where adjacent property and infrastructure are at risk	• Bank erosion and channel migration rates are zero or negligible in critical locations • Integrity of infrastructure is maintained • Adjacent properties are not affected by channel movement or erosion
	Create permanent or long-lived structures to limit channel change (where required)	• Integrity of structures persists over time • Structures remain in place • Structures relying on vegetation establishment achieve design vegetation density and growth rates
SOCIAL EXPECTATIONS	Create a channel configuration and corridor landscape that are aesthetically pleasing to the extent possible	• The majority of affected residents and/or users agree that aesthetic goals have been realized

* - inherent performance criteria applicable to all NCD projects

Because the overarching goal of NCD projects is to create a channel and corridor that replicate the form and function of an undisturbed watercourse that is subject to the same independent controls, it is necessary that performance criteria be related to characteristics of such a watercourse. The performance criteria in Table 2.3 refer to *reference locations*, which are locations where observations may be made of watercourse form and function that can be used to define the ideal undisturbed condition. Ideally, a reference location or locations would be present nearby in the same watercourse as where the project is proposed; as this provides the greatest confidence that the reference channel characteristics reflect the same controlling conditions. Qualified NCD practitioners will identify reference locations in the design process if they exist, as the characteristics of reference sites are used in the formulation of design parameters for NCD projects. Parallel monitoring of reference sites and the project reach provides an extremely effective means of evaluating project success, as the monitoring data from the reference sites is translated into the quantitative performance criteria against which the performance of the constructed channel is assessed. The application of reference sites in monitoring is described in further detail in the following sections.

For many projects an appropriate reference location may not exist, such as where past channel modification has left no undisturbed reaches of watercourse remaining, or where surficial geology or slope are highly variable. In such cases, reference characteristics or values to use as the basis for performance criteria must be selected based on data collected in other areas. There is an extensive body of literature in which the morphological characteristics and rates of channel change of natural, undisturbed watercourses have been measured and documented. However, such data must be used with caution as the settings and controlling influences of these watercourses often differ significantly from Southern Ontario conditions. Further, researchers have rarely studied the form and behaviour of watercourses subject to the effects of urbanization in the contributing upstream catchment, although the resulting hydrologic regime is known to have a profound function on stream geomorphology.

In the TRCA jurisdiction, useful data may be obtained from the TRCA Regional Watershed Monitoring Network (RWMN) that includes measurements of fluvial geomorphology, fish communities, water quality, benthic macroinvertebrates, and physical habitat at more than 150 locations in several watersheds reflecting a variety of controlling land uses, topography, and geology. It is expected that qualified practitioners undertaking NCD projects will already have a compiled the most appropriate local or literature data of this type in order to prepare the channel design, which can then be adapted for the selection of reference values for performance criteria. It will be necessary in such cases to provide broad target ranges in the determination of quantitative criteria to account for uncertainty, as well as to rely on additional qualitative criteria such as observations of improvement from the pre-project condition. Some of the case studies that accompany this document provide examples of performance criteria selected for NCD project monitoring in the absence of nearby reference sites.

2.3 Spatial Extent of Monitoring

Ideally, monitoring should characterize and document the condition of the entire project reach. However, for most NCD projects a significant length of watercourse is affecting, making monitoring of the entire site impractical. In such instances, it is necessary to select portions of the reconstructed channel that are representative of the project as a whole. The majority of the monitoring techniques presented in this protocol involve the definition of a specific channel segment site for monitoring; where the scale of the project exceeds the size of such a segment, monitoring sites should be selected to capture each section of the project with unique design characteristics, such as slope, plan form, landscape planting, or engineered stabilization features. Long projects with uniform design characteristics will still require multiple representative sites to capture variation in channel response over the entire project area. For all projects, a the maximum distance between representative monitoring locations should 500 meters or 80 times the design channel bankfull width, whichever is less. A minimum distance of 40 meters between monitoring sites should be applied; if this cannot be achieved it suggests that the entire project length can be monitored.

Monitoring plans for NCD projects should include monitoring of reference sites and/or control sites, which provide a basis for comparison with data from the project reach in order to evaluate project performance and success. In the context of this protocol, a *reference site* is defined as a section of watercourse with the same controlling characteristics as the project reach but that has not been directly altered or degraded and represents the ideal condition that can exist given the setting and watershed context. A *control site* is defined as a section of watercourse with the same controlling characteristics as the project reach but that is degraded in similar fashion and that will not be subject to reconstruction or restoration as part of the NCD project. Reference and control sites provide a basis for accounting for some of the effects of background environmental variability on the watercourse, such as climate patterns or land use change, which might otherwise be erroneously interpreted as a project outcome. They also provide data with which to compare project monitoring outcomes to evaluate success.

Reference sites, as noted previously, are useful not only in identifying background variability but also in providing the basis for setting performance criteria for a channel design. If a suitable reference reaches are available, their characteristics and processes are can be quantified at the same time as those of the project reach and that information is effectively used to define the criteria against which the project is evaluated, either in whole or in part. Reference sites for NCD projects should be located nearby on the same watercourse in order to best ensure similarity of controlling variables, at locations with similar or identical slope, geology, valley confinement, discharge, and sediment input. Ideally, reference sites are located immediately upstream of project sites to avoid the influence of the disturbed and adjusting project reach, although downstream reference sites may be used with careful interpretation. Reference sites may also be selected from different watercourses, although caution in interpretation of data is required as it is difficult to ensure that setting and context are comparable. Where appropriate reference sites exist, it is expected that some will already have been identified by qualified practitioners through the NCD project design process that can be used for monitoring purposes. While a single, carefully selected reference site may be sufficient for monitoring and evaluation, larger projects or projects involving sensitive or a high degree of risk may warrant the use of multiple reference sites to account for natural spatial variability. Reference sites should be monitored at the same time as the project site, using the same parameters and methods in order to generate directly comparable data. Each reference site should be monitored to the same extent as a representative monitoring site on the project reach.

Control sites should be monitored for projects where suitable reference sites are not available. While control site monitoring does not provide data that can be used to evaluate the ultimate success of a project in achieving its ideal reference condition, it provides an indication of whether the project condition represents an improvement in comparison to a channel in a similar environment that has not been reconstructed. For projects without reference sites, the ideal reference condition and associated performance criteria will be determined using other methods as described in the previous section. While some aspects of such improvement can be evaluated through pre-construction monitoring of the project reach (as described in the following section), the ongoing monitoring of control sites allows the detection of external influences on the entire watercourse that would otherwise be misinterpreted. As with reference sites, control sites should be located upstream of the project reach if at all possible. A single control site should be sufficient for most monitoring plans as long as it is thoughtfully selected. Monitoring at control sites should take place at the same time and at the same scale as monitoring on the project reach. Unlike reference reaches, monitoring of some parameters measured in the project reach may not be required, as some control sites such as those located in concrete channels may not possess properties or processes that those parameters describe.

For some projects, neither reference sites nor control sites will be available, although it is expected that such cases will be relatively uncommon. In these circumstances it is more difficult to detect background influences that will influence findings of monitoring with the project reach, but it may be accomplished to some degree through comparison with data from watershed-scale monitoring initiatives such as the TRCA RWMN or the Ontario Ministry of Natural Resources HABPROGS database. Data from these programs can be used for comparison with project site monitoring data and to distinguish some of the regional climatic or land use influences that may be affecting monitoring results.

2.4 Frequency and Duration of Monitoring

Evaluation of the success of NCD projects requires monitoring of a significant duration, as the geomorphic and ecological change and recovery in the constructed channels takes place over years and even decades. Researchers and practitioners generally concur that a minimum duration of monitoring for stream restoration projects is a period of approximately three to five years (e.g. Miller et al, 2001; US Army Corps of Engineers, 2003), and that an ideal monitoring duration to determine the performance of a complex restoration initiative such as an NCD project is at least ten years (Kondolf and Micheli, 1995; Annable, 1999; Downs and Kondolf, 2002). Many past NCD projects in the TRCA jurisdiction were subject to basic monitoring for periods of up to three years after construction. Observations of current condition of some existing projects up to ten years after construction suggest degradation and poor performance, which was not captured and corrected by the scope or duration of past short-term monitoring that took place, if any. The absence of comprehensive, long-term monitoring in such cases has resulted in lack of project success with no current means of identifying the need for, or implementing, corrective action.

Post-construction monitoring of NCD projects, according to this protocol, should take place for a minimum ten-year period. While it is recognized that this is a significantly longer duration than current monitoring practice (when it takes place), experience both within the TRCA jurisdiction and elsewhere indicate that a shorter monitoring period is not adequate to evaluate NCD success and to truly determine if a project has successfully created a channel with the dynamic physical and complex ecological properties of a natural watercourse. Further, monitoring of this duration will hopefully maintain awareness of individual NCD projects for a greater period of time after construction, so that the need for maintenance, modifications and repairs can be brought to the attention of the individuals or organizations that are charged with this responsibility. It is acknowledged that extension of monitoring over ten years will increase the expenditure and level of effort associated with the monitoring component of NCD projects; but in general this increase will be very small in proportion to the cost and effort associated with project design and construction and may make the difference between long-term project success and failure.

The frequency of monitoring should vary according to the expected rate of change over the post-construction period. The most intensive monitoring should occur in the first three years after project completion, as channel changes tend to occur during that time period, while vegetation is re-establishing and the watercourse is adjusting to the prevailing conditions. In general, for these three years monitoring should be undertaken at least once per year, preferably during the same season each year to ensure comparability between data sets. For most monitoring parameters, the preferred timing is late summer when base flow conditions allow geomorphic variables and aquatic habitat conditions to be easily identified and measured. Monitoring of riparian vegetation is best done in the summer as well, to take advantage of full leaf-out conditions for ease of assessment. In addition, geomorphic monitoring should take place after a high flow event during this initial three-year period. For all parameters, monitoring in subsequent years should take place as closely as possible to the date on initial monitoring. The first occurrence of post-construction monitoring should take place in the first summer season after the channel has been completed and connected. In some cases, this means that monitoring will begin after significantly less than one year after construction. After the initial three-year period, monitoring can be conducted less frequently as the initial process of channel adjustment should be largely complete. Subsequent monitoring measurements should be conducted at five years, seven years, and ten years after project construction.

Baseline monitoring should be undertaken for all projects in advance of site disturbance and construction to document the condition of the subject watercourse reach. It is important to characterize the pre-construction geomorphology and ecology of the reach to be altered to provide a basis for comparison with future measurements of the constructed channel to determine if improvements have been realized. Baseline monitoring should be conducted at the same time of year anticipated for post-construction monitoring, and should take place in both the reach to be affected, as well as at any reference or control sites that have been selected in order begin the development of reference data as soon as possible. Much of the baseline data collection at reference sites, where they exist, is similar to that required to support the NCD project design and therefore will already be a component of project planning, although some additional data collection may be required. Pre-construction monitoring of control sites is required to identify the variability between the control location and unimproved project reach for consideration in comparison of post-construction monitoring data. Baseline data should be collected in at least one year before project construction at the same time of year during which future post-construction monitoring will be conducted. While project timelines will typically limit data collection to a single year, larger projects and those located on sensitive watercourses may warrant longer baseline study in order to establish pre-construction rates of change and annual variation of ecological condition.

In addition to pre-construction monitoring, *as-built monitoring* should be conducted to document the channel and adjacent corridor condition immediately after project construction is complete. Such information is critical as the construction process often results in deviation from design plans, which then no longer provide an accurate depiction of the initial condition. As-built monitoring should take place as soon as possible after project construction; it is not necessary that it take place at the same time of year as later post-construction monitoring. The focus of as-built monitoring will be primarily on the built form of the channel, as it cannot be expected that vegetation or aquatic ecosystems will be established. As a matter of good construction practice, the entire length of channel should be subject to a topographic survey identifying the constructed plan form of the watercourse and the bathymetry of the channel. Additional geomorphic measurements should be undertaken at the selected representative locations throughout the projects, and monumented features such as cross-sections and erosion pins should be installed at this time.

Coordination of monitoring programs lasting ten years may require a change in approach when compared to existing short-term monitoring initiatives. In Southern Ontario, at present short-term (one- to three-year) monitoring is usually conducted by project proponents in response to the requirements of regulatory agencies. Proponents may not wish to be committed to project monitoring for a longer period and as a result the long-term component of monitoring may need to be completed by agencies, municipalities or local interest groups. In such cases, project budgets should be prepared to ensure availability of funds to support monitoring by others and to complete maintenance or repairs if a need is identified through long-term monitoring.

2.5 Monitoring Parameters and Methods

Monitoring parameters should be selected with the intent of generating the best information for evaluating an NCD project's achievement in meeting the stated goals, objectives and performance criteria. Due to the common overall goals of NCD projects, many of the parameters selected and techniques used will apply to all monitoring initiatives. This monitoring protocol provides a standardized 'toolbox' of monitoring parameters and techniques, including parameters which are expected to be included in all monitoring programs and additional parameters that are appropriate for addressing project-specific objectives and that are expected to be used primarily for monitoring hybrid or modified designs.

Table 2.4 lists the standard monitoring parameters included in the TRCA NCD monitoring protocol, which are expected to be applicable to address the general goals and objectives of virtually any NCD or modified/hybrid NCD project. Each parameter is described briefly, along with a rationale for inclusion, and an outline of methods to be used for data collection. In the "Applicability" column, the project conditions for which monitoring of each parameter is applicable are described, although most parameters are applicable to virtually all projects. Projects that are limited in scope or that take place in highly impacted areas where fisheries or terrestrial fauna cannot be expected to improve, may not require monitoring of some of the listed parameters. Other projects may have very specific performance criteria related to a unique project objectives that are not addressed by the list; in such cases additional monitoring parameters may need to be selected at the discretion of the monitoring plan designer. Care should be taken to ensure that the corresponding monitoring methods are standardized, repeatable and provide the data required to evaluate project performance with respect to the guiding objective.

The monitoring parameters listed reflect the parameters most often used in current stream monitoring practice to measure the stream characteristics and behaviour that are most relevant to NCD project performance. Similarly, the data collection methods prescribed reflect commonly used or accepted techniques in general practice and/or in use in the TRCA jurisdiction. A number of the prescribed methods are taken or adapted from the Ontario Stream Assessment Protocol (v. 7.0) which is widely used in the TRCA jurisdiction and throughout Ontario. Other methods are consistent with data collection techniques used by the TRCA for its RWMP activities. As a result, the data collected in NCD monitoring may be directly related to a large repository of existing data for comparison or reference purposes. Detailed descriptions of each monitoring method and literature references for further guidance are provided in Appendix A. For jurisdictions outside of the TRCA, it may be appropriate for monitoring plans to use equivalent standardized protocols in use in those areas by natural resource management agencies.

Table 2.5 provides a summary of how the monitoring parameters described in Table 2.4 may be applied to the various temporal (pre-construction, as-built, post-construction) and spatial (project reach, reference site(s), control site) components of a typical monitoring plan. While all of the parameters are not applicable to post-construction monitoring of the project site itself, they may not be applicable to all phases of monitoring or to reference and control sites; the table provides guidance in this regard.

Table 2.4: Monitoring Parameters and Field Methods.

	PARAMETER	Purpose	Field Method	Spatial Scale for Project and Reference Reaches	Monitoring Frequency and Duration	Applicability	Timing
FLUVIAL GEOMORPHOLOGY	**Channel Cross-Section Geometry**	Documents channel shape, quantifies bank erosion and channel migration rates, and sediment accumulation or depletion.	Monumented cross-sections installed above bankfull elevation.	Representative sections of project and reference/control reaches.	Pre-construction and as-built monitoring. Post-construction once per monitoring year (e.g. 1,2,3,5,7,10).	All projects.	Summer / Fall (after spring freshet). Same time each year.
	Longitudinal Profile	Quantifies channel slope and bed level changes, bed form configuration and change, and sediment accumulation or depletion.	Monumented longitudinal profile using survey equipment.	Entire project area and reference/control reaches.	Pre-construction and as-built monitoring. Post-construction once per monitoring year.	All projects.	Summer / Fall (after spring freshet). Same time each year.
	Bed Substrate Characteristics	Quantifies surficial sediment particle size distribution and change in distribution over time.	Pebble count at cross-sections.	Performed at cross-sections in project area and reference/control reaches.	Pre-construction and as-built monitoring. Post-construction once per monitoring year .	All projects.	Summer / Fall (after spring freshet). Same time each year.
	Sub-Reach Map	Characterizes the geomorphic and aquatic habitat features of a site as functional units, and change in location and number of features over time.	Observation-based mapping of project area on standard forms.	Entire project area if feasible; for extensive projects use representative areas. Project and reference/control reaches	Pre-construction and as-built monitoring. Post-construction once per monitoring year.	All projects.	Summer / Fall (after spring freshet). Same time each year.
	Visual/ Photographic Observations	Documents channel adjustments, bank erosion, success of riparian vegetation and the integrity of structural features.	Photographic documentation of project.	Taken at each cross-section and throughout project area including upstream and downstream extents, and reference/control reaches	Pre-construction and as-built monitoring. Post-construction once per monitoring year.	All projects.	Summer / Fall (after spring freshet). Same time each year.
	Bank Erosion Rates	Quantifies bank erosion and channel migration rates.	Installation of erosion pins.	Installed at permanent cross sections, plus areas not subject to cross-section surveys in extensive projects. Project and reference/control reaches	Pre-construction and as-built monitoring. Post-construction once per monitoring year.	All projects.	Summer / Fall (after spring freshet). Same time each year.

Table 2.4 cont'd: Monitoring Parameters and Field Methods.

	PARAMETER	Purpose	Field Method	Spatial Scale for Project and Reference Reaches	Monitoring Frequency and Duration	Applicability	Timing
AQUATIC ECOSYSTEM	**In-Stream Habitat**	Provides quantitative measures of organic matter input, riparian habitat condition, relative amounts of cover, habitat types and available substrate. Can be used to track change in physical habitat as well as channel structure.	In-stream habitat assessment procedure per OSAP Section 4, Module 2*.	Characteristic sampling site, or multiple sites for extensive projects, per OSAP Section 4, Module 1*. Project and reference/control reaches	Pre-construction monitoring. Post-construction once per monitoring year.	All projects.	Summer / Fall (after spring freshet). Same time each year.
	Fish Species	Provides an inventory of fish species and overview of community structure from which indices of biotic integrity can be calculated. Can be used to track change over time.	Single-pass electrofishing survey following OSAP Section 3*. Multiple pass surveys may be required where quantification of species biomass is required.	Characteristic sampling site, or multiple sites for extensive projects, per OSAP Section 4, Module 1*. Project and reference/control reaches	Pre-construction monitoring. Post-construction once per monitoring year.	Projects where fish species are present in project reach or nearby upstream/downstream reaches.	Summer (general community) or Spring / Fall (species-specific). Same time each year
	Benthic Macroinvertebrates	Provides an overview of benthic community composition, reflecting overall aquatic ecosystem health and composition, transport patterns of bed substrate and water quality.	Transect traveling kick and sweep survey per OSAP Section 2, Module 3*.	Characteristic sampling site, or multiple sites for extensive projects, per OSAP Section 4, Module 1*. Project and reference/control reaches	Pre-construction monitoring. Post-construction once per monitoring year.	Projects where benthic macroinvertebrates are present in project reach or nearby upstream/downstream reaches.	Summer/ Early Fall. Same time each year
	Water Chemistry and Suspended Sediment	Allows determination of chemical and sediment inputs of constructed channel.	Spot measurements of basic water chemistry parameters and total suspended solids (TSS)	At upstream and downstream limits of project. Additional monitoring within extensive sites may be required to identify locations of chemical or sediment inputs	Three visits annually for pre-construction monitoring and in each of post-construction monitoring years.	All projects.	Summer low flow conditions for water chemistry, elevated flows for suspended sediment
	Water Temperature	Determines temperature changes over channel length and allows assessment of effectiveness of bank vegetation in providing shading and cover.	Continuous measurement and recording of water temperature per OSAP Section 5, Module 2.	At upstream and downstream limits of project. Additional monitoring within extensive sites may be required to identify locations of thermal inputs.	Continuous summers(s) of pre-construction monitoring and in each of post-construction monitoring years.	Projects in or contributing to cold- or cool-water streams.	May 1 to Sept 30 (continuous)

Table 2.4 cont'd: Monitoring Parameters and Field Methods.

	PARAMETER	Purpose	Field Method	Spatial Scale for Project and Reference Reaches	Monitoring Frequency and Duration	Applicability	Timing
RIPARIAN ECOSYSTEM	**Vegetation Community Distribution**	Characterizes the overall vegetation community distribution, allows determination of changes over time and comparison with local and regional reference locations.	Ecological Land Classification (ELC) to the level of vegetation type and vegetation species inventory	Entire valley or stream corridor area over project length. Project and reference/control reaches	Pre-construction monitoring, first post-construction monitoring year after completion of landscaping and again in tenth monitoring year.	Projects involving disturbance and revegetation of riparian corridor and where long-term monitoring is feasible.	May to October (Depends on vegetation type. Multiple visits may be required.)
	Vegetation Community Species Composition and Distribution	Provides quantitative data describing the density and distribution of vegetation species, which can be used to evaluate the success of the project landscaping design in achieving a resilient native vegetation community.	Vegetation transects and quadrats	Minimum four (4) transects per site, maximum distance between transects 100 m. Project and reference/control reaches	Pre-construction monitoring and once per monitoring year.	Projects involving disturbance and revegetation of riparian corridor.	May to October (Depends on vegetation type)
	Faunal Biodiversity	Provides an indication of success of design in creating habitat appropriate to overall faunal biodiversity.	Fauna species survey and checklist	Entire valley or stream corridor area over project length. Project and reference/control reaches	Pre-construction monitoring and once per monitoring year.	Projects involving disturbance and revegetation of riparian corridor.	
	Amphibian Population	Allows determination of project success in creating floodplain and riparian habitat for amphibian species.	Breeding amphibian surveys	Entire valley or stream corridor area over project length. Project and reference/control reaches	Pre-construction monitoring and once per monitoring year.	Projects involving disturbance of existing amphibian habitat and/or projects with amphibian habitat restoration objectives.	April to July (temperature dependent)
	Breeding Bird Population	Allows determination of project success in creating habitat for breeding birds.	Breeding bird surveys	Entire valley or stream corridor area over project length. Project and reference/control reaches	Pre-construction monitoring and once per monitoring year.	Projects involving disturbance and revegetation of riparian corridor where breeding bird habitat exists.	Early June to mid-July

Table 2.4 cont'd: Monitoring Parameters and Field Methods.

	PARAMETER	Purpose	Field Method	Spatial Scale for Project and Reference Reaches	Monitoring Frequency and Duration	Applicability	Timing
PROPERTY AND INFRASTRUCTURE	**Channel Change in Vulnerable Areas**	To proactively identify rates or modes of channel change that could threaten property or infrastructure	Additional cross-section surveys and/or erosion pins	Sections of channel in proximity to vulnerable property or infrastructure.	Once per post-construction monitoring year.	Projects where property and/or infrastructure are located with the valley or stream corridor or at the top of eroding banks or slopes.	At time of geomorphic monitoring
	Integrity of Engineered Structures	Allows early detection of damage or impending failure of structures designed to protect property and infrastructure	Visual assessment of structures and photographs. Total station surveys should be undertaken for large and/or critical structures	Locations of engineered or bioengineered stabilization structures.	Once per post-construction monitoring year.	Projects where engineered or bioengineered structures are incorporated to restrict channel movement for protection of property or infrastructure.	At time of geomorphic monitoring
SOCIAL ASPECTS	**Resident/User Response**	To determine the response of local residents and other users of the project area to determine if aesthetic and functional expectations have been realized.	Opinion surveys.	Entire project area		Projects with adjacent residents, in highly used areas, or with significant public interest.	Recommended sometime between spring and fall

* - Monitoring of in-stream habitat, fish species, and benthic macroinvertebrates using OSAP techniques requires the application of OSAP Section 1, Modules 1 and 3 for site identification and documentation. Where possible and appropriate, in-stream habitat assessment, fish community sampling and benthic macroinvertebrate collection should take place at the same sampling site(s).

Table 2.5: Recommended applicability of parameters to monitoring plan components

	PARAMETER	PRE-CONSTRUCTION BASELINE			AS-BUILT	POST-CONSTRUCTION		
		Project Reach	Reference Site(s)	Control Site(s)	Project Reach	Project Reach	Reference Site(s)	Control Site(s)
FLUVIAL GEOMORPHOLOGY	Channel Cross-Section Geometry	✓	✓	✓	✓	✓	✓	✓
	Longitudinal Profile	✓	✓	✓	✓	✓	✓	✓
	Bed Substrate Characteristics	✓	✓	✓	✓	✓	✓	✓
	Sub-Reach Map	✓	✓	✓		✓	✓	✓
	Visual/Photographic Observations	✓	✓	✓	✓	✓	✓	✓
	Bank Erosion Rates		✓	✓		✓	✓	✓
AQUATIC ECOSYSTEM	In-Stream Habitat	✓	✓	✓	✓	✓	✓	✓
	Fish Species	✓	✓	✓		✓	✓	✓
	Benthic Macroinvertebrates	✓	✓	✓		✓	✓	✓
	Water Chemistry and Sediment	✓	✓	✓		✓	✓	✓
	Water Temperature	✓	✓	✓		✓	✓	✓
RIPARIAN ECOSYSTEM	Vegetation Community	✓	✓	✓		✓	✓	✓
	Vegetation Species Composition	✓	✓	✓		✓	✓	✓
	Faunal Biodiversity	✓	✓	✓		✓	✓	✓
	Amphibian Population	✓	✓	✓		✓	✓	✓
	Breeding Bird Population	✓	✓	✓		✓	✓	✓
OTHER	Channel Change in Vulnerable Areas					✓	✓	✓
	Engineered Structures					✓	✓	✓
	Resident/User Response					✓	✓	✓

2.6 Monitoring Plan Document

For all NCD projects, a formal monitoring plan should be documented in a report accompanying the project design documentation. The monitoring plan document should describe the monitoring program in detail, from project objectives and performance criteria to monitoring parameters and methods. This explicit recording of the monitoring approach will ensure consistency in action over the course of the monitoring program, which is particularly important if multiple individuals or organizations are involved. The documentation of project objectives and performance criteria also provides a clear framework for the future interpretation of monitoring data, and decisions regarding project success and need for corrective action. The design basis for the project should also be documented in the monitoring plan so that the original intent and rationale for the various components of the channel and corridor design can provide a context for the interpretation of the monitoring results. Table 2.6 provides a standard structure for the monitoring plan document; some modifications may be required to account for unique project characteristics or objectives but the general framework should be applied in all cases for consistency and completeness.

Table 2.6: Monitoring Plan Document Structure

SECTION	CONTENT	FIGURES
Project Description	• Project location • Watercourse name • Upstream drainage area to project location • Physiographic setting • Project proponent	• Key map of project site • Map of project area with recent air photo base
Goals and Objectives	• Purpose of / need for project • Statement of standard NCD project goals and objectives (per Table 2.1) • Additional project-specific goals and objectives	
Design Basis	• Description and location of design reference site(s) if applicable • Description and citation for design reference information from other sources if applicable • Summary of rationale for project design parameters and features: - channel plan form configuration - channel cross-section shape - channel slope and bed form configuration - bed substrate size and placement - bank treatments and plantings - floodplain/corridor landscape plan and species selection - engineered/bioengineered channel stabilization structures - constructed riparian/terrestrial habitat features	• Key map of design reference sites
Performance Criteria	• List of standard NCD project performance criteria (per Table 3) and associated targets • List of additional project-specific performance criteria and associated targets • Description of reference sites to be used for criteria targets, if applicable • Basis for criteria targets (literature, watershed monitoring, etc.) in addition to or in place of reference sites	
Monitoring Plan	• List of monitoring parameters and techniques to be used (per Table 2.4 and additional project-specific parameters) • Description of reference and control site(s) • Description of pre-construction baseline monitoring locations • Description of as-built / post-construction monitoring locations • Monitoring schedule - Dates pre-construction monitoring undertaken and completed - Expected dates of as-built monitoring and timing with respect to completion of construction - Schedule for post-construction monitoring activities by year including date range for timing of measurements each monitoring year (per Table 2.1).	• Scale map illustrating future as-built and post construction monitoring locations
Pre-constr. Monitoring Results	• Geomorphic monitoring results from project site and reference / control sites • Aquatic habitat and biotic monitoring results • Riparian monitoring results	• Scale map illustrating pre-construction monitoring locations for all parameters including reference sites
Appendices	• Project design report and complete design drawings on CD-ROM • Pre-construction monitoring data – field data collection sheets, data summaries, tables, etc, • Digital files of pre-construction monitoring data – HabProgs files, other spreadsheets/databases, photos, etc.	

2.7 Data Management

Monitoring results must be document in a consistent format in order to ensure that the integrity and quality of the data is maintained for future analysis. All monitoring programs should include the development or use of databases appropriate to the data being collected. In many cases, spreadsheets or a simple database using widely available software will be sufficient to permit consistent data collection and comparison throughout a monitoring program. This approach is appropriate for most of the fluvial geomorphology and riparian ecosystem data collected according to this protocol. The monitoring practitioner(s) should ensure that the structure of spreadsheets and databases mirrors that of field data collection sheets to facilitate data entry and to ensure that all field observations and measurements are recorded. The structure should also be designed to facilitate extraction of data for across locations and subsequent monitoring years, and should have sufficient documentation and intuitive features to allow different users to view and manipulate the data.

Aquatic monitoring data collected using OSAP should be entered and stored in the HabProgs relational database that has been developed specifically for that purpose and is maintained by the Ontario Ministry of Natural Resources for the storage of data collected across the province. HabProgs, which is available at http://stonecraftindustries.hypermart.net, has data entry screens structured in the same way as the OSAP field data collection sheets, allowing straightforward data entry. The OSAP protocol document includes a section (Section 6, Module 1) that provides a tutorial for the use of HabProgs.

2.8 Data Analysis

Analysis of monitoring data should take place after each monitoring event, other than the initial baseline pre-construction monitoring. While the comprehensive analysis of project success will not be performed unit the full ten years of monitoring is complete, regular examination of monitoring data and comparison to reference sites and performance criteria will permit identification of change outside of expected parameters, which in some cases should be addressed through corrective action.

It is expected that rigorous statistical analysis of quantitative monitoring data will not be possible for most NCD projects because of the spatial and temporal extent of data collection is necessarily limited by practical and economic constraints. For most parameters, the quality of the analysis will rely on it being undertaken by qualified practitioners using numerical or graphical comparison of data from different monitoring sites (i.e. project, reference, control) and different monitoring events to evaluate the type and degree of change in the project area and progress towards success in the context of performance criteria. Other aspects of channel condition that are not suited to quantitative measurement will require qualitative interpretation of results based on the professional experience of monitoring practitioners. The practitioners should be cautious in using the interpretation to draw conclusions, and in attempting to identify causes of change should always relate monitoring results from the project site to data from reference and control sites as well as watershed-scale trends. Table 2.7 lists standard aspects of change that should be assessed for standard NCD monitoring parameters and used to provide measures that in most cases allow quantitative analysis. Other measures may be required to address project-specific monitoring parameters.

Table 2.7: Analysis of monitoring data for NCD parameters

	PARAMETER	CHARACTERISTICS OF CHANGE	TYPE OF ANALYSIS	TO BE COMPARED TO		
				Reference Site(s)	Control Site(s)	Watershed Data
FLUVIAL GEOMORPHOLOGY	Channel Cross-Section Geometry	• Cross-section bankfull width, depth, area • Cross-section shape • Channel entrenchment	• Numerical • Graphical	✓	✓	✓
	Longitudinal Profile	• Channel slope • Bed form configuration • Bed form location	• Graphical	✓	✓	✓
	Bed Substrate Characteristics	• Substrate particle size distribution • Presence or absence of original constructed substrate	• Graphical	✓	✓	✓
	Sub-Reach Map	• Location of hydraulic and physical features • Variety and number of features	• Graphical • Visual	✓	✓	
	Visual/Photographic Observations	• Channel erosion • Vegetation growth • Bank condition	• Visual • Qualitative interpretation	✓	✓	
	Bank Erosion Rates	• Bank erosion rates	• Numerical	✓	✓	✓
AQUATIC ECOSYSTEM	In-Stream Habitat	• Location and number of undercuts • Bank angle • Bank composition • Amount of rooted vegetation • Water depth • Cover quality and type • Aquatic vegetation type	• Numerical • Qualitative interpretation	✓	✓	✓
	Fish Species	• Fish species assemblage • Total fish numbers and biomass • Number and biomass of individual fish species	• Numerical	✓	✓	✓
	Benthic Macroinvertebrates	• Macroinvertebrate species assemblage • Total number of macroinvertebrates • Number of individual species • Quality indices	• Numerical	✓	✓	✓
	Water Chemistry and Sediment	• Change in constituent concentration over site length	• Numerical	✓	✓	✓
	Water Temperature	• Change in water temperature over site length	• Numerical	✓	✓	✓

Table 2.7 cont'd: Analysis of monitoring data for NCD parameters

	PARAMETER	CHARACTERISTICS OF CHANGE	TYPE OF ANALYSIS	TO BE COMPARED TO		
				Reference Site(s)	Control Site(s)	Watershed Data
RIPARIAN ECOSYSTEM	Vegetation Community	• Vegetation community types • Vegetation species	• Graphical • Numerical	✓	✓	✓
RIPARIAN ECOSYSTEM	Vegetation Species Composition	• Species composition in riparian area • Relative number of non-native and invasive species • Species assemblage relative to original planting/seeding • Quality indices	• Numerical • Qualitative interpretation	✓	✓	✓
RIPARIAN ECOSYSTEM	Faunal Biodiversity	• Species assemblage and populations	• Numerical • Qualitative interpretation	✓	✓	✓
RIPARIAN ECOSYSTEM	Amphibian Population	• Species assemblage and populations	• Numerical • Qualitative interpretation	✓	✓	✓
RIPARIAN ECOSYSTEM	Breeding Bird Population	• Species assemblage and populations	• Numerical • Qualitative interpretation	✓	✓	✓
OTHER	Channel Change in Vulnerable Areas	• Rate and direction of channel movement	• Numerical			
OTHER	Engineered Structures	• Presence and condition of structures	• Qualitative interpretation			
OTHER	Resident/User Response	• Resident/user opinion of current channel condition	• Numerical • Qualitative interpretation	✓	✓	

2.9 Reporting

Interim monitoring reports should be prepared shortly after each monitoring event and provided to the project proponent as well as other stakeholders such as regulatory agencies and community groups. Interim reports should summarize the monitoring tasks that were completed, document monitoring data, provide an assessment of project performance to date, and make recommendations for corrective action and/or modifications to the monitoring program if appropriate. The results should be presented comprehensively and in formats that permit visualization and interpretation of the data by the reader. Wherever possible, summary graphs, tables or illustrations should be used to the end. A standard list of information that should be included in all monitoring reports as a minimum is provided in Table 2.8. Projects with unique or highly specific goals and objectives may require additional discussion. Each monitoring report should follow the same format as the previous ones to facilitate comparison between monitoring years.

Table 2.8: Monitoring Report Content

SECTION	CONTENT	FIGURES
Completed Tasks	• Dates of all monitoring activities in period being reported • Description and rationale for any deviations from the project monitoring plan • Description of any new or moved monitoring locations	• Map illustrating location of new or modified monitoring locations
Monitoring Results and Analysis	• Comparison of current monitoring data to pre-construction, as-built and post-construction monitoring results for all parameters • Analysis of change and rates of change in monitored parameters within the project area and at reference and control sites for all parameters • Comparison of conditions and rates of change at project site to those at reference and control sites for all parameters • Comparison of conditions and rates of change to watershed monitoring data or other project performance criteria not derived from reference or control sites	• Tables and graphs illustrating temporal and spatial change • Photos illustrating current conditions and changes observed
Interpretation and Evaluation	• Summary of observations where current condition of project and / or changes observed in project reach are do not conform with performance criteria. • Association of non-conformance with project design, external environmental influences and / or unforeseen circumstances. • Projection of expected future condition of channel with respect to non-conformance without corrective action.	
Corrective Action	• Recommendations for corrective action to address non-conformance if evaluation of results indicates necessity	
Modifications to Monitoring Plan	• Recommendations for modifications to monitoring plans if required to address project areas of concern	• Map illustrating location of proposed new or modified measurements
Appendices	• Raw monitoring data from reported year - field data collection sheets, data summaries, tables, etc, • Digital files for monitoring data from reported year– database files, spreadsheets, photos • Text of previous monitoring reports in digital format	

Final monitoring reports should be prepared after 10 years of monitoring that summarize all of the monitoring data collected and provide a final evaluation of the overall performance of the project. The final report should follow a similar format to the interim reports, but should include a more comprehensive analysis of project performance and discuss the positive and negative aspects of the design that contributed to success or lack of success of the project components. Recommendations should be made regarding ongoing needs beyond for ongoing monitoring and corrective action beyond the 10-year period in order to ensure long-term project performance, if it has been concluded that the channel has not achieved the self-sustaining condition that is the objective of NCD. Recommendations should also be made regarding aspects of the design and / or construction approaches project that could be modified for future projects to improve results, based on the analysis of the current project. The final monitoring report should include also package and include all of the raw monitoring data, and summarize the results of all interim reports, as it is the most likely to be retained and used in future.

3.0 REFERENCES

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APPENDIX A:

Fluvial Geomorphology Monitoring Methods

FLUVIAL GEOMORPHOLOGY

CHANNEL CROSS-SECTION

Objective

To measure channel cross-sectional shape and area, assess channel stability and partial fulfillment of data required to evaluate aquatic habitat conditions.

Background

Cross sections evaluate geomorphic changes and provide appropriate locations to conduct other monitoring assessments (i.e. pebble counts, aquatic habitat assessments). Replicates of similar morphological units (i.e. riffle, pool, run, transition, and glide) within the study reach should be captured (Kondolf and Micheli 1995). A minimum of 5 cross-sections is required to characterize channel form and stability (Davis *et al*. 2001). When used for monitoring a number of the established cross-sections should be monumented. Monumented cross-sections should be installed at different representative geomorphic units (i.e., pools, riffles and transitions).

*Methods**

1. Establish permanent markers for cross-sections, by driving re-bar (4' x ½") into the ground well above bankfull depth and at a distance from the banks where the markers are not at risk from channel adjustment, marked with paint and flagging tape. Install a 12" galvanized spiral nail in close proximity to each re-bar to use as endpoints for the cross-section.
2. Attach a measuring tape to both nails in a straight, level line across the channel for the surveying. Use the surveying equipment to obtain elevations at regular intervals (minimum every 5% of cross-sectional width).
3. Note measures of the deepest point of the channel, bottom of bank, top of bank, bankfull stage and water depth on the day (Annable 1999). Presence of large woody debris, sediment facies, or features such as bank undercuts should also be documented. Refer to Figure 4 as example.

* Methods are described for the use of a total station.

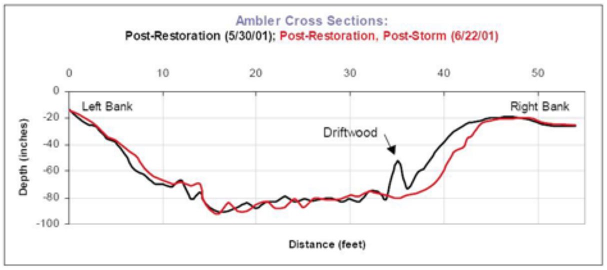

Figure A1: Example of a repeated, monumented cross-section showing change in cross-sectional area and pool scouring between surveys.

Equipment

- ✓ Survey equipment
- ✓ Flagging tape
- ✓ Marking paint
- ✓ Measuring tape
- ✓ Re-bar (4' x ½")
- ✓ 8-12" galvanized spiral nails
- ✓ 8-10 lb. sledge hammer
- ✓ Field book or data sheets

Reference(s)

Annable, W.K. 1999. On the design of natural channels: decisions, direction and design. *In* Stream Corridors: Adaptive Management and Design. Proceedings of the Second International Conference on Natural Channel Systems (CD). March 1-4, 1999. Niagara Falls, Canada.

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FLUVIAL GEOMORPHOLOGY

LONGITUDINAL PROFILE

Objective

To measure bed form adjustment, stability and maintenance of geomorphic units (such as pools), assess potential downcutting or aggradation, and partial fulfillment of data required to evaluate aquatic habitat conditions.

Background

A monumented longitudinal profile provides numerous data on channel characteristics. Surveying equipment is used to take measurements of bankfull elevations, maximum pool depths, top and bottom of riffles, and any obstructions to flow (Harrelson *et al.* 1994). The survey provides accurate information on pool depths, riffle gradients and overall channel gradient and can document types and rates of change over time. The length of survey required is 10 to 20 times the bankfull width (Annable 1999).

*Methods**

1. Set up the survey equipment in a manner that will allow maximum visibility of the stream channel and available benchmarks. This will reduce the number of set-ups and minimize overall survey time.
2. Choose a representative section with a length of at least 10 to 20 times the bankfull channel width.
3. Measure start point of survey to several permanent or established bench marks (3 to 5).
4. Select culvert inverts or riffle features for your start and end points to minimize error in measured gradients (i.e. riffle-to-pool profile will have a higher gradient than a riffle-to-riffle profile).
5. Along the thalweg, obtain elevations at regular intervals (approximately 1 m) and include breaks in slope and areas where there are changes in geomorphic features (i.e. top of riffle, bottom of riffle, top of pool, bottom of pool). Surface water level and bankfull indicator elevations should also be included in the profile. Presence of large woody debris, sediment facies, or features such as knickpoints should also be documented.

* Methods are described for the use of standard survey equipment.

Equipment

- ✓ Survey equipment
- ✓ Measuring tape
- ✓ Field book or data sheets

Reference(s)

Annable, W.K. 1999. On the design of natural channels: decisions, direction and design. *In* Stream Corridors: Adaptive Management and Design. Proceedings of the Second International Conference on Natural Channel Systems (CD). March 1-4, 1999. Niagara Falls, Canada.

Harrelson, C.C., Rawlins C.L. and Potyondy, J.P. 1994. Stream channel reference sites: an illustrated guide to field technique. Gen. Tech. Rep. R M-245. Fort Collins, CO: Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 1-61.

FLUVIAL GEOMORPHOLOGY

SURFICIAL SEDIMENT CHARACTERISTICS

Objective

To measure channel stability, systematic adjustments in channel substrate, and partial fulfillment of data required to evaluate aquatic habitat conditions.

Background

There are numerous methods for characterizing channel substrate, summarized in Bunte and Abt (2001). The simplest and most widely used method for characterizing surficial sediments as part of reach characterization is pebble count methods such as that proposed by Wolman (1954). These measurements can be used to estimate grain roughness, predict bed mobilization thresholds, assess framework size of spawning gravels, or track changes in surficial sediment size and content (Figure 2).

This protocol was adapted from the Ontario Stream Assessment Protocol (Stanfield 2005) and the TRCA Regional Monitoring Network protocol (TRCA 2001). For the methods described herein, a modified Wolman (1954) pebble count is to be performed at each cross-section to provide baseline data on sediment characteristics. In very fine sediment beds, laboratory analysis of collected samples may be more appropriate.

An internet-based tool is available to assist with analyzing pebble counts:

www.stream.fs.fed.us/publications/ PDFs/Size-ClassPebbleCountAnalyzer2001.xls

Methods

1. At each cross-section select bankfull indicators and ensure that all areas between these two points are sampled.
2. Along the cross section, randomly select at least 40 particles, measure the intermediate or median axis and record particle size.
3. Samples should be collected at even intervals to reduce bias. Samples should be collected by looking away from the sampling location, lowering a hand vertically, and selecting the first particle contacted.
4. Sampling only within wetted cross-sections is advisable to reduce chance of sampling bank materials and for consistent methodology.
5. Attempt to sample from representative geomorphic units.
6. Note geomorphic units associated with each cross-section.

Equipment

- ✓ Measuring tape
- ✓ Meter stick
- ✓ Field book or data sheets

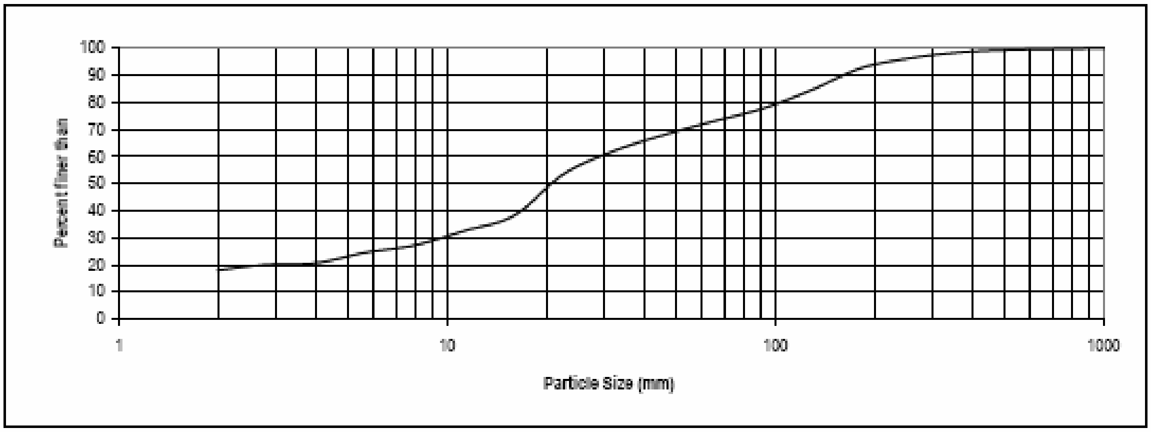


Figure A2: Example of a grain size distribution curve determined from pebble counts.

Reference(s)

Bunte, K. and Abt, S. 2001. Sampling Surface and Subsurface particle-Size Distributions in Wadeable Gravel- and Cobble-Bed Streams for Analyses in Sediment Transport, Hydraulics, and Streambed Monitoring. USDA Forest Service, Rocky Mountain Research Station General Technical Report RMRS-GTR-74.

Stanfield, L. (ed). 2005. Ontario Stream Assessment Protocol. Version 7, Fish and Wildlife Branch. Ontario Ministry of Natural Resources, Peterborough, Ontario.

TRCA. 2001. Regional Watershed Monitoring Program 2001: Status Report. Toronto and Region Conservation Authority.

Wolman, M.G. 1954. A method of sampling coarse riverbed material. Transactions of the American Geophysical Union, 35 (6): 951 – 956.

FLUVIAL GEOMORPHOLOGY

SUB-REACH MAP

Objective

To characterize channel geomorphology, and partial fulfillment of data required to evaluate aquatic habitat conditions.

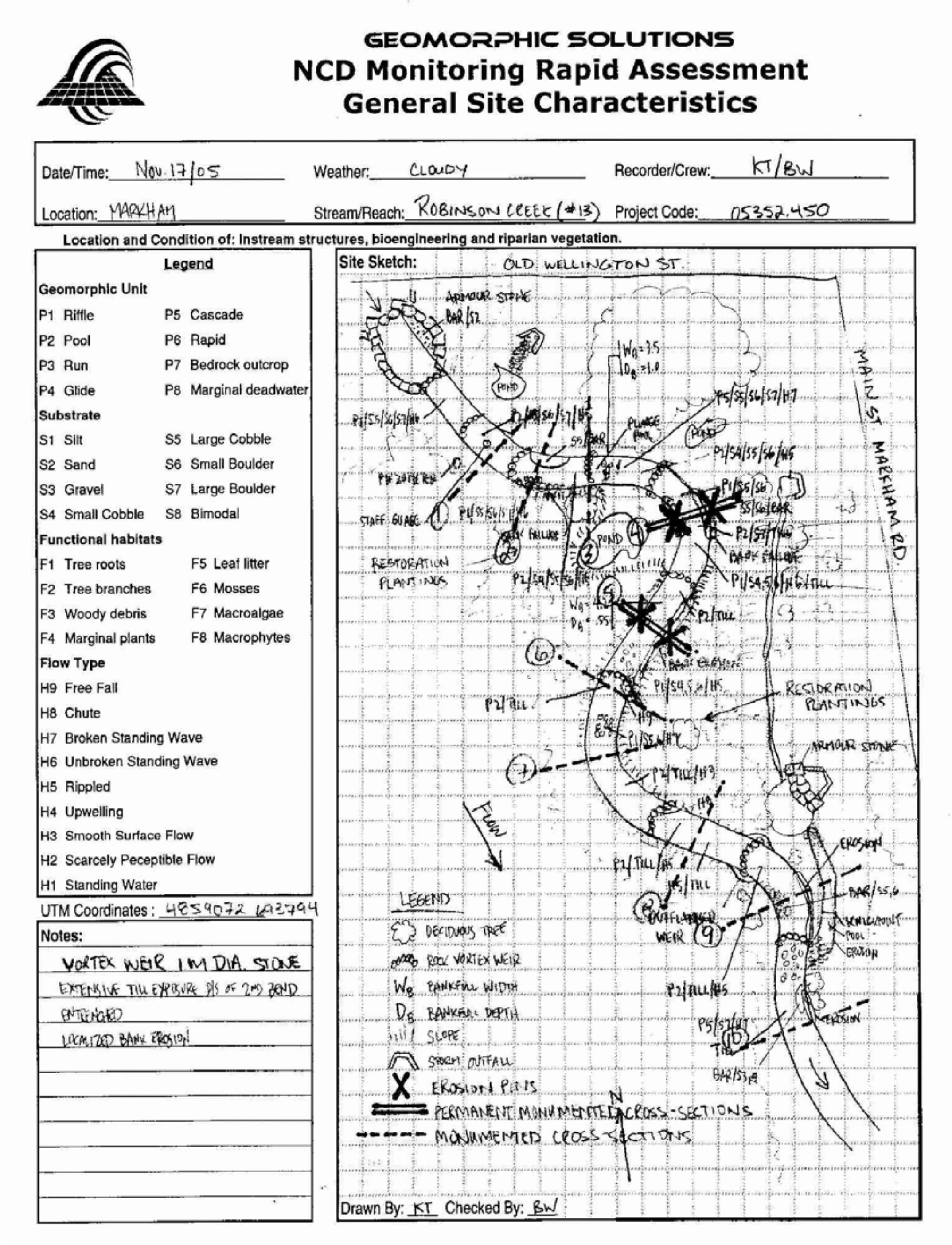
Background

Although the sub-reach map is an optional monitoring component, it is a simple and inexpensive method for documenting channel conditions, and integrating measures of fluvial geomorphology and aquatic ecology. In a sub-reach map, channel form and function is documented by recording morphological variability. This form of mapping hydraulic stream ecology provides a visual record of the interrelationships between stream velocity, depth and substrate that can be used to infer biotic community presence (Statzner *et al.* 1988). Functional habitats are typically associated with distinct depth-velocity conditions (Kemp *et al.* 1999), and can be mapped as patches of uniform flow and substrate, called biotopes (Newson and Newson 2000). Biotopes are the ecological equivalent of geomorphic units (i.e. pools, riffles, runs) at the sub-reach scale. Such integrative measures of morphology and habitat are invaluable for monitoring changes over time.

Sub-reach maps are also useful for locating landmarks of the project site. Prominent features such as roads, trees and large boulders can be included for future observers to locate the site, survey pins and benchmarks (Harrelson *et al*. 1994). An approximate scale, legend and coordinates should be included as well as cross-section and sampling locations (Stanfield 2005). Sub-reach maps also provide valuable information regarding pre-construction conditions, to compare with post-construction monitoring into the future. A representative area of channel needs to be walked to properly sketch a sub-reach map.

Methods

1. Walk the entire project area and choose a representative section with a length of at least 10 to 20 times the bankfull channel width. If feasible, map the entire project area.
2. Sketch the selected area to characterize the site conditions and landmark features. Ensure that enough detail is provided for useful interpretation with future monitoring activities. A standard form should be used, as exampled in Figure 3.
3. Label geomorphic units and flow types using a combination of letter/number codes and symbols.
4. Periodically include bankfull dimensions and water depths along the channel.
5. This assessment should be conducted during low flow conditions to provide access to substrate, highest visibility and to define hydraulic units.



GEOMORPHIC SOLUTIONS
NCD Monitoring Rapid Assessment
General Site Characteristics

Date/Time: Nov. 17/05 Weather: CLOUDY Recorder/Crew: KT/BW

Location: MARKHAM Stream/Reach: ROBINSON CREEK (#13) Project Code: 05352.450

Location and Condition of: Instream structures, bioengineering and riparian vegetation.

Legend

Geomorphic Unit

P1 Riffle	P5 Cascade
P2 Pool	P6 Rapid
P3 Run	P7 Bedrock outcrop
P4 Glide	P8 Marginal deadwater

Substrate

S1 Silt	S5 Large Cobble
S2 Sand	S6 Small Boulder
S3 Gravel	S7 Large Boulder
S4 Small Cobble	S8 Bimodal

Functional habitats

F1 Tree roots	F5 Leaf litter
F2 Tree branches	F6 Mosses
F3 Woody debris	F7 Macroalgae
F4 Marginal plants	F8 Macrophytes

Flow Type

H9 Free Fall
H8 Chute
H7 Broken Standing Wave
H6 Unbroken Standing Wave
H5 Rippled
H4 Upwelling
H3 Smooth Surface Flow
H2 Scarcely Peceptible Flow
H1 Standing Water

UTM Coordinates : 4859072 623794

Notes:

VORTEX WEIR 1 M DIA. STONE
EXTENSIVE TILL EXPOSURE D/S OF 2ND BEND
ENTRENCHED
LOCALIZED BANK EROSION

Site Sketch:

Drawn By: KT Checked By: BW

Figure A3: Example of a sub-reach map characterizing the project area and landmark features.

Equipment

- ✓ Measuring tape
- ✓ Meter stick
- ✓ Field book or data sheets

Reference(s)

Harrelson, C.C., Rawlins C.L. and Potyondy, J.P. 1994. Stream channel reference sites: an illustrated guide to field technique. Gen. Tech. Rep. R M-245. Fort Collins, CO: Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 1-61.

Kemp, J. L., Harper, D. M. and J. Crosa. 1999. Use of 'functional habitats' to link ecology with morphology and hydrology in river rehabilitation. Aquatic Conservation: Marine and Freshwater Ecosystems 9:159-178.

Newson, M.D. and Newson, C.L. 2000. Geomorphology, ecology and river channel habitat: mesoscale approaches to basin-scale challenges. Progress in Physical Geography 24(2):195-217.

Stanfield, L. (ed). 2005. Ontario Stream Assessment Protocol. Version 7, Fish and Wildlife Branch. Ontario Ministry of Natural Resources, Peterborough, Ontario.

Statzner, B., Gore, J.A.. and Resh, V.H. 1988. Hydraulic stream ecology: observed patterns and potential applications. Journal of the North American Benthological Association, 7: 307-360.

FLUVIAL GEOMORPHOLOGY

PHOTOGRAPHS FROM FIXED VANTAGE POINTS

Objective

To document a range of site conditions and characteristics in a manner that allows time-trend analyses, and partial fulfillment of data required to evaluate aquatic habitat conditions.

Background

Photographic documentation of a site from fixed vantage points is a simple and cost-effective monitoring method. Photographic documentation of pre- to post-construction conditions is also a standard monitoring requirement of most *Fisheries Act* authorizations issued by the Department of Fisheries and Oceans.

Photographs from fixed vantage points can be used to permanently document channel adjustments, bank erosion, success of riparian vegetation, and effectiveness of in-stream structures (Doll *et al*. 2003). It is a versatile monitoring tool that provides reasonably accurate data for long-term monitoring comparisons, and economically documents project evolution. Harrelson *et al*. (1994) provides a methodology for incorporating site photographs into a benchmarked survey.

Methods

1. Take photographs at each cross-section looking upstream and downstream. The vantage point of the photograph should be tied into the longitudinal survey.
2. At the upstream extent of the project area, take photographs looking downstream. At the downstream extent of the project area, take photographs looking upstream. The vantage points of the photographs should be tied into the longitudinal survey.
3. Record the photograph locations on the sub-reach map.
4. Take photographs from the same vantage point at the same time of year each monitoring interval to maximize effectiveness of this monitoring tool.

Equipment

- ✓ Camera
- ✓ Measuring tape (to illustrate cross-sections if necessary)
- ✓ Meter stick (to provide scale for photographs)
- ✓ Field book or data sheets (indicate photograph locations on reach sketch map)

Reference(s)

Doll, B.A., Grabow, G.L., Hall, K.R., Halley, J., Harman, W.A., Jennings, G.D., and Wise, D.E. 2003. Stream Restoration: A Natural Channel Design Handbook. Prepared by the North Carolina Stream Restoration Institute and North Carolina Sea Grant.

Harrelson, C.C., Rawlins C.L. and Potyondy, J.P. 1994. Stream channel reference sites: an illustrated guide to field technique. Gen. Tech. Rep. R M-245. Fort Collins, CO: Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 1-61.

FLUVIAL GEOMORPHOLOGY

BANK EROSION PINS

Objective

To measure channel adjustments, lateral migration and bank erosion.

Background

Erosion pins are installed along meander bends and straight sections of stream channel to provide a comparison of erosion rates. A 1m long piece of re-bar is driven horizontally into the bank leaving approximately 10 cm exposed (Harrelson *et al*. 1994). As erosion occurs, measurements of exposed re-bar indicate relative rates of bank loss.

Methods

1. At each cross-section install one piece of re-bar horizontally into each bank. Installation should occur below bankfull but above the average water level. Mark the re-bar with paint to assist with relocation at a future date.
2. Location of each erosion pin should be clearly documented. Record the erosion pin locations on the sub-reach map and the exposed lengths at time of installation.
3. Erosion pins should be installed in areas of expected erosion, such as the outside bend of meanders, and in areas of low potential erosion, such as riffles, as controls.

Equipment

- ✓ Marking paint
- ✓ Re-bar (4' x ½")
- ✓ Sledge hammer
- ✓ Field book or data sheets

Reference(s)

Harrelson, C.C., Rawlins C.L. and Potyondy, J.P. 1994. Stream channel reference sites: an illustrated guide to field technique. Gen. Tech. Rep. R M-245. Fort Collins, CO: Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 1-61.

APPENDIX B:

Aquatic Monitoring Methods

AQUATIC MONITORING

IN-STREAM HABITAT ASSESSMENT

Objective

To document the in-stream cover, habitat types and substrate types available to fish and aquatic benthos.

Background

Aquatic habitat conditions are documented with many of the geomorphic methods outlined in this protocol, and these data can be reviewed to assess in-stream aquatic habitat (i.e. sub-reach maps and cross-sectional data). For most projects, evaluation of aquatic habitat conditions can be accomplished using the geomorphic data collected in other sections of this protocol.

If preferred however, additional in-stream habitat data can be obtained by applying Section 4, Modules 1 or 2 (dependent upon level of detail desired) of the Ontario Stream Assessment Protocol (Stanfield 2005). Application of these modules increases overall sampling effort, but can be useful if specific habitat studies are required to evaluate project-specific objectives. Following the OSAP methodology allows for more detailed analysis of data (i.e. Habitat Suitability Indices), and provides a data set that is consistent with the TRCA Regional Monitoring Network.

Evaluation of both the biological and physical stream indicators allows for establishment of quantifiable restoration targets and provides a benchmark to assess enhancements or impairments with regard to aquatic ecology.

Methods

1. Refer to the detailed methods outlined in the Ontario Stream Assessment Protocol, Section 4, Modules 1 or 2.

Monitoring Frequency

Revisit after a large flow event within the first year of monitoring and then on an annual basis over a 3-year monitoring period.

Equipment

- ✓ Metre stick
- ✓ Pencils
- ✓ Field book or data sheets (Rapid Assessment Methodology)

Reference(s)

Stanfield, L. (ed). 2005. Ontario Stream Assessment Protocol. Version 7, Fish and Wildlife Branch. Ontario Ministry of Natural Resources, Peterborough, Ontario.

AQUATIC MONITORING

FISH COMMUNITY SAMPLING

Objective

To document fish community composition and relative abundance.

Background

A common objective of NCD projects is to increase or improve habitat for fish, and in some cases the projects have a fish habitat compensation component as a condition of approval in the Department of Fisheries and Oceans permitting process. Measures of pre-construction habitat usage by fish can be obtained by conducting a fish inventory following the screening level survey methods outlined in Section 3, Module 1 of the Ontario Stream Assessment Protocol (Stanfield 2005). The screening level survey characterizes the fish community and provides a qualitative assessment of species abundance (Stanfield 2005). Electrofishing is used as the survey method because it is non-lethal, effective, quick to perform, and can be used in a standardized way.

Fish community structure is a useful indicator of aquatic health. By examining the trophic structure of the community, the sensitivities of the individual species present, and the historical composition of the fish community, an assessment of impact or enhancement can be made.

The recommended screening level survey is consistent with the methods outlined in the TRCA Regional Monitoring Network, and allows for multi-metric data analyses to identify impacts, document problems, and monitor trends temporally and spatially.

Methods

1. Refer to the detailed methods outlined in the Ontario Stream Assessment Protocol, Section 3, Module 1.

Equipment

✓ Refer to the equipment list and training requirements provided in the Ontario Stream Assessment Protocol.

Reference(s)

Stanfield, L. (ed). 2005. Ontario Stream Assessment Protocol. Version 7, Fish and Wildlife Branch. Ontario Ministry of Natural Resources, Peterborough, Ontario.

AQUATIC MONITORING

WATER QUALITY

Objective

To measure local water chemistry parameters, document baseline or reference conditions, and demonstrate maintenance or improvement of conditions after project construction.

Background

Water quality monitoring can be an important component of characterizing and monitoring natural channels. Assessing water quality provides information on the state or condition of the watercourse but also provides insight regarding the causal factors influencing the biotic community. Where project objectives include improvements to water quality, and the NCD project is designed to positively influence water chemistry parameters, basic *in situ* water chemistry monitoring can be included.

TRCA Regional Monitoring Network protocol (TRCA 2001) outlines basic methods for surface water quality monitoring. The following parameters are recommended as a minimum to collect in situ, but grab samples can be taken if laboratory analysis of additional parameters is desired.

- ✓ Turbidity
- ✓ Conductivity
- ✓ pH
- ✓ Temperature
- ✓ Total Suspended Solids

Methods

1. Refer to the standard methods outlined in the Regional Monitoring Network protocol.

Equipment

- ✓ Refer to the equipment list provided in the Regional Monitoring Network protocol.

Reference(s)

TRCA. 2001. Regional Watershed Monitoring Program 2001: Status Report. Toronto and Region Conservation Authority.

WATER QUALITY

BENTHIC MACROINVERTEBRATES

Objective

To measure benthic community composition and relative abundance as indicators of aquatic ecosystem health.

Background

Benthic macroinvertebrates are widely used as bio-indicators because they are inexpensive and simple to sample and identify (Resh *et al.* 1995; Whiles *et al.* 2000). They are also less mobile than fish and are responsive to watershed-scale influences (Chessman *et al.* 1999). The Ontario Stream Assessment Protocol (Stanfield 2005) provides a kick-and-sweep method for sampling and measuring the composition of benthic macroinvertebrate communities that is consistent with the protocol developed by the Ontario Benthos Biomonitoring Network (Jones *et al*. 2004). Based upon the varying sensitivities of the organisms collected, an evaluation of biotic health can be determined.

The kick-and-sweep method is recommended for both riffles and pools and should be representative of all habitat types within the sample area. This method is consistent with the TRCA Regional Monitoring Network protocol, and the data can thus be integrated into the efforts of that program.

Species richness and abundance information can be combined to produce diversity indices, most of which combine information on richness and the evenness of the abundances of collected taxa. Biotic indices are summaries that combine the known pollution tolerances of taxa with richness or abundance information to evaluate biological condition based on ecological theories. These indices allow practitioners to manage complex community data using simple mathematical calculations, and compare index values against established thresholds or standards. Biotic and diversity indices are also valuable because they enable spatial or temporal comparisons of biological data for a project area.

Methods

1. Refer to the detailed methods outlined in the Ontario Stream Assessment Protocol, Section 2, Module 3.

Equipment

✓ Refer to the equipment list provided in the Ontario Stream Assessment Protocol.

Reference(s)

Chessman, B., Growns, I., Curry, J., and Plunkett-Cole, N. 1999. Predicting diatom communities at the genus level for the rapid biological assessment of rivers. Freshwater Biology, 41: 317-331.

Jones, C., Somers, K.M., Craig, B. and Reynoldson, T. 2004. Ontario Benthos Biomonitoring Network Protocol Manual. Version 1.0. Ontario Ministry of Environment, Environmental Monitoring and Reporting Branch, Biomonitoring Section.

Resh, V.H., Norris, R.H. and Barbour, M.T. 1995. Design and implementation of rivers of the Tennessee Valley. Ecological Applications, 4: 768-785.

Stanfield, L. (ed). 2005. Ontario Stream Assessment Protocol. Version 7, Fish and Wildlife Branch. Ontario Ministry of Natural Resources, Peterborough, Ontario.

Whiles, M.R., Brock, B.L., Franzen, A.C. and Dinsmore, S.C. 2000. Stream invertebrate communities, water quality, and land-use patterns in an agricultural drainage basin of northeastern Nebraska, USA. Environmental Management 26(5): 563-576.

APPENDIX C:

Riparian Monitoring Methods

RIPARIAN MONITORING

VEGETATION COMMUNITY ASSESSMENT

Objective

To document riparian vegetation community characteristics and species composition.

Background

General riparian vegetation community assessment provides prior to project initiation is useful for input into project design and comparison with future monitoring data. Assessments shortly after project construction and after several years of regeneration can be compared with control and reference site data to determine success in recreating or restoring a desirable vegetation community. As the development of vegetation communities is a long-term process, assessment should be undertaken only immediately after restoration and then at the end of the 10-year monitoring term.

Ecological Land Classification (ELC) to the vegetation type level should be performed according to the methodology developed for Southern Ontario (Lee et al. 1998) can be used to classify the riparian vegetation community types. In the TRCA jurisdiction, reference lists (TRCA, 2007) specific to vegetation communities should be used that include communities not included in the Southern Ontario Protocol.

A full inventory of flora species on site should be undertaken concurrently with the ELC during each monitoring event. All species present in the monitoring location (either the project area or reference / control sites) should be recorded and associated with each mapped vegetation polygon from the ELC exercise in which they are found. In the TRCA jurisdiction, checklists listing all floral species found in the area (TRCA, 2007) can be used to facilitate the inventory. These checklists also include rankings of conservation concern, which should be noted in the results of the inventory.

Methods

1. Refer to the detailed methods outlined in the Ecological Land Classification for Southern Ontario Field Guide (Lee *et al.* 1998). The Toronto and Region Conservation Authority' Terrestrial Natural Heritage Program Data Collection Methodology (2007), provides additional guidance relevant to the TRCA jurisdiction.

Equipment

✓ Refer to the equipment lists in the Ecological Land Classification for Southern Ontario Field Guide (Lee *et al.* 1998).

Reference(s)

Lee, H.T., Bakowsky, W.D., Riley, J., Bowles, J., Puddister, M., Uhlig, P. and McMurray, S. 1998. Ecological Land Classification for Southern Ontario: First Approximation and Its Application. Ontario Ministry of Natural Resources, Southcentral Science Section, Science Development and Transfer Branch. SCSS Field Guide FG-02.

TRCA, 2007 (updated annually). Natural Heritage Program Data Collection Methodology.

RIPARIAN MONITORING

VEGETATION SPECIES COMPOSITION AND DISTRIBUTION

Objective

To document species composition and distribution of the riparian vegetation community.

Background

Detailed monitoring of the evolution of a vegetation community requires quantitative measurement of the number and density of plant species. The results can be used to assess the survival of planted or seeded species and the spread of invasive species, and to compare the vegetation species composition within a restoration project site to that of target reference areas.

Transects and quadrats are widely used tools in vegetation monitoring to provide consistent and repeatable measurements of these parameters (e.g. Harris et al, 2005). Permanent transects are established across the entire span of the monitoring area, whether in the project site or reference / control sites, and are used as an alignment across which to measure the occurrence of large species such as trees and shrubs as well as to locate quadrats that will be used for more detailed analysis of all plant species. Quadrats are square plots that are established along transects at representative locations as permanent locations where detailed identification of all individual plants within the plot will be undertaken.

If property located and measured, the results from transect and quadrat measurements can be considered representative of the entire monitoring area, and can be used to calculate telative frequency, relative cover, and relative importance value of plant groups and individual species. Frequently used metrics of vegetation community quality, such as the Coefficient of Conservatism and Floristic Quality Index, can also be calculated.

Methods

General guidance on the use of transects and quadrats for monitoring can be found in Harris et al., 2005). These following guidance should be used for the application of these techniques to the monitoring of NCD projects:

1. Monitoring sites should be set up with a series of permanent transects perpendicular to the riparian zone in order to cross all moisture and elevation gradients. The number of transects varies with the size of the site, with a minimum of four per site and a maximum distance of 100 m between transects. Transects always begin on the left side of the stream as one faces upstream. From a marked starting point each transect is cuts perpendicularly across the corridor to another marker on the opposite top-of-slope.

2. Tree and shrub information should be gathered along each transect. Surveyors should walk along the transect (careful not to trample any vegetation in the quadrats) with a 2m long rod and count any tree or shrub greater than 1.3m (height at which DBH is taken) that's stem base falls within 1m on either side of the transect.

3. At least four 1 m2 quadrats are placed along the upstream side of each transect. Very long transects (i.e. over 100 m) may have one or more additional quadrats. Quadrats should be located so that they are placed randomly but also reflect the vegetation zones that are present.

4. Within each quadrat, all the vascular plants are identified and percentage covers for each species is estimated in increments of 5% unless the percent cover is less than 1. To aid in cover estimates, a wire mesh grid that is 1m by 1m and contains 100 squares is placed over the quadrat. In addition to vascular plants, cover estimates should be provided for mosses and liverworts (not distinguished beyond the category of "moss" or "liverwort"). The amount of visible open ground is also estimated. When a species can not be identified with certainty, the lowest taxonomic level should be used.

Equipment

✓ Refer to the equipment lists provided in Harris *et al.* (2005) for transect and quadrat techniques.

Reference(s)

Harris, R.R., Kocher, S.D. Gerstein, J.M. and Olson, C. 2005. Monitoring the Effectiveness of Riparian Vegetation Restoration. University of California, Center for Forestry, Berkeley, CA.

RIPARIAN MONITORING

AMPHIBIAN MONITORING

Objective

To document the variety and abundance of amphibian species.

Background

Most NCD projects, by virtue of their location in river and stream corridors, affect amphibians (primarily frogs and toads) and their habitat. Some projects may also have specific objectives related to the restoration or improvement of amphibian habitat. Consequently, it is important to assess amphibian populations both before and after construction to determine if the project has been successful in maintaining or restoring amphibian populations relative to reference sites and specific project objectives related to amphibians.

Amphibian surveys should begin in spring (typically April) to capture early breeding species, and require multiple visits through the spring and early summer to capture intermediate and late breeding species as well. Surveys are conducted through auditory observation of breeding calls, which can be identified by experienced practitioners.

Methods

Guidance regarding amphibian surveys is provided in TRCA (2007).

Equipment

- ✓ Refer to TRCA (2007)

Reference(s)

TRCA, 2007 (updated annually). Natural Heritage Program Data Collection Methodology.

RIPARIAN MONITORING

BREEDING BIRD SURVEYS

Objective

To document the variety and abundance of breeding bird species.

Background

Riparian corridors provide important habitat, including breeding habitat, for a variety of bird species. Breeding bird surveys provide data with which to confirm project success in restoring or improving breeding habitat in the affected area.

Breeding bird surveys are conducted by visiting the site at least twice during the breeding season which can last from early June to mid-July, in the early morning when birds are most active in calling. Depending on the species present, surveys may include both on-site auditory observation of breeding calls and tape playback.

Methods

General guidance regarding breeding bird surveys is found in Federation of Ontario Naturalists (2001). For monitoring in the TRCA jurisdiction, specific guidance for conducting breeding bird surveys to be consisten with the TRCA Terrestrial Natural Heritage program is found in TRCA (2007).

Equipment

✓ Refer to equipment lists in Federation of Ontario Naturalists (2001).

Reference(s)

Ontario Breeding Bird Atlas, 2001. Guide for Participants. Atlas Management Board, Federation of Ontario Naturalists, Don Mills.

TRCA, 2007 (updated annually). Natural Heritage Program Data Collection Methodology.

APPENDIX D:

Other Monitoring Methods

ENGINEERED / BIOENGINEERED ELEMENTS

VISUAL ASSESSMENT

Objective

To monitor the performance of engineered and bioengineered design elements.

Background

Engineered and bioengineered elements increase bank stability, provide aquatic habitat and limit hazards associated with channel migration, and provide additional aquatic habitat such as localized scour, deeper pools and low flow refugia. Specific evaluation of the effectiveness of these techniques in enhancing aquatic habitat can be done by comparing the distribution and quantity of in-stream habitat elements before and after construction as described in the aquatic monitoring methods. Photographs of the specific design elements should be also taken from fixed vantage points. Where the precise position or orientation of structures is critical, total station surveys may be required to establish the exact nature of any movement in the structure over time.

Observations of bioengineering elements should be conducted during the growing season. Documentation of plant survival, growth in target species, plant height, amount of growth, canopy cover, and evidence of disease or animal damage should be included. This assessment is useful for determining if maintenance repairs are necessary.

Methods

1. Document the engineered and bioengineered elements on a sub-reach map along with habitat features created by or associated with these elements, as described in the geomorphic monitoring techniques.

2. Record the condition of design elements with photographs from fixed vantage points as detailed in the geomorphic monitoring techniques.

3. Establish the location of engineered or bioengineered elements using total station survey equipment where ma position and orientation are critical.

Monitoring Frequency

Annual basis over a 3-year monitoring period. Preferably measured during low flow conditions.

Equipment

- ✓ Meter stick
- ✓ Measuring tape
- ✓ Camera
- ✓ Field sheets (modified RSAT)
- ✓ Survey equipment (if applicable)

Reference(s)

Doll, B.A., Grabow, G.L., Hall, K.R., Halley, J., Harman, W.A., Jennings, G.D., and Wise, D.E. 2003. Stream Restoration: A Natural Channel Design Handbook. Prepared by the North Carolina Stream Restoration Institute and North Carolina Sea Grant.

Galli, J. 1996. Rapid stream assessment technique: field methods. Metropolitan Washington Council of Governments.

SOCIAL AND CULTURAL ELEMENTS

OPINION SURVEYS

Objective

To document social and cultural perspectives on the project being monitored and to initiate further education on the practice and science of 'natural' channel design.

Background

There is limited guidance within the literature regarding the assessment of aesthetics, recreation and community involvement in NCD. Surveys can be developed to assess public perception of natural features, construction activities and improvements to watercourses and stream corridors for projects that have substantial social value or where social/cultural values are an integral component of the overall design.

The TRCA Regional Monitoring Network protocol outlines a methodology for surveying public opinion with the assistance of volunteers (TRCA 2001). The number of survey questions and respondents required to make the survey meaningful are dependent upon project scale.

Methods

1. Refer to the sampling framework outlined in the TRCA Regional Monitoring Network protocol.

Equipment

✓ Survey questionnaire

Reference(s)

TRCA. 2001. Regional Watershed Monitoring Program 2001: Status Report. Toronto and Region Conservation Authority.