The Evaluation of Wetland and Riparian Restoration Projects

Jeffrey C. Davis and Gay A. Muhlberg
Alaska Department of Fish and Game, Habitat and Restoration Division, Anchorage, AK.
April, 2002

ABSTRACT

Although we have applied and continue to apply State and Federal Laws to eliminate or minimize development and human-use impacts to aquatic systems, these systems continue to be altered. Restoration projects are conducted to compensate or mitigate for direct and indirect impacts. However, little work has been directed toward determining the effectiveness of restoration efforts. This paper outlines proposed methods to measure the effectiveness of restoration projects. The underlying tenet of the evaluation procedure and goal of restoration projects is to restore natural ecological structure and function. To meet this restoration goal, project objectives are to replace or modify individual physical, chemical, or biological characteristics of the system and the interactions among these characteristics, or both. The measurement of these characteristics and comparison to the undisturbed reference condition are used to determine how close the projects come to meeting the restoration goal. Comparisons between pre-project assessments at impacted and reference locations, identify differences in characteristics and processes. These differences become the project objectives that must be addressed during project design and become the post-project parameters measured. Assessment includes the evaluation of constructed features, biological structure and function, and physical structure and processes. The methods used to measure these parameters are tiered to allow for increasing levels of analyses. Thus, assessment begins with simple qualitative measures of structure, and progresses to detailed quantitative measures of function and processes. This approach provides flexibility so evaluations can be tailored to fit the experience, capabilities, budget, time, and needs of the investigators.

> ***Restoration.* "the return of an ecosystem to a close approximation of its condition prior to disturbance. In restoration, ecological damage to the resource is repaired. Both the structure and functions of the ecosystem are recreated" (National Research Council 1992 p.18)**

INTRODUCTION

WHY EVALUATE RESTORATION PROJECTS

Unfortunately, at this time we do not fully understand the many interacting physical and biological processes that occur within aquatic ecosystems. We also are unable to fully and accurately predict the result of our efforts to restore these processes once they have been altered. When we do, project evaluation and monitoring will no longer be necessary, for post-project monitoring provides us with the information we must have to further our ability to effectively restore damaged aquatic systems. Project evaluation ensures that project planners evaluate

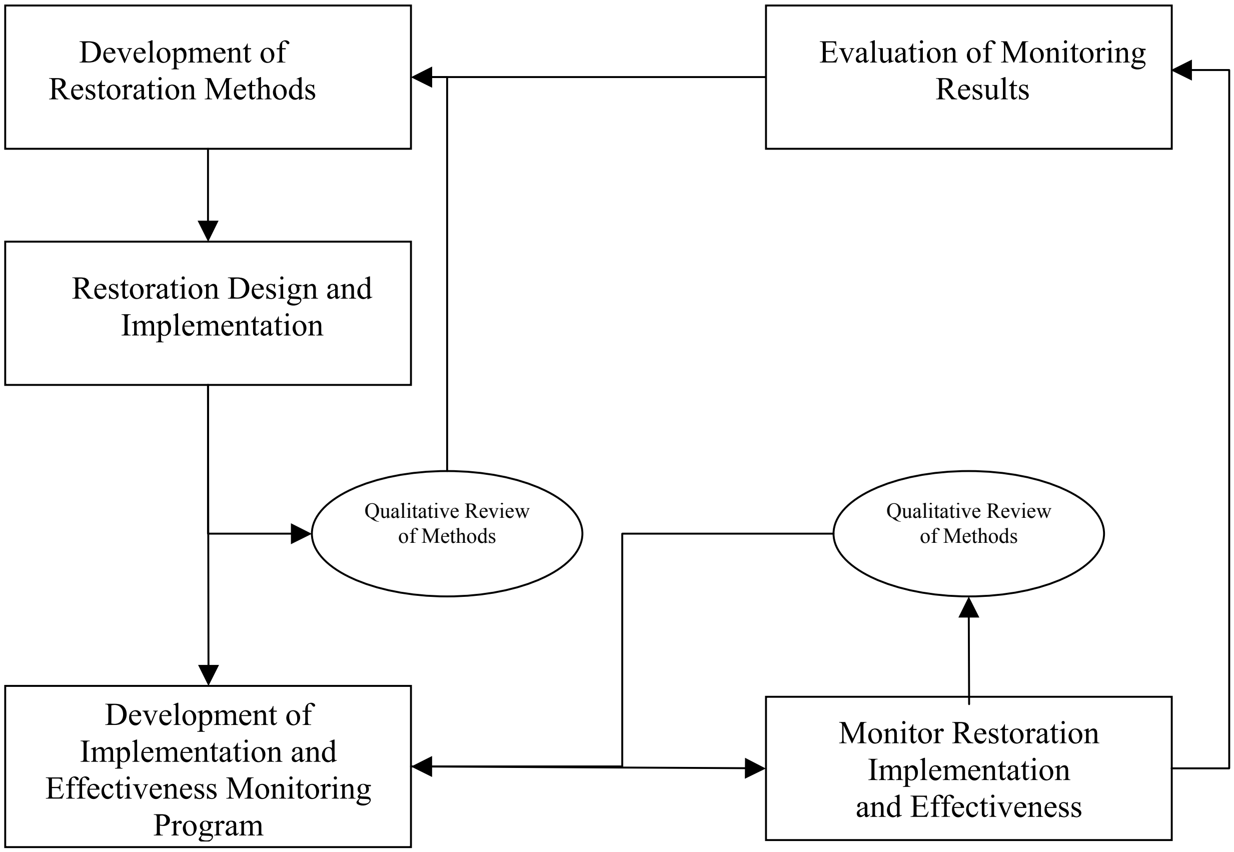

Figure 1. Diagram showing relationship between restoration design and monitoring.

systems prior to designing projects and clearly define objectives. In addition, immediate post-project as-built surveys, as part of the post-project monitoring, will determine whether projects were constructed as designed. All of these benefits from project evaluation will promote the efficient expenditure of funds.

Although numerous aquatic restoration projects are conducted annually throughout the world, project success (based upon the limited evaluation data) is limited or unknown (Roni et al. 2002). For example, surveys conducted by Frissell and Nawa (1992) found of 60% of projects within western Oregon and Washington either were damaged or ineffective. Although presumably much has been learned since that time, the lack of any published evaluation results makes it difficult to determine what problems were encountered in the past and how those problems were addressed. Evaluation of the success of projects is difficult without monitoring and record keeping (Carothers et al. 1990). Only through systematically evaluating restoration successes and failures can advances be made. Documenting the evaluation methods and results will allow others to determine whether the lessons learned apply to their specific situations and help to avoid repeating mistakes at numerous locations (Everest et al. 1991). Documentation of evaluation methods will also provide a monitoring template that can be adjusted over time through comments based on others experiences gained through its application (Figure 1).

Goals and Objectives

The goal of every restoration project should be to meet the definition of "restoration," to restore an ecosystem to its natural pre-disturbance structure and function (USEPA 1995). Roni et al. (2002) state that the objective of restoration projects is to reflect the "range of conditions that existed naturally in a watershed and presumably supported diverse biotic communities." A common goal of restoration is a return to the natural state (Jensen and Platts 1990). To meet this goal, each project must have definite objectives that will convert the site from its present condition to its natural condition or as close of an approximation as possible (Erwin 1990). To do this the evaluation must define both the current, and the natural ecological structural and functional states. Documenting the existing state can be used to evaluate the potential for restoration and can serve as a baseline for evaluation restoration (Jensen and Platts 1990). Defining the present condition is accomplished through pre-project evaluation. Describing the natural ecological structure and function is best accomplished through the evaluation of reference locations where possible or through the use of historic data (Kondolf and Curry 1986, Kondolf and Micheli 1995). Determining natural channel conditions is essential in determining underlying causes for degradation (Kondolf 1995). Comparisons between the current condition and the natural condition should highlight differences in ecological characteristics, which should be used to formulate project objectives.

The objectives of restoration projects are determined through pre-project evaluations and define certain ecosystem parameters at impacted sites that differ from the natural state. A comparison of the physical, chemical, and biological parameters at reference and impacted sites will specify whether parameters are within the range of natural variability, and if not, to what degree they differ. These differences can then be used to define objectives. Clearly defined objectives leads to evaluation criteria (Kondolf and Micheli 1995). For example, cross-sectional surveys may show that bank sloughing at the impacted location has resulted in an increase in the ratio of stream width to depth and the loss of fish habitat provided by undercut banks. Project objectives may then be to reduce stream widths and create under cut banks or some other near-shore cover feature. The restoration project will then be designed and implemented to address these objectives and post-project monitoring will evaluate whether these parameters have changed following project implementation.

Implementation and Restoring Ecological Structure and Function

While pre-project evaluations provide information on the altered state of the system and the design reflects project features that will be implemented to initiate restoration, it is the final constructed project that defines the primary state of the site. For example, project design may call for specific channel geometry and post-project elevation. However, construction may not exactly coincide with the design and post-project monitoring one year later will not be able to determine whether differences between design and measured cross-sectional data are due to construction or alluvial processes. Therefore, a post-project as-built survey should be part of the restoration evaluation protocol (Kondolf and Downs 2001).

Restoration projects generally involve the construction or placement of features to perform some type of function thereby altering ecosystem characteristic. Restoration evaluation, therefore, requires the evaluation of the construction as well as evaluation of the characteristic to be affected. This is necessary to determine whether project failure (or success) was the result of faulty design or implementation. Similarly, we must be assured that project successes are truly the result of design. Therefore, restoration evaluation is divided into two categories: implementation and ecological structure and function.

Implementation is the actual "hands on" work or construction done at the restoration location. Project construction features are often the cause of project failure (Frissell and Nawa 1992). Project implementation can be further subdivided in abiotic and biotic components. The abiotic components are structures such as rock, walkways, fencing, and other stabilization structures. Root wads and coir logs would be considered abiotic when used as stabilization feature. Biotic components generally consist of reintroduced plants or animals. Evaluation of abiotic components is accomplished through documentation of the materials and construction methods and then determining their resistance to change over time. For biotic components, evaluation includes collection and storage, site pre-treatment, placement timing, post-project treatment, and subsequent survival and propagation. These steps will be discussed in more detail below.

The evaluation of ecological structure and function is the determination of the ecological state or the position of the system on the continuum from its initial to natural states. That is, a determination as to whether the characteristics that differed between the reference and altered location has changed since implementation of the restoration project. The evaluation of ecological structure and function is accomplished through the post-project measurement of structural and functional characteristics, which were the basis for project objectives. For example, based upon pre-project evaluation objectives may include restoring the riparian plant community (structure), undercut bank habitat (structure), invertebrate community composition (structure), stream bank to stream sediment transfer rates (function), riparian nutrient uptake rates (function), and riparian organic matter input (function). Quantifying these characteristics prior to, and post project-implementation will provide the information required to evaluate project success. Obviously some of the characteristics listed in the previous example require much more effort to quantify than others. Therefore, our evaluation procedures are organized in a hierarchical fashion so that the evaluation detail for each characteristic is flexible while providing consistent baseline data.

MONITORING PLAN: THE HEIRARCHICAL APPROACH

In order to be widely used any proposed monitoring plan must be able to conform to different levels of experience, funding, and expenditure of time. The monitoring plan must be equally useful to those with little experience in qualitative methods as well as professionals. The monitoring plan also must be equally useful to those with little time and money and those for whom monitoring is a priority. The monitoring plan we propose accomplishes this through a nested series of measurements for each parameter beginning with simple qualitative measures and progressing toward more complex quantitative measures (Davis et al. 2001). The basic measures are taken at all sites to ensure comparability among projects. More detailed analyses of parameters includes both the basic and more complex measures.

The hierarchical monitoring approach allows those with little experience, time, or money to conduct a Level 1 analysis of the selected parameters, which will be composed of simple qualitative measures. However, for those with more experience, funding, and time Level 2 or 3 analyses can be conducted for all or some of the selected parameters. However, Level 1 analysis is conducted at all sites.

METHODS

The application of the proposed monitoring method requires accomplishing an organized process as outlined in Figure 2. Pre-Project evaluation at reference and impacted or proposed restoration sites provides the information to determine project objectives. The selection of project objectives helps formulate the project design and construction. Post-project evaluation includes both project implementation and ecological evaluation.

IMPLEMENTATION

Monitoring project implementation is an evaluation of the structures associated with the project. These include both abiotic (non-living) structures that may include walkways, stairs, fences, mesh fabric, coir logs, and rootwads; and biotic (living) components such as introducer riparian or wetland plants. Therefore, monitoring of project implementation is largely a documentation of the location and condition, or survival (for living structures), over time following project construction.

Abiotic Structures

The primary purpose in evaluating non-biological structures is to determine whether the construction materials and methods were appropriate for the given site, and to determine the stability and longevity of project features. That is, to answer questions such as, how deep should coir logs be buried or where root boles should be placed relative to ordinary high water? The stability or longevity of project features is a function of the material used, and its application or construction; therefore, this type of information must be recorded during project construction. The amount of information recorded will depend on the level of analyses. For larger projects most of this information can be obtained from project design and bid documents and post-project as-built surveys. For smaller projects this information will need to be recorded by the investigator.

Biotic Structures

The evaluation of biological implementation is a determination of the survival and propagation of introduced species. For most projects this is the seeding or planting of riparian or wetland areas. Post-project evaluations must determine the survival of planted or transplanted species, and the factors affecting percent survival. Species survival is a function of many different things including the species selected; collection and storage methods; planting location and timing, site characteristics; and subsequent care. Survival also is related to the physical characteristics of the site and so can be interpreted relative other monitoring information. However, detailed records of the collection and treatment of reintroduced plants (and animals) ultimately will allow identification of the causes of failures and successes.

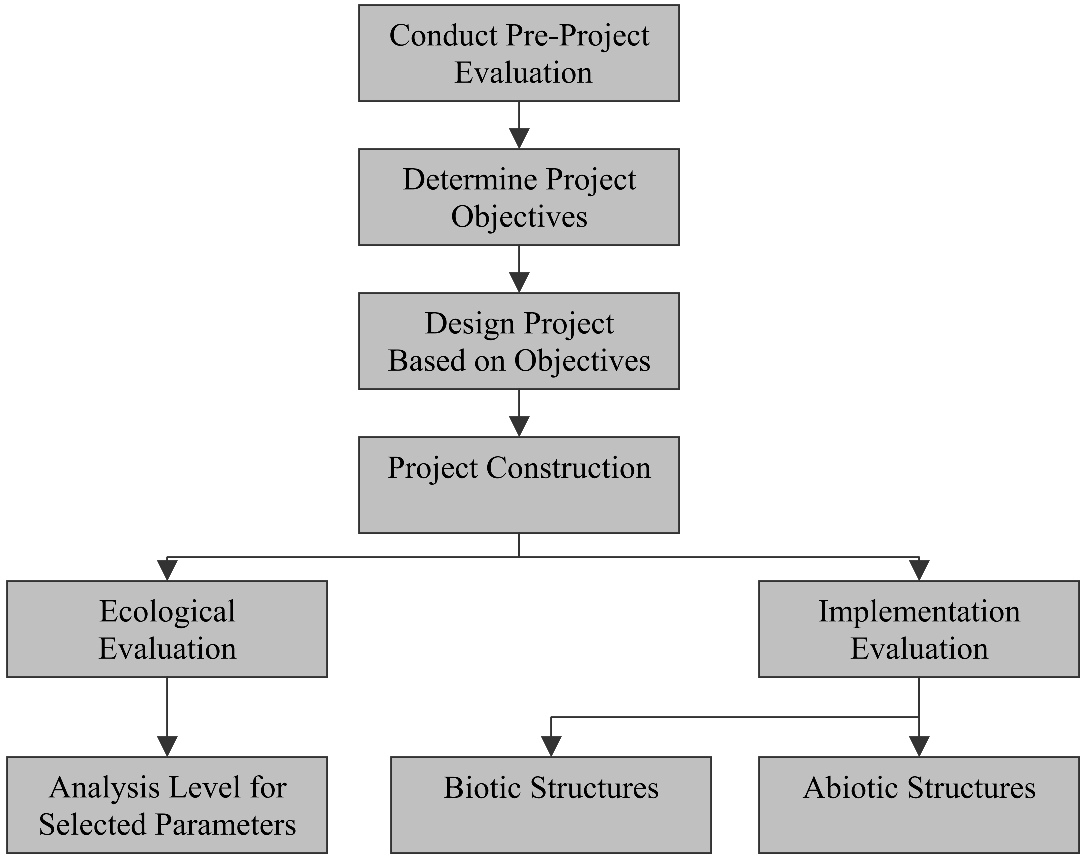

Figure 2. Flow diagram of evaluation process.

RESTORING ECOLOGICAL STRUCTURE AND FUNCTION

The selection of project objectives leads to the evaluation of specific biological, physical, or chemical stream or wetland characteristics that will be addressed in project design and subsequent monitoring. The parameters measured are derived from project objectives (Jensen and Platts 1990). Once the characteristics are selected the level of analysis is determined. Within each analysis level we have organized measurement parameters under physical, biological, and chemical characteristics (Table 1). Measurement of the parameters under these three characteristics for the evaluation of restoration projects is supported in the literature (e.g. Federal Interagency Stream Restoration Working Group 1998), although different investigators believe one characteristic should receive more attention than others.

Physical Characteristics

The physical stream characteristics are defined by hydrologic, morphologic, and substratum parameters. In order to re-establish riparian and wetland ecosystems successfully, restoration projects must recreate the physical conditions necessary to maintain natural communities (Kondolf and Larson 1995). Hydrology recognized as an important characteristic that defines stream and wetland structure and function. Erwin (1990) states that hydrology is the "single most important factor" to be considered in designing and implementing restoration projects. Jensen and Platts (1990) also state that hydrologic variables are expected to be the most important factors affecting restoration. Level 1 analysis is limited to a qualitative estimate or direct measure of stream depth during the growing season. For wetlands this may be an estimate of soil moisture (wet, moist, dry) or a measure of standing water depth. Level 2 increases the level of analyses to a quantitative measure of stream discharge. The establishment of a stage discharge relationship has been recommended to get a clearer picture of flow variability (Davis et al. 2001; Kondolf and Micheli 1995) and is included at this level. Further understanding of flow variability can be obtained from analyses of gauged data, if available, or regression relationships with nearby gauged sites. Depth to water table and inundation frequency and duration is an important variable controlling the distribution of riparian and wetland plants and can be monitored with wells along transects (Kondolf and Micheli 1995; Carothers et al. 1990). Reduction in water table can lead to the loss of bank vegetation followed by bank erosion and widening. (Kondolf and Curry 1986). Stream water velocity profiles are also incorporated at Level 2. The variability in velocities profiles with flow and as effected by riparian vegetation, wetland recharge and discharge, and measures of evapotranspiration become part of the monitoring protocol and the highest level of analysis.

Stream channel morphometry and substratum are the other two physical parameters measured. Repeated cross-section surveys are a well-tested tool to detect changes in channel form and should include an assessment of bed material size (Kondolf and Micheli 1995). The minimum amount of information obtained at Level 1 includes measures of stream bankfull width and depth or wetland elevation. Qualitative surveys are used to estimate bank stability. The habitat assessment methods of the Alaska Stream Condition Index (Major and Barbour 2001) works well for assessment of physical habitat at this level of analysis. At level 2 the stream cross-section is measured at multiple locations, stream slope and undercut banks are measured, and substratum size distribution is quantified and substrate stability estimated. Topographical surveys along transects document wetland surface elevations. Stream shading has been identified as an important physical habitat component (Jensen and Platts 1990, Davis et al. 2001) and solar radiation under the riparian canopy and project features (walkways) is measured at this level. Processes such as direct measures of bank erosion rates, point bar formation, sediment deposition and bedload movement, and wetland soil development are quantified at Level 3.

Biotic Characteristics

Biotic characteristics include parameters that define the plant and animal populations and communities within riparian and wetland systems. Initial qualitative evaluation of riparian and wetland vegetation cover is accomplished at Level 1. Fixed-point photography has been identified as a good tool for evaluating vegetation cover, and other parameters, (Erwin 1990, Kondolf and Micheli 1995) and is used for Level 1 analysis. Photography points are selected so that the view is not blocked by developing plants (Kondolf and Micheli 1995). Species presence, abundance, diversity, and density, size, and vigor are important variables in determining the success of riparian vegetative restoration (Kondolf and Micheli 1995). At Level 2, plant community composition and percent cover are quantified in quadrats located along transects through the riparian and/or wetland zones. Extending channel cross sections up the bank onto the floodplain can provide a basis for vegetation transects, provided that care is taken not to disturb vegetation (Kondolf and Micheli 1995). Level 2 expands the analyses to include measures of abundance of stream algae and large woody debris.

Table 1. Measurement parameters for the physical, biological and chemical characteristics at each level of analyses.

Level 1: Qualitative Structure	**Measurement/Parameter**	**Method**
Physical Characteristics:		
Hydrology	Mid-Summer Stream Stage or Wetland Water Surface Elevation	Direct Measurement or Observation
Morphometry	Channel Bankfull Width and Depth or Wetland Elevation	Direct Measurement or Observation (Estimate)
	Channel or Bank Stability	Fixed Point Photography
	Undercut Banks	
Substratum	Stream Substrate Size or Wetland Soil Type	Limited Measurement or Estimate
Biotic Characteristics:		
Riparian or Wetland Vegetation	Vegetation Cover	Fixed Point Photography
	Overhanging vegetation	Fixed Point Photography
Chemical Characteristics		
Turbidity	Mid and Post Project Observation	Direct Measure
Water Temperature	Mid-Summer Maximum and Min	Direct Measure
Level 2: Quantitative Structure	**Measurement/Parameter**	**Method**
Physical Characteristics		
Hydrology	Local Stage Discharge Relationship	Direct measure
	Annual Flow analysis	Gauge data or Regression with Nearby Gauged Drainage
	Wetland Hydroperiod	Direct measure
	Water Velocity Profiles	Direct measure of vertical and horizontal water velocity
Morphometry	Channel Cross-sectional Morphometry	Direct measure at multiple locations
	Undercut Banks	Direct Measure
	Stream slope	Direct Measure
	Wetland Topography	Direct Measure

Substratum	Stream Substrate Size Distribution	Wolman Pebble Counts
	Substrate Stability	Empirical estimate
Solar Radiation	Riparian light penetration	Direct Point or continuous measures
	Wetland and Riparian Light Penetration Under Abiotic Structures (Walkways etc)	Direct Point or continuous measures during the growing season.
Biotic Characteristics		
Riparian or Wetland Vegetation	Community Composition and Cover	Percent Cover of Species within Plots or Transects
Algae	In stream abundance	Chlorophyll-a Concentrations
Large Woody Debris	Amount and Distribution of Pieces and Dams	Woody debris count and index.
Invertebrates	Macroinvertebrate Community Composition	Direct Measure and replicate locations
Fish	Fish Population Estimates	Direct Measure Through Multiple Pass or Mark Recapture
Birds	Riparian and Wetland Use	Species presence and relative use
Chemical Characteristics		
Temperature	Continuous water temperature	Data loggers
Alkalinity		
Hardness		
pH		
Conductivity		
Nutrient Concentrations	Nitrogen, Phosphorus	Laboratory Analysis of Water Samples
Level 3: Ecological Function and Processes	**Measurement/Parameter**	**Method**
Physical Characteristics		
Hydrology	Change in water velocity profiles	Direct measure of nearshore velocities at multiple flows.
	Riparian velocity reduction	Velocity reduction during high flows
	Wetland Discharge and Recharge	Measure of wetland water movement.
	Evapotranspiration	Direct Measure

Channel Morphology	Bank Erosion rates	Direct Measure
	Point Bar formation	Direct Measure
Substratum	Fine Sediment Deposition Rates	Deposition Trays
	Bedload Movement	Direct Measure
	Riparian and Wetland Soil Layer Development	Measure Soil Horizons
Biotic Characteristics		
Riparian or Wetland Vegetation	Primary Production	Change in biomass/Length of annual shoots
	Herbivory	Herbivore Exclusion Plots
Algae	Primary Production	Oxygen release or open system
Organic Matter	Decomposition Rates	Litter Bags
	Input Rates	Measure litter input vertical and horizontal
Invertebrates	Secondary Production	Cohort numbers and biomass
Fish	Fish productivity	Change in biomass over time
	Winter Survival	Change in number: Fall to Spring
	Egg survival	Redd Pumping
Chemical Characteristics		
Nutrient Cycling	Decomposing Salmon	Count
	Riparian Uptake	Nutrient Injections
	Instream Uptake rates	Nutrient Releases
Nutrient Limitation	Growth Response to Additions	Nutrient Diffusing Substrates
Redox Potential	Wetland Soil Reduction/Oxidation Potential	Direct Measure

The success in achieving restoration objective of enhancing fish and wildlife is often difficult to assess directly (Jensen and Platts 1990) and some investigators recommend limiting evaluations to physical habitats (Kondolf and Micheli 1995). Information on changes to the biotic community often is the primary objective and the response of biota to restoration has not been assessed adequately (Roni et al. 2002). Likewise, the success of restoration projects should not be limited to the evaluation of biotic populations alone. Level 2 analyses include measures of fish and invertebrate community composition. The relative use of wetlands and riparian areas by birds and other wildlife is also part of this level of evaluation. Level 3 incorporates measures of stream and wetland function. These include measures of riparian or wetland and instream primary production. Competition with exotics and the effects of herbivory have been identified as factors influencing restoration success (Carothers et al. 1990; Kondolf and Micheli 1995; Erwin 1990) and will be evaluated at Level 3. Building upon measures of animal community composition of Level 2, Level 3 looks and the production on invertebrates and fish. Wherever possible isolating smolt production in the treatment area of a stream from untreated areas by strategic placement of smolt traps is desirable (Everest et al. 1991). In addition to fish production, overwinter and egg survival are suggested parameters.

Chemical Characteristics

Stream water and wetland temperature and chemistry may have a lower priority as restoration objectives than functional processes involving nutrient or pollution uptake rates or immobilization, respectively. However, water chemistry may be more important for larger scale watershed restoration projects (Kondolf and Micheli 1995). Water temperature is included as a measurement parameter under the chemical characteristics and direct measures of mid-summer maximum and minimum values is included under Level 1. Level 2 builds upon the temperature data and adds basic macronutrients, alkalinity, conductivity, and pH. At Level 3 instream, riparian and/or wetland nutrient uptake rates are evaluated. Growth limiting nutrients are determined through the response of plants or algae to additions. The potential chemical state of molecules within wetlands is determined by measuring the redox potential at various depths.

MONITORING FREQUENCY AND DURATION

In general monitoring frequency and duration will vary with the parameter under investigation. Most investigators believe that monitoring should be more frequent in the first few years following implementation (Carothers et al. 1990; Kondolf and Downs 2001). For many parameters long-term monitoring will be necessary. Kondolf and Downs (2001) state that the longer the period of monitoring the more valuable the data source is likely to be, and suggest 5 to 10 years for full post-project appraisals. However, channel adjustments to changes in hydrology or sediment transport may occur over 40 years or longer (Simon 1989).

SUMMARY

The proposed monitoring protocol describes a method whereby initial site investigations are compared against the natural condition derived from reference sites or historic data identifies restoration objectives. These objectives are used to design a restoration project to alter stream or wetland parameters to meet project objectives. As-built surveys or immediate post project measurements provide a description of the initial state against which future measurements are compared. In addition, documentation of biotic and abiotic construction features allows for evaluation of the structural integrity and survival and propagation of introduced features. The separation of each measurement parameter into three different levels of analysis provides a methodology that everyone can use regardless of funding or experience. Because Level 1 analyses are conducted for all evaluations the results of a Level 1 study at one site can be compared with the data collected during a Level 3 study at another. The final product is a comprehensive look at the physical, biological, and chemical characteristics at a restoration site prior to and following the implementation of a restoration project, which can be compared with data, collected from reference sites or obtained from historic information. The application of these methods is described for three different projects in Appendix A.

LITERATURE CITED

Carothers, S.W., G. S. Mills, and R.R. Johnson. 1990. The creation and restoration of riparian habitat in southwestern arid and semi-arid regions. Pages 351-366 *in* J. Kusler, and M. Kentula (eds.), Wetland creation and restoration: The status of the science. Island Press, Washington, DC.

Davis, J.C., G.W. Minshall, C.T. Robinson, and P. Landres. 2001. Monitoring wilderness stream ecosystems. Gen. Tech. Rep. RMRS-GTR-70. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 137p.

Erwin, K.L. 1990. Wetland evaluation and creation. Pages 429-458 *in* J. Kusler, and M. Kentula (eds.), Wetland creation and restoration: The status of the science. Island Press, Washington, DC.

Frissell, C.A. and Nawa, R.K. 1992. Incidence and causes of physical failure of artificial habitat structures in streams of Western Oregon and Washington. North American Journal of Fisheries Management 12:182-197.

Everest, F.H., J.R. Sedell, G.H. Reeves, and M.D. Bryant. 1991. Planning and evaluating habitat projects for anadromous salmonids. American Fisheries Society Symposium 10:68-77.

Jensen, S.E., and W.S. Platts. 1990. Restoration of degraded riverine/riparian habitat in the Great Basin and Snake River regions. Pages 367-404 *in* J. Kusler, and M. Kentula (eds.), Wetland creation and restoration: The status of the science. Island Press, Washington, DC.

Kondolf, G.M. and Curry, R.R. 1986. Channel erosion along the Carmel River, Monterey County, California. Earth Surface Processes and Landforms 11:307-319.

Kondolf, G.M., and P.W. Downs. 2001. Post-project appraisals: the key to river restoration success. Proceedings of American Society of Civil Engineers: Wetlands Engineering and River Restoration Conference. Reno, NV, 25-31 August 2001

Kondolf, G.M. and Larson, M. 1995. Historical channel analysis and its application to riparian and aquatic habitat restoration. Aquatic Conservation: Marine and Freshwater Ecosystems 5:109-126.

Kondolf, G.M. 1995. Geomorphological stream channel classification in aquatic habitat restoration: uses and limitations. Aquatic Conservation: Marine and Freshwater Ecosystems 5:127-141.

Kondolf, G.M., and E.R. Micheli. 1995. Evaluating stream restoration projects. Environmental Management 19: 1-15.

Major, E.B., and M.T. Barbour. 2001. Standard operating procedures for the Alaska Stream Condition Index: A modification of the U.S. EPA rapid bioassessment protocols, 5th edition. Prepared for the Alaska Department of Environmental Conservation, Anchorage, Alaska.

Simon, A. 1989. A model of channel response in disturbed alluvial channels. Earth Surface Processes and Landforms 14:11-26.

U.S. Environmental Protection Agency (USEPA). 1995. Ecological Restoration: A Tool to Manage Stream Quality. EPA 841-F-95-007. U.S. Environmental Protection Agency, Office of Water, Washington, D.C.

Viereck, L. A., C. T. Dryness, A. R. Batten, and K. J. Wenzlick. 1992. The Alaska Vegetation Classification. Gen. Tech. Rep. PNW-GTR-286. Portland OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 278 p.

APPENDIX A

CASE STUDY 1: COTTONWOOD CREEK CULVERT REMOVAL

Methods

Cottonwood Creek is located within the Matanuska-Susitna Valley and drains directly into Cook Inlet. The stream supports anadromous coho (*Oncorhynchus kisutch*) and sockeye salmon (*Oncorhynchus nerka*), and rainbow trout (*Oncorhynchus mykiss*). One of the major factors influencing the fish community within Cottonwood Creek is migration barriers to spawning, rearing, and juvenile over-wintering areas.

Two culverts (side by side) were identified through a drainage-wide survey as potential blockages (ADF&G Unpublished). Pre-Project evaluation (July 2001) at the culvert location included a Level 1 qualitative survey with Level 2 measurements taken for selected parameters including cross-sectional morphometry and water velocity. Pre-project culvert survey elevations were obtained through the basin-wide culvert survey (ADF&G 2001). A Level 1 survey also was conducted at a reference location on the same stream. Similarly post-project evaluation (September 2001) included Level 1 data with Level 2 data for cross-sectional morphometry and water velocity.

Pre-project water velocities were measured at the culvert inlet and outlet at 0.6 times depth with a Price mini (pygmy) velocity meter and top-set rod. Velocities within the two culverts were derived using the FishXing program (Version II, San Dimas Technology and Development Center) and measurements of culvert size, length, slope, and downstream hydraulic control, for three different discharge estimates. Post-project velocities were measured concurrent with cross-sectional surveys described below.

Stream morphological parameters were determined from two (pre-project) or three transects located above, below, and within the restored reach. A measuring tape was stretched across the stream and elevations were measured at approximately 20-cm intervals using a laser level and leveling rod. Elevations were relative to a benchmark, which was located at the corner post of an adjacent fence (Figure A-1).

Stream substrate size distribution was estimated. Vegetation cover along the stream margin was determined through fixed-point photography and community composition of the riparian zone was documented by classification of distinct zones based upon the vegetation classification of Vireck et al. (1992).

Pre-Project Evaluation Data and Design

The pre-project evaluation revealed water velocities that would block the upstream migration of juvenile coho salmon (55-mm fork length) (Table A-1). Culvert input data are listed in Table A-1. The FishXing output indicated that both culverts presented velocity barriers to fish at the design discharge of 0.34 m^3/s (12 cfs), which was near the 0.28 m^3/s (10 cfs) measured in September (Table A-2). Mid culvert water velocities exceeded 1.2 m/s (4 feet per second). Measured inlet velocities were near those calculated by FishXing.

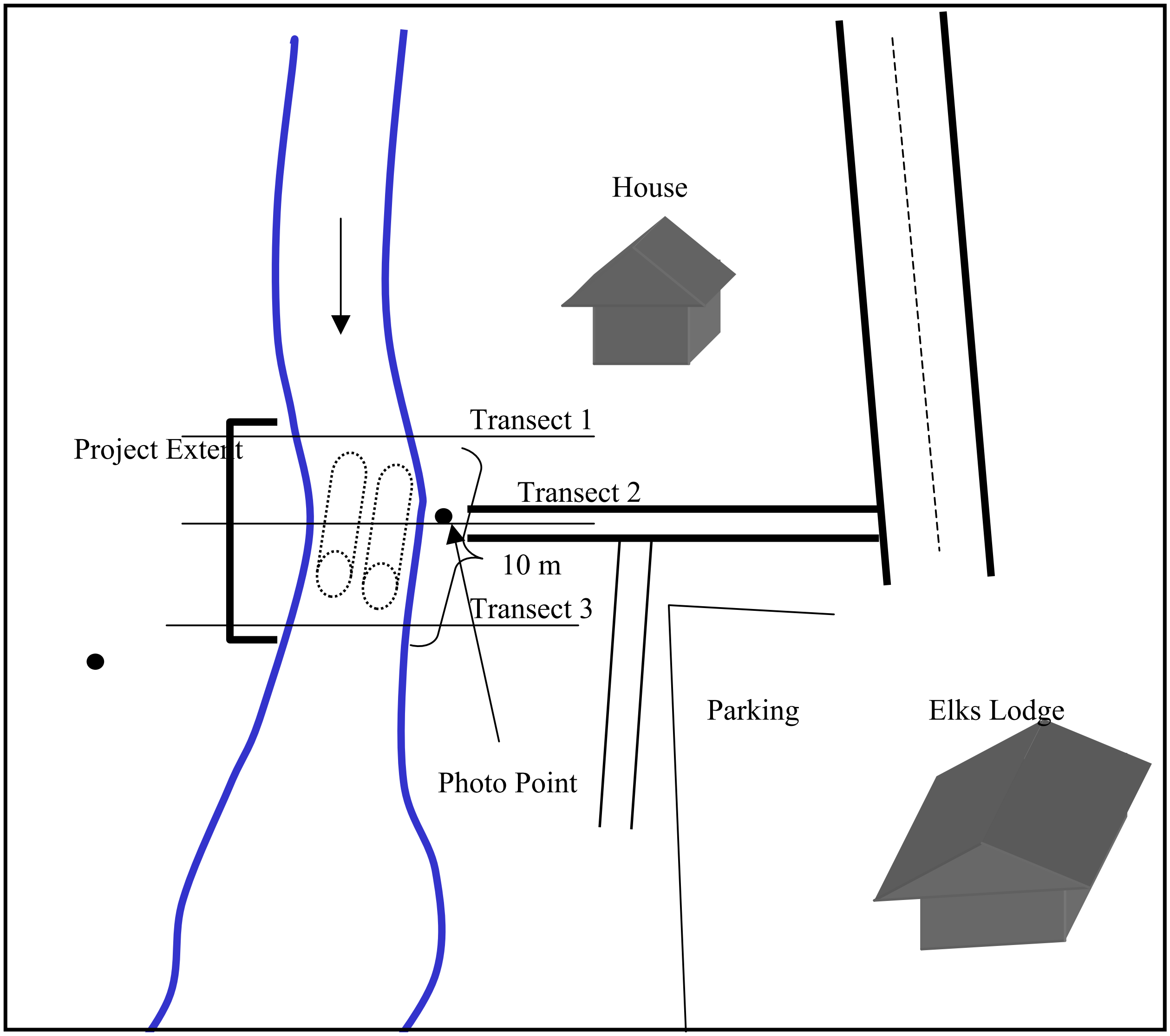

Figure A-1. Plan view of Cottonwood Creek culvert removal location

Table A-1. Right and left culvert input parameters for Cottonwood Creek.

Culvert Installation Data	**Right Bank Culvert**	**Left Bank Culvert**
Culvert Type:	36 in Circular	36 in Circular
Construction:	CMP (5 X 1 in corr.)	CMP (5 X 1 in corr.)
Installation:	At Grade	At Grade
Culvert Length:	20.3 ft	22.8 ft
Culvert Slope:	0.39%	1.93%
Culvert Roughness Coefficient:	0.025	0.025
Inlet Invert Elevation: ft	89.79	90.1 ft
Outlet Invert Elevation:	89.71 ft	89.66 ft
Inlet Headloss Coefficient (Ke):	0.5	0.5

Table A-2. Stream channel characteristics at three transects prior to (July) and following (September) culvert removal.

Cottonwood Creek

Channel Characteristics

	Transect 1 (0.5m)		**Transect 2 (5m)**		**Transect 3 (10m)**	
	July	**Sept**	**July**	**Sept**	**July**	**Sept**
Width (m)	4.2	4.25	NA	4.10	6.14	5.4
Mean Depth (m)	0.25	0.13	NA	0.12	0.29	0.10
w/d ratio	16.63	32.10	NA	32.98	20.98	51.78
Area (m^2)	0.96	0.59	NA	0.33	1.22	0.51
Perimeter (m)	4.28	4.32	NA	4.12	6.20	5.41
Radius (m)	0.22	0.14	NA	0.08	0.20	0.09
Discharge (m^3/s)	NA	0.28	NA	0.28	NA	0.28
Slope	NA	0.0084	NA	0.0084	NA	0.0084
Velocity (m/s)*	1.4/0.9	0.478	NA	0.844	1.7/0.3	0.552
Manning's n	NA	0.051	NA	0.0202	NA	0.365

*July data are culvert inlet/outlet velocities and September data are discharge/area.

Based upon pre-project evaluation, the primary project objective was to reduce water velocities so that juvenile coho salmon could pass through this stream section. The design called for the removal of the culverts, thereby increasing stream cross-sectional area and roughness resulting in reduced water velocities. Secondary objectives were to construct a channel with similar morphology and substratum to reference sites and to reestablish riparian vegetation. The toe of the stream banks would be held in place with coir logs. Riparian vegetation would be reestablished with three layers of soil raps and brush layering. At this time only one post project evaluation has been conducted approximately 2 months following construction.

Results and Discussion: Post-Project Evaluation

Non-Biological Structures

Non-biological structures for this project was limited to coir logs placed at the toe of the stream bank slope on both sides of the stream and two layers of mesh fabric. The coir logs were placed at grade and were held in place with wooden stakes and backfilled with topsoil. Three soil raps with brush layers extended up the bank (Figure A-2). The soil raps were constructed of two layers of 100% coconut fiber. Specifications and post-project survey elevations are shown in Table A-3.

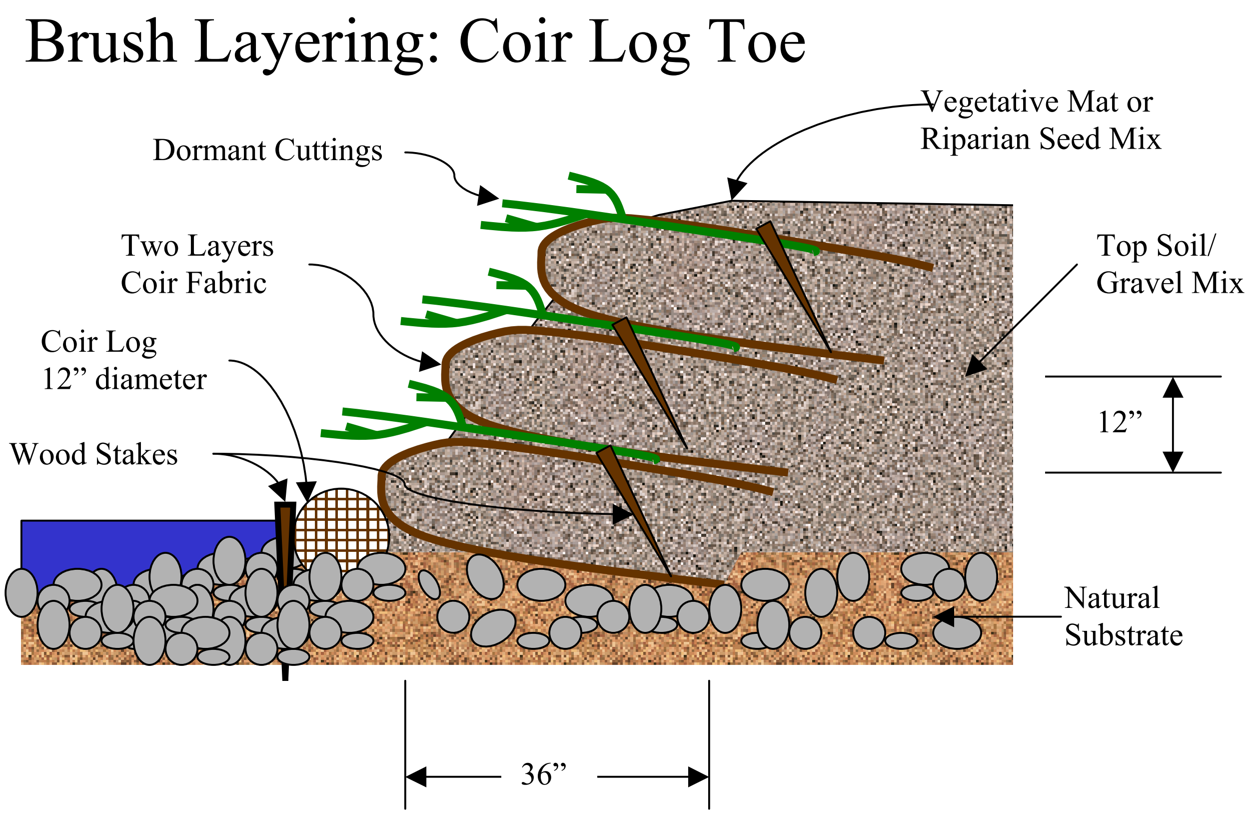

Figure A-2. Schematic diagram of bank restoration method used on Cottonwood Creek following culvert removal.

Table A-3. Specifications for non-biological structures with elevations from first post-project evaluation.

Specifications	Coir Log	Soil Rap (Outer)	Soil Rap (Inner)
Material	Coconut Fiber	Coconut Fiber	Coconut Fiber
Length (m)	7	7	7
Width or Diam. (m)	0.20	2.4	0.20
Manufacturer		RoLanka Int. Inc.	RoLanka Int. Inc.
Product Name		BioD-Mat 70	BioD-OCF 30
Placement Date	July 2001	July 2001	July 2001
Elevation* (m)			
Rt. Lower	98.8	99.2	
Rt. Top		99.6	
Lt. Lower	98.8	99.2	
Lt. Top		99.7	

* Elevations relative to assumed 100-m at benchmark.

Biologic Structures

Dormant plant cuttings were the only biological structures used in the project. Cuttings were used for the brush layering and shown in Figure 1. The cuttings were black cottonwood (*Populus trichocarpa*) were collected during the previous winter and stored frozen. The stem diameter of the cuttings was not measured but was approximately 2.5-cm on average. Cuttings were roughly 1.5-m long with 0.75 of the length placed below ground at a density of 100/m after having thawed for less than 48 hours. No fertilizer was used and the stems were not watered after planting. Table A-4 shows the relative height of each layer to ordinary high water and percent survival after 2 months.

Table A-4. Elevation (m) of brush layers above ordinary high water (OHW) and percent survival.

	Right Bank			
Layer	Elev. above OHW	# Alive	# Dead	Percent Survival
1	0.31	29	7	80.56
2	0.5	51	15	77.27
3	0.8	68	7	90.67
	Left Bank			
Layer	Elev. above OHW	# Alive	# Dead	Percent Survival
1	0.31	42	12	77.78
2	0.4	47	20	70.15
3	0.7	59	10	85.51

Ecological Structure

Following culvert removal water velocities decreased substantially at both the upstream and downstream transect locations (TableA-2). Mean water velocities within the restored reach were still fairly high; however, there were areas of considerably lower velocities, particularly along the right bank where velocities of 0.03-m/s were measured. Juvenile fish were not sampled following the culvert removal; however, spawning adult coho salmon were observed throughout the restored section of stream. Both the upstream and downstream scour pools began to fill with substrate following culvert removal (Figure A-3). This reduction in stream depth without a corresponding reduction in stream width resulted in an increase in ratios of width to depth.

The unmodified riparian vegetation both upstream and downstream was composed of patches of closed (canopy of 60 to 100% cover) tall alder shrub and closed black cottonwood forest. Planted riparian vegetation was 100% cottonwood and extended 1-m laterally from ordinary high water (Figure A-4). The three-cottonwood brush layers extended vertically from ordinary high water to 0.7 to 0.8 m. Percent survival of the planted cottonwoods ranged from 70 to 90% 2-months following planting. Plant survival was lowest for the middle layer on both banks and may be due to a combination of elevation above OHW, soil compaction, and shading.

The culvert removal met the project objective of reducing water velocity to allow juvenile fish passage. Even lower water velocities could have been achieved within the restored reach by increasing stream depth and thereby cross-sectional area. Future projects should consider the potential for an increase in width depth ratios at the upstream and downstream scour pools begin to fill with sediment.

Figure A-3. Photographs taken from photo point located downstream of restored reach one week following design implementation (left) and prior to (right).

Figure A-4. Photograph of riparian vegetation at restored reach 2-months after culvert removal.

CASE STUDY 2: WILLOW CREEK PRE-PROJECT EVALUATION

Introduction

Willow Creek is located within Southcentral Alaska. The stream drains into the Susitina River which flows into Cook Inlet. The stream supports a popular chinook salmon fishery which is enhanced by easy access and a State Park located at the confluence with the Susitna River. Bank trampling has resulted in denuded stream banks for approximately 300-m upstream. The loss of riparian vegetation appears to have resulted in bank sloughing and an apparent loss of rearing and spawning fish habitat. Pre-project surveys were conducted to refine project objectives, and to provide a baseline for post-project evaluations.

Physical Characteristics

<u>Hydrology</u>

Level 1 analysis was conducted and limited to determining bankfull water depth. Bankfull water depth was obtained concurrently with measurements of stream cross-sectional morphometry (see Morphometry below). Bankfull water depth is the hydraulic radius and is shown for each transect in Table A-5.

<u>Morphometry</u>

Stream morphometry was evaluated at Level 2. Level 1 channel-bank characteristics were determined through fixed-point photography (Table A-6). Channel cross-sectional morphometry was determined by cross-sectional surveys at 6 transects located every 60-m. A 100-m tape was secured on the left and right banks perpendicular to the channel. Bed height was measured every 0.2 to 1.0 m using a laser level and leveling rod. More frequent measures were taken at points of rapidly changing bed heights. Bank undercut depth was measured at both ends of the tape with a meter stick. Stream bed slope and water surface slope were calculated by determining the slope of the regression line between downstream distance and minimum bed height and water surface height, respectively. Channel characteristics determined from cross-sectional measurements are shown in Table A-5.

<u>Substratum</u>

Channel bed particle size distribution was evaluated at Level 2. Substratum size distribution through Wolman pebble counts of 100 particles as modified by Bevenger and King (1995). The length B-axis was determined using a substratum sampler developed by the U.S. Forest Service. Particles were sorted into those less than 2-mm, 2-2.8 mm, 2.8-4 mm, 4-5.6 mm, 5.6-8 mm, 8-11 mm, 11-16 mm, 16-22.6 mm, 22.6-32 mm, 32-45 mm, 45-64mm, 64-90 mm, 90-128 mm, and greater than 128 mm. The cumulative portion than a given size class are plotted in Figure A-5. The critical grain size was determined from the tractive force equation of Kaepesser (1985).

Biotic Characteristics

<u>Riparian Vegetation</u>

Measurements of riparian vegetation were conducted at Level 2. Level 2 analysis of a parameter includes Level 1 measure. Therefore, measures included fixed-point photography and classification of distinct zones of vegetation. Vegetation classification was determined along a line defined by extending the stream cross-section across the uplands. Each distinct zone of vegetation was classified using the methods of Viereck et al. (1992).

Table A-5. Stream channel characteristics. Water surface elevation at the sampling date. Maximum water depth at the sampling date is the difference between minimum bed elevation and water surface elevation.

Willow: Mouth Bankfull Channel Characteristics	T1	T2	T3	T4	T5	T6
Station Dist (m)	344.00	285.00	225.00	165.00	105.00	45.00
Min Bed Elev. (m)	-100.83	-100.78	-100.68	-100.66	-100.69	-100.65
Water Surface Elev. (m)	-100.51	-100.48	-100.44	-100.43	-100.41	-100.37
Width (m)	16.80	16.00	16.40	15.30	20.50	17.40
Area (m^2)	15.48	12.79	17.57	12.33	16.63	18.67
Perimter (m)	17.45	16.78	17.90	16.64	21.20	18.20
Hyd. Radius (m)	0.89	0.76	0.98	0.74	0.78	1.03
Mean Depth (m)	0.82	0.77	0.95	0.69	0.83	1.04
w/d ratio	18.94	21.00	16.71	20.64	26.14	16.97
Undercut Rt. (m)	0	0	0	0	0.44	0
Undercut Lt. (m)	0	0	0	0	0	0
Bed Slope	0.00057					
Water Surface Slope	0.00044					
Critical Grain (mm)	5.09					

Table A-6. Location and aspect of photography points.

Latitude	Longitude	Station (ft)	Direction	Comments	File Name
61.77803	150.16089	0.0	Downstream to 24.0	Stations measured with 0.0 being the upstream end of the project at the base of the Alders present currently	willowm.11
61.77816	150.16057	24.0	Perpendicular	From across stream (right bank) 10 ft from large birch.	willowm.12
61.77803	150.16089	0.0	Downstream	Ordinary high water bank profile.	willowm.13
61.77815	150.16098	30	Downstream	Center of trail	willowm.14
61.77828	150.16102	59	Perpendicular	Divet or hole	willowm.15
61.77827	150.16112	84	Perpendicular		willowm.16
61.77827	150.16112	84	Downstream	Center of trail	willowm.17
				Lamprey in bucket	willowm.18
61.77842	150.1612	122		Rt bank at birch tree	willowm.19
61.77851	150.16153	194		Rt bank 10 feet from large spruce tree	willowm.20
61.77826	150.16134	125	Downstream	On trail	willowm.21
61.77836	150.16173	200		Looking down trail	willowm.22
61.77864	150.16203	20	Perpendicular	Rt. Bank in from of Birch	willowm.23
61.77842	150.16198	250	Upstream		willowm.24
61.77866	150.16198	325	Perpendicular		willowm.25
61.77871	150.16251	366	Perpendicular		willowm.26
61.7787	150.16274	366	30* upstream	2 m upstream of leaning spruce	willowm.27
61.7787	150.16274	366	45* upstream	2 m upstream of leaning spruce	willowm.28
61.7787	150.16274	366	60* upstream	2 m upstream of leaning spruce	willowm.29

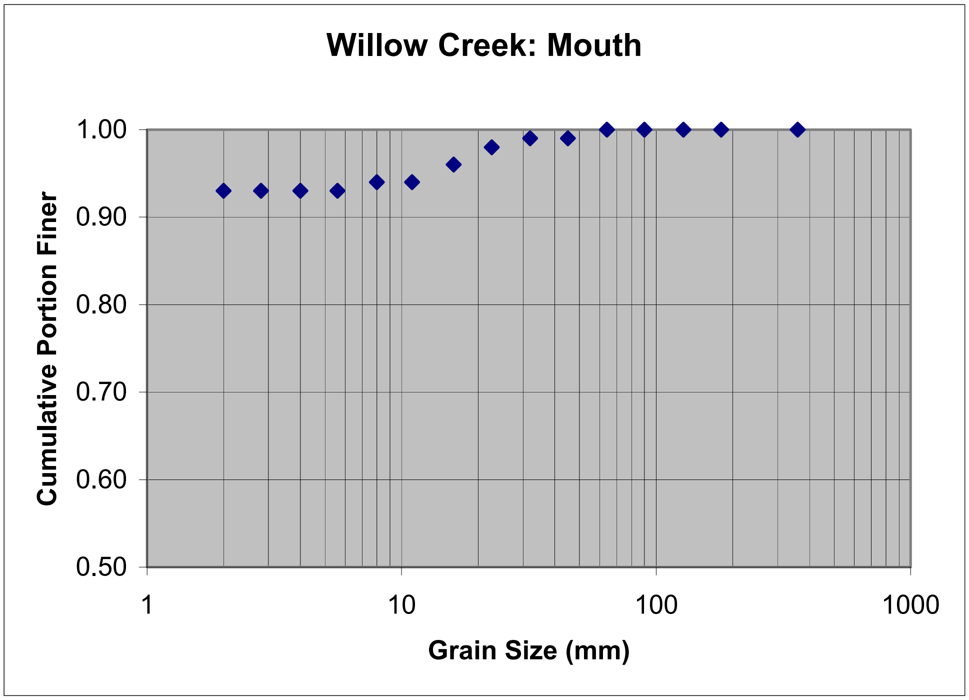

Figure A-5. Substratum size distribution at the mouth of Willow Creek showing dominant sand grain size.

Invertebrates
The invertebrate community was sampled at Level 2. Invertebrates were sampled with D-frame kick nets with 0.350-m mesh as per the Alaska Stream Condition Index methodology (Major and Barbour 2001).

Fish
The fish community was evaluated at Level 2. Fish population estimates were determined through multiple-pass electroshocking. The upstream and downstream ends of a 47-m long reach of the left bank were blocked with mesh net. Fish from each pass were retained in separate buckets and the electroshocking time was recorded.

Summary

Stream bank sloughing is obvious throughout the sampling area. Sloughing has resulted in a stream bed composed almost entirely of particles less than 2-mm in diameter. Bankfull stream widths range from 16 to 20-m, which is approximately 2 fold greater than upstream-unmodified locations. The hydraulic radius is approaching 1-m and stream slopes are very low. Based on channel characteristics the critical grain size for transport would be near 5 mm. Comparisons between the critical grain size and the particle distribution shows a greater portion of smaller particles than expected and confirms aggradation.

Natural riparian vegetation consisted of small patches of willow-alder shrubs adjacent to the stream and either bluejoint meadows or open spruce-birch forests (Table A-7). The invertebrate samples have not been processed at this time but densities and diversity appears to be extremely low.

Fish habitat in the form of undercut banks and cover from overhanging vegetation or woody debris is totally absent. Only one coho salmon juvenile was captured during fish sampling (Table A-8). Pacific Lamprey dominated the fish community, which were abundant within the sandy substrate.

Based upon observations and pre-project data project objectives must include stream bank stabilization and revegetation, increase in undercut banks and overhanging vegetation, and an increase in substratum size distribution. Bank stabilization and revegetation should accomplish most of these objectives. The reduction in sediment input from bank sloughing should result in stream-bed degradation and expose the underlying gravel substrate.

Table A-7. Riparian vegetation classification and definition at the 6 transect locations.

Vegetation on Left Bank at Transects		
T1	**344 ft**	
Dist (m)	**Veg Class**	**Defined**
0-3	V	Unvegetated: Human caused
3-9	IIC2K	Open low Alder-willow shrub
9-	IC1a	Closed Spruce-Paper Birch forest
T2	**285 ft**	
Dist (m)	**Veg Class**	**Defined**
0-7	V	Unvegetated: Human caused
7-18	IIIA2c	Bluejoint-Shrub
18-	IC2a	Open Spruce-Paper Birch Forest
T3	**225 ft**	
Dist (m)	**Veg Class**	**Defined**
0-4	V	Unvegetated: Human caused
4-15	IIIA2c	Bluejoint-Shrub
15-	IC2a	Open Spruce-Paper Birch Forest
T4	**165 ft**	
Dist (m)	**Veg Class**	**Defined**
0-3	V	Unvegetated: Human caused
3-12	IIIA2c	Bluejoint-Shrub
12-20	IC2a	Open Spruce-Paper Birch Forest
20-100	IIIA2a	Bluejoint Meadow
T5	**105-ft**	
Dist (m)	**Veg Class**	**Defined**
0-2	V	Unvegetated: Human caused
2-100	IIIA2a	Bluejoint Meadow

Vegetation on Left Bank at Transects		
T6	**45-ft**	
Dist (m)	**Veg Class**	**Defined**
0-1.5	IIC2f	Open Low Shrub Birch-Willow Shrub
1.5-2.5	V	Unvegetated: Human caused
2.5-14	IIIA2a	Bluejoint Meadow
14-22	IC2a	Open Spruce-Paper Birch Forest
22-100	IIIA2a	Bluejoint Meadow

Table A-8. Fish sampling results.

FISH	13-Sep-01	
	1st Pass	2nd Pass
Species	Length (mm) or number	Length (mm) or number
Coho salmon (FL)	50	0
Pacific Lamprey (No.)	13 (#)	8
Sculpin (No.)	2 (#)	0

CASE STUDY 3: WILLOW CREEK BANK STABILIZATION

Introduction

The left bank of Willow Creek below the Parks Highway Bridge was restored in the spring of 2001. Restoration methods included brush layering with a root-wad toe. Three brush layers were used. The upper banks were reseeded using a riparian seed mix. A split-rail fence protected the restored site. Access was limited to elevated platforms. Stream access was provided by a stairway from one of the three platforms. No pre-project evaluations were conducted; however, some pre-project photographs and some historical data were available. The data presented here is from a post-project evaluation conducted in September, 2001. Post-project evaluation consisted of project implementation including both the biological and non-biological structures and Level 1 analyses with Level 2 analyses of morphometry, riparian vegetation, invertebrates, and fish.

Implementation

Abiotic Structures

The abiotic project structures included three elevated platforms with ramp access, a 125-m split rail fence, stairs from the middle platform to the stream, and root wads (Figure A-6). The platform foundations were 3-inch diameter steel pipe buried during project construction. The platforms and ramps were constructed with outdoor wood (“brown wood”) supporting metal grating (Figure A-7). A post-project as-built was not obtained. The distance between the ground and the surface of the platforms was measured at each transect (see Table A-9). Subsequent evaluations will be based upon fixed-point photographs taken looking upstream and downstream at five transects established throughout the restored section (Figure A-6).

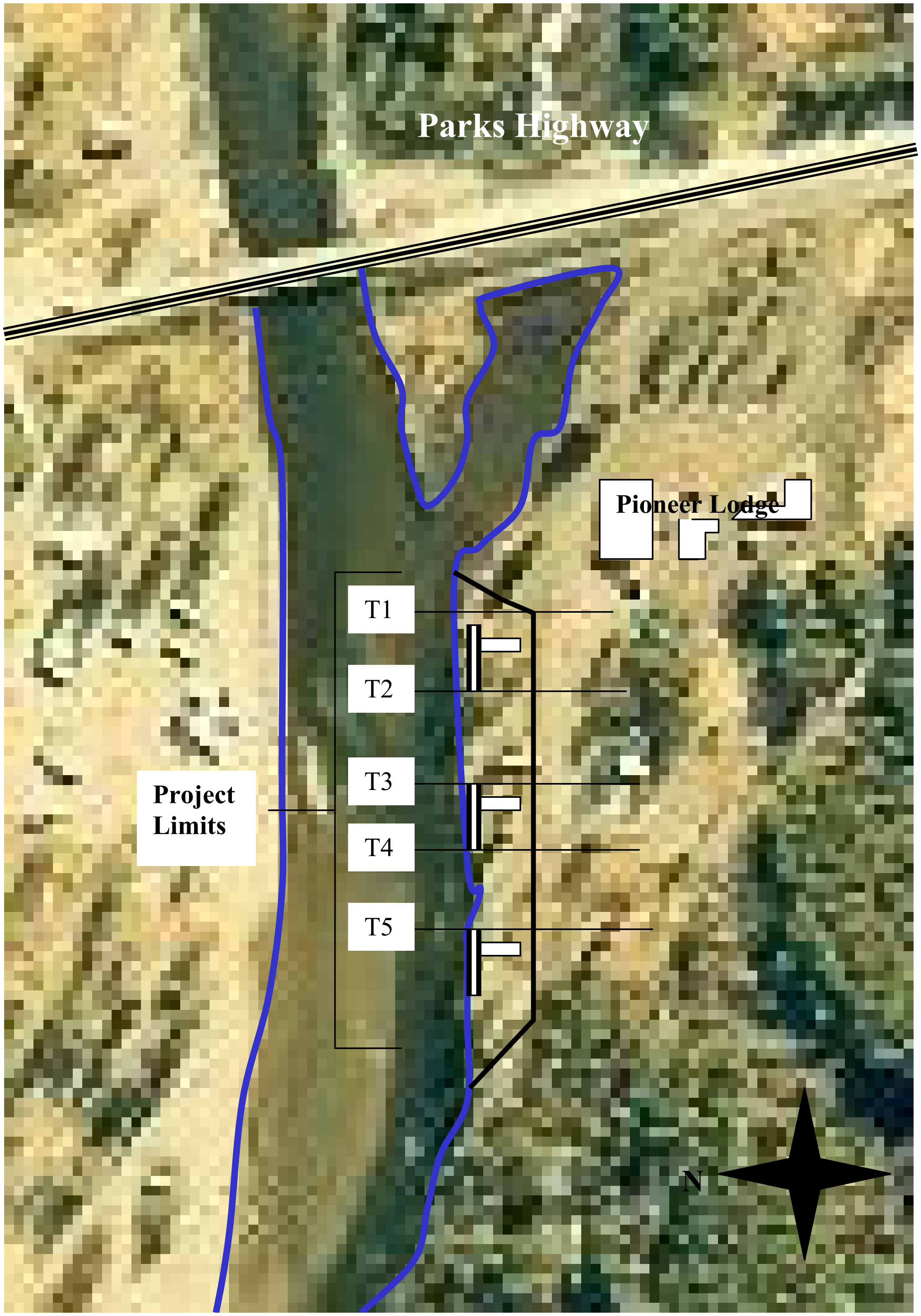

Figure A-6. Transect (T1-T5) locations relative to Willow Creek project structures.

Figure A-6. Photograph showing platform construction.

Table A-9. Distance downstream, elevations, and stream bank characteristics for transect 1 (T1) through transect 5 (T5). Elv.= elevation, OHW=ordinary high water, WS=water surface.

	T1	T2	T3	T4	T5
Distance (m)	9	25	50	65	104
Water Surface Elv. (m)	97.89	97.92	97.81	97.76	97.43
OHW (center bole)	98.45	98.64	98.63	98.45	98.26
WS-OHW	0.56	0.722	0.82	0.692	0.833
1st Layer to WS	0.90	1.17	1.14	1.17	1.30
1st Layer to OHW	0.34	0.45	0.32	0.48	0.46
2nd Layer to WS	1.11	1.43	1.31	1.32	1.30
2nd Layer to OHW	0.55	0.70	0.49	0.62	0.46
3rd Layer to WS	1.39		1.55		1.63
3rd Layer to OHW	0.83		0.73		0.80
Ground to Platform (m)	0.89	0.64	0.88	0.73	0.76
Upper Bank Slope	0.46	0.56	0.55	0.41	0.46
Water Surface Slope	0.00499				

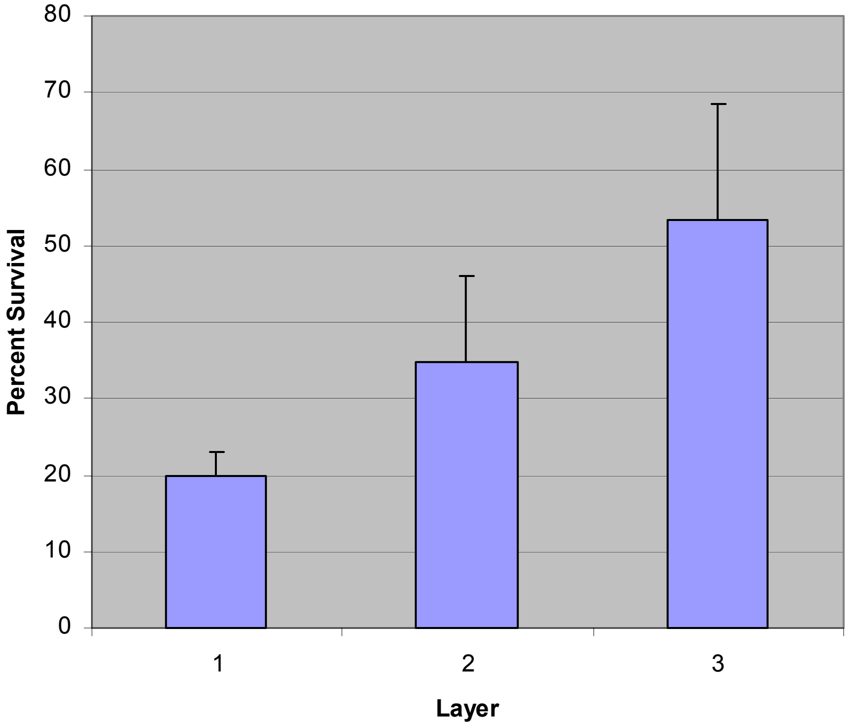

Figure A-8. Survival of planted willows for each brush layer in September 2001. Error bars are one standard deviation.

Biotic Structures

The biotic structures consisted of the dormant willow cuttings used in the brush layers. Willows were harvested the previous winter from the adjacent Willow airport. Willows were stored frozen until project implementation. Willow species included feltleaf (*Salix alaxensis*), Pacific (*Salix lasiandra*), and Sitka (*Salix sitchensis*). Average stem diameter was approximately 2.5 cm and average length 1.5 meters. Willows were layered at a density of roughly 100/m with 75% of the stem buried. The elevation of the willow layers above ordinary high water ranged from 0.4 to 0.8-m.

Planting success was determined through fixed-point photography and by counting all live and dead stems for 1-m for all three willow-layers. Percent survival of planted willows is shown in Figure A-8). Willow average survival ranged from 20 to 53% with the highest survival rates for the upper layer (Layer 3).

ECOLOGICAL STRUCTURE

Physical Characteristics

Hydrology

Evaluation of hydrology at the site was conducted at level 1 and was limited to determining the elevation of the water surface and ordinary high water relative to the benchmark at all 5 transects. Elevations for these two points are shown in Table A-9. The water surface was 0.7-m below ordinary high water by the sampling date of September 17.

Morphometry

The shape and the stability of the left bank were evaluated at Level 1 using fixed-point photographs. Level 2 analysis included surveying the left bank at 5 transects using a laser level and leveling rod. Bank characteristics from survey data are shown in Table A-9.

Substratum

The near-shore substratum size distribution was evaluated at Level 1, which consisted of photography and estimates. The substratum was composed 20% sand, 10% gravel, 60% cobble, and 10% boulder (FigureA-9).

Biotic Characteristics

Riparian Vegetation

Vegetation cover was evaluated with photography (Level 1) and classification of vegetation zones (Level 2). By September, the introduced willows and riparian seeds had become established (Figure A-10). Riparian vegetation throughout the project consisted of the shrub layer composed of willows extending out 1.5 to 2-m followed

Invertebrates

Stream invertebrates were collected using the ASCI methods (Major and Barbour) as recommended for Level 2 analysis of biotic characteristics. Invertebrates were sampled from the near-shore zone extending roughly 1.5-m into the stream channel. Invertebrate identification has not been completed at this time.

Fish

Juvenile fish were collected by electrofishing 56-m of shoreline. All fish captured through a single pass were identified to species and measured to fork length prior to returning them to the stream. Total fishing time was 204 seconds. Fish sampling data are shown in Table A-10.

SUMMARY

Pre-project surveys were not conducted. However, the project was designed to reduce bank erosion rates. The increase in bank erosion rates was assumed to be due to the loss of riparian vegetation due to foot traffic. The restoration project was designed with abiotic and biotic structures to reduce erosion rates and their causes. The objective of the abiotic structures (i.e. fence, ramps, platforms, and stairs) was to provide stream access without impacting riparian vegetation. The objective of the biotic structures was to restore riparian vegetation (willow brush layers and seeding) and reduce erosion rates (root wads). Post-project evaluation was primarily directed toward the evaluation of these project structures. Accelerated bank erosions affects stream and riparian ecological characteristics. The riparian vegetation community was lost. Stream substrate size composition appeared to be reduced. The habitat provided by undercut banks, reduced nearshore velocities, and bank complexity were not present. Habitat changes are likely to affect the aquatic invertebrate and fish community composition. Therefore, additional project objectives were to restore these stream characteristics.

Post-project monitoring has provided a general plan view and photographic documentation of the abiotic structures associated with this project. A post-project as-built survey would provide better documentation of the location of structures.

Figure A-9. Stream bank prior to and following implementation of restoration project showing rood wad fans and stream substrate.

Figure A-10. View upstream from transect 3 just following project completion and in September 2001 showing first-season vegetation establishment.

Table A-10. Fish sampling data for a56-m of restored stream bank.

Coho Fork Length (mm)	King Fork Length (mm)	Rainbow Fork Length (mm)
45	55	45
	68	36
	62	45
	68	35
	47	48
	68	
	60	
	45	
	50	
	54	

Project costs limited the monitoring to Level 1. Current data shows the location of the structures, their elevation, and their location relative to each other (i.e. platforms relative to the fence). The project objective of reducing foot traffic has been successful to this point. The abiotic structures were sound and there were no signs of human use between the fence and the stream bank.

The biotic structures also currently met project objectives. Although only a short-term evaluation, the root wads appeared stable and erosion rates reduced. The cross-sectional transect data and photographs can be used to evaluate bank and root-wad stability in subsequent evaluations. Percent survival of introduced willows of near 50% is acceptable, and riparian vegetation cover was at 100%.

The reestablishment of ecological structure is more difficult to evaluate because no reference data are available. The qualitative evaluation of stream substratum shows a shift toward more natural size distribution; however, there are still some areas with high accumulations of sand sized material. The stream banks appear to more closely reflect natural conditions. The aquatic invertebrates have not been identified at this time; however, the Alaska Stream Condition Index, and reference data for Willow Creek could be used to evaluate how close the invertebrate community reflects natural conditions.

The community composition of riparian vegetation, at this point, does not reflect natural conditions at distances greater than 2 meters from ordinary high water. At unmodified stream banks a zone of willows or alders is often observed and is reflected in the restored reach. However, greater than 2 meters an open birch forest predominates along Willow Creek, particularly at the drier sites, in contrast to the midgrass herb community in the restored section. Subsequent evaluations will document whether this area converts toward the reference riparian vegetation community.