Appendix 7: Planning for Streams

Introduction

Many stream alterations made during development will be responsible for their future quality. In this respect, the window of time before development is complete is an opportunity to protect existing stream integrity, correct degraded conditions or alternatively cause or allow worsening of the overall stream and water quality. This document lays out critical objectives that must be met in order to protect the long-term stream integrity.

As Figure 1 illustrates below, there are many variables responsible for stream integrity. Most frequently monitored stream characteristics, such as the water chemistry, habitats features or the biota found in the stream, are the result of other variables. Some variables, such as geology or rainfall (on the far left of the diagram) aren't significantly affected during development. Stream flow and stream form (morphology) are often significantly changed during development and often negatively influence stream integrity. This document focuses primarily on the need to build desired characteristics on practical steps of physical stream integrity. Site hydrology and stream flow are not discussed here, since they are subject of stormwater detention and development standards. Stream form or morphology is the primary concern here, since changes to stream form subsequently impact stream functions and characteristics such as water quality or habitat.

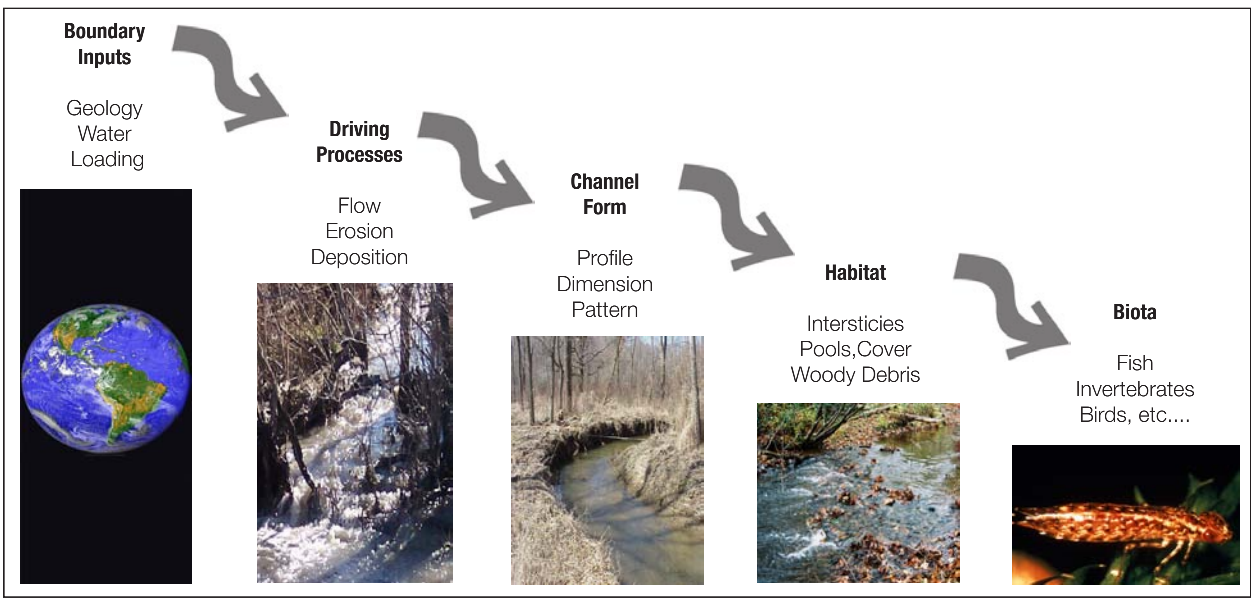
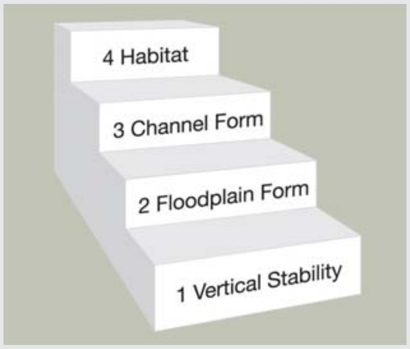


Figure 1 Relationship of the stream variables responsible for stream integrity

Initial stream conditions vary from site to site, therefore addressing physical integrity of a stream should start with an assessment of the channel morphology. Site designers should first have a sense of the morphology issues not just at one stream reach, but also of the entire drainage network. While quantitative measures are useful, gathering data must not distract designer from understanding what is good and bad about the physical conditions of a drainage network. Of course, existing condition is not always the best point of reference, therefore many tools, such as reference conditions or stream classification systems will be very useful for comparing current condition to stable natural forms.

Use prioritized objectives (Figure 2) when planning, designing or altering channels in Ohio. Ultimately prioritizing issues is essential for success and this guidance describes aspects of morphology that are most fundamental to overall stream health. These objectives are hierarchical; therefore you must begin with the most critical aspect of stream form and build upon these.

Planning for Quality Streams Requires Prioritizing Objectives



Prioritized Objective	Prerequisite
1. Vertical Stability	
2. Floodplain Form	Vertical Stability
3. Channel Form	Floodplain Form and Function
4. Habitat	Dependent on Objectives 1, 2, and 3

Figure 2 Planning for quality streams requires prioritizing objectives

Objective 1: Vertical Channel Stability

Vertically stable streams are in a dynamic equilibrium, maintaining a balance between bed material transport and supply. Vertical *instability* can be exhibited as either degrading (also known as incising or downcutting) or aggrading (depositing or filling up), although degradation is by far the most common vertical instability threat to Ohio streams.

Physical degradation is caused by increased bed load transport, perhaps the result of increasing runoff (e.g. urbanization), shortening stream length, and restricting floodplains. Reduced bed load supply also causes downcutting in channels such as from "hardening" headwater channels or when dams trap bed load. When more bed material is washed away than is supplied, incision or downcutting results as is shown in Figure 2, leading to channels becoming deeper and more entrenched. "Entrenched" describes channels that have reduced access to their floodplains and less interaction with riparian areas.

In Ohio, low gradient entrenched channels are characterized by low stream quality and often long-term instability exhibited in excess bed and bank erosion. Even high quality streams that are not vertically stable are in the process of degradation and will continue to have positive characteristics diminished or lost over time. Vertical stability is necessary for every other desired characteristic of channel morphology.

Headcut shown in an incising stream

Assessment

A variety of approaches exist for evaluating vertical stability, including very sophisticated sediment transport models, threshold of motion criteria for bed materials, ratio of bank height to bankfull channel depth, or simple observation (Table 1). More rigorous evaluations may be appropriate where existing conditions are already vertically unstable and the consequence of failure is severe. Where proposed changes to a stream have no potential to decrease vertical stability, more simplified evaluation approaches become appropriate.

Table 1 General indicators of vertical instability or stability

Instability		Stability
Headcuts		
Near vertical banks accompanied by bank erosion		
Bank Height Ratio		Bank Height Ratio
Moderately Unstable	1.06 -1.3	near 1.1
Unstable:	1.3 - 1.5	
Highly Unstable:	exceeds 1.5	

Note: Bank height ratio is the height of the bank (from the thalweg) divided by the height of the bankfull channel. See Rosgen, D.L. 2001. A Stream Channel Stability Assessment Methodology. A Practical Method of Computing Streambank Erosion Rate. In: 7th Federal Interagency Sedimentation Conference, March 25-29, Reno, Nev.

For example, vertical stability is typically not a concern for low energy streams, particularly where straight, entrenched, low-gradient channels, such as drainage ditches are expected to gain floodplain and stream length through proposed changes. Conversely, reducing stream length, which increases stream slope may induce downcutting in many Ohio channels.

Actions

Solutions to vertical instability may include system-wide solutions such as watershed-scale stormwater management that better controls higher energy runoff events and prevents or manages the initial causes of downcutting. Solutions may also focus on site level tools such as the construction of grade control riffles, cross vanes, w-weirs or even designing culverts to prevent further downcutting[1]. General approaches to addressing incised streams are described by Rosgen 1997[2].

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1 Newbury, R.W. and Gaboury, M.N. Stream analysis and Fish Habitat Design: A Field Manual. Newbury Hydraulics Ltd. Manitoba Habitat Heritage Corporation and Manitoba Fisheries Branch. 1993.

Maryland Department of the Environment (MDE) Water Management Administration. 2000. Maryland's Waterway Construction Guidelines. Available at http://www.mde.state.md.us/assets/document/wetlandswaterways/mgwc.pdf

Department of Conservation and Recreation (DCR), Division of Soil and Water Conservation. 2004 The Virginia Stream Restoration & Stabilization Best Management Practices. Guide Richmond, Virginia. Available at http://www.dcr.virginia.gov/sw/docs/streamguide.pdf

Schueler T., & K. Brown. 2004. Urban Subwatershed Restoration Manual No. 4: Urban Stream Repair Practices. Version 1.0. Center for Watershed Protection.

2 Rosgen, D.L., 1997. A Geomorphological Approach to Restoration of Incised Rivers. Proceedings of the Conference on Management of Landscapes Disturbed by Channel Incision.

Objective 2: Floodplain Form

Floodplain form, that is, having access to a functional floodplain at normal flood flows[3] (see Figures 3 and 4) is the most significant aspect of morphology for the long-term integrity of streams and for water quality. Floodplains are nature's primary ways of managing stormwater, improving water quality and organizing substrates for aquatic habitat. Stream processes associated with floodplain form occur in the smallest headwater streams as well as the largest rivers in Ohio, each overflowing their banks during significant storm events. Because maintaining streambed elevation (preventing downcutting and entrenchment) maintains the stream's access to its floodplain at normal flood flows, vertical stability is listed as the first objective in this section. However, maintaining functional floodplain form is the overarching goal and the second objective.

If a stream has access to its floodplain, during high flows:

- the erosive energy of the stream is dissipated by spreading the flow across the floodplain;
- the lower velocities associated with shallow flow on the floodplain allow eroded sediment and other pollutants to be settled out of the flow;
- flood waters infiltrate into the shallow groundwater that sustains stream baseflow.

When streams become entrenched (i.e., when they downcut and lose access to their floodplain) beneficial channel processes are lost or diminished. With entrenched streams, all of the erosive energy, eroded sediments and polluted runoff are contained within the channel and passed downstream where they cause channel incision, excessive streambank erosion, localized flooding and degraded stream habitat.

The vast majority of natural streams have extensive floodplains that are saturated or inundated several times a year. This is characteristic of streams with slopes less then 2%. The average stream slope in Ohio
is only 0.3%. The stability of steeper streams is also dependent on appropriate floodplain widths, but these are generally narrower with increasing slope.

Streams beginning to utilize floodplains

Channels with limited floodplain form

3 The term "normal flood flows" equates to the typical out-of-bank events that occur under natural watershed and stream conditions. In undeveloped areas, most streams will flood (i.e., get out of bank) two or three times per year. In urban and suburban areas, streams typically may experience 5 to as many as 20 out of bank events per year.

When floodplains are extensive, low and frequently wet, streams have a tremendous ability to assimilate pollutants. Additionally, these streams are more resilient, and more resistant to watershed impacts.

Furthermore, while recovery of stream integrity is possible, the "natural" redevelopment of floodplain is the aspect that takes the most time, being measured in terms of years and perhaps decades. While floodplain recovery is ultimately positive, it is also associated with highbanks being lowered through bank erosion and subquently higher sediment loads until an adequate floodplain width is achieved. Thus it is much less likely to be allowed to occur where intensive land uses have encroached near the channel and will likely not occur in low energy (lower gradient) channels such as ditches.

Assessment

The quality of floodplain form is first an issue of elevation or how accessible it is (Figure 3) and second an issue of how extensive or wide it is (Figure 4). Ideally floodplain elevations are at and below "bankfull stage" and allow the ground surface to be saturated or inundated several times per year for most channels. Floodplain elevation can be quantified a number of ways including the ratio of the height of the floodplain relative to the bankfull channel depth, frequency of inundation, or relative depth of a particular flow event (usually in terms of recurrence interval).

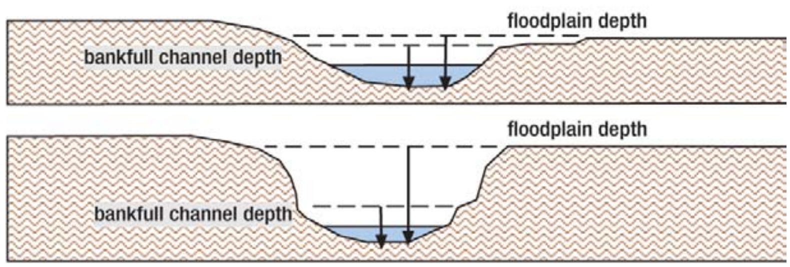

Figure 3 Appropriate floodplain form is first an issue of elevation

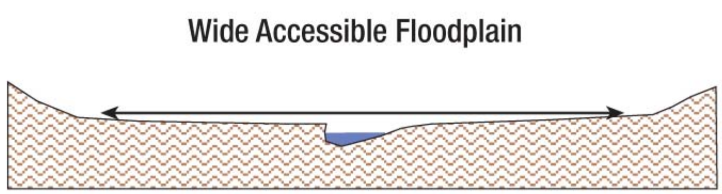

Figure 4 Appropriate floodplain form is also an issue of extent or width

Given the variability in natural channels, defining adequate floodplain width is understandably imprecise. One potential target is pre-disturbance conditions. Another is the width of the meander pattern past, present or projected. For most streams it is simply a matter of the more floodplain width, the better. However, floodplain immediately adjacent to the channel is most critical and diminishes in importance with increasing distance from the channel. Since floodplain width comes at a cost and may conflict with other land uses, a definition of ranges of floodplain width is provided below. Adequate floodplain (for streams that naturally have floodplain) is defined by the three descriptive reference points given below.

Floodplain width dimensions defined here are in multiples of the bankfull channel width[4] (Figure 5).

> THREE TIMES the bankfull width is the bare minimum. Below this threshold streams are characterized by poor quality, lateral instability, degraded habitat and minimal or no watershed benefit.
>
> FIVE TIMES the bankfull width is frequently associated with fairly good streams. Clear ecological benefits are associated with floodplains of this width. Flood hydraulics and sediment transport exhibit a break at about this floodplain width, with bedload transport (and subsequent channel instability) increasing at a faster rate below this point. Lastly, common meander pattern beltwidths begin to be restricted below this floodplain width.
>
> TEN TIMES the bankfull width and greater is typical of the highest quality streams, undeveloped conditions and streams that provide considerable downstream benefit through their assimilative capacity and hydrologic functions.

A number of indications and arguments suggest 10 times the channel width is a general threshold above which floodplain width does not limit stream quality[5]. Below this threshold the floodplain width appears to begin limiting stream quality, changing the hydraulics and interactions between the channel and floodplain (Ward, 2002[6]). The effects are gradual until the floodplain is reduced to a width somewhere around 5 times the channel width. Floodplain widths below 5 times bankfull width exhibit consistently lower stream quality and reduced floodplain services until the lowest threshold is reached around 3 times the channel width. Below 3 times the bankfull channel width, streams typically cannot maintain a stable floodplain form. The instability problems equate to a loss of services locally and an increasing contribution to stability, water quality and habitat problems downstream.

Using channel width to determine appropriate floodplain width can be problematic due to variability of apparent bankfull channel width and subjectivity involved in stream measurements. Drainage area provides a more robust variable for programs requiring appropriate floodplain widths be applied to channel projects. By using empirical relationships of channel dimension, meanders and watershed size, equations can be generated relating the target floodplain width to drainage area. This approach also can be tailored more to particular watersheds as additional data for an area becomes available. The following equations utilize empirical relationships for channel dimensions, drainage area and meander beltwidth from Dunne & Leopold (1978[7]) and Williams (1986[8]) for the three floodplain-width thresholds described earlier.

$$BW_{10}=147(\text{Drainage Area})^{0.38} \quad BW_5=74(\text{Drainage Area})^{0.38} \quad BW_3=44(\text{Drainage Area})^{0.38}$$

Where BW_x = beltwidth or floodplain width associated with x times the channel width (feet)
Drainage Area = contributing watershed area (square miles)

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4 Floodplain width refers to the width that is saturated or inundated by bankfull flow. It is generally the width of flow just above the bankfull stage. More information regarding means of estimating is available in the Stream Setback practice in Chapter 2.

5 High quality E-4 stream types naturally have very wide floodplains; 57 times the channel width is the average of Rosgen's Classification references. Rosgen, D.L. (1994). A classification of natural rivers. Catena, Vol. 22, 169-199. Elsevier Science, B.V. Amsterdam.

6 Ward, A., D. Mecklenburg, J. Mathews and D. Farver. 2002. Sizing Stream Setbacks to Help Maintain Stream Stability. American Society of Agricultural Engineers Paper Number 022239, for presentation at the 2002 ASAE Annual International Meeting / CIGR XVth World Congress, Chicago, IL. 35 pp.

7 Dunne, T. and L.B. Leopold, 1978. Water in Environmental Planning. W.H. Freeman, New York, 818p.

8 Williams, G.P., 1986. River meanders and channel size. Journal of Hydrology, 88 pp.147-164

Actions

Desirable floodplain form can be protected by restricting floodplain fill and levee construction, in addition to the actions described for controlling down cutting in objective 1. Options for improving floodplain form are: 1) lowering the ground adjacent to the channel to create active floodplain; 2) raising the streambed elevation to connect channel with abandoned floodplain; 3) create a overly wide channel where floodplain deposition and formation can occur; 4) lower banks to increase floodwater access; and 5) utilize stormwater or conservation easements to allow areas where natural erosion and deposition processes are creating improved floodplain form overtime. These options are not all equally beneficial and solutions to better floodplain form may involve some combination of approaches that fit the site and watershed constraints. For example, increasing the bed elevation generally requires much less work and utilizes historical floodplain areas, but is often limited by drainage needs or adjacent land uses.

Objective 3: Channel Form

The form of the bankfull channel is represented by the cross sectional dimension, meander pattern and bed profile. While channel form is typically emphasized in design, its relative importance follows vertical stability and floodplain form. Ideally channel form should target the best potential that would naturally be built and maintained by the stream in the particular watershed. Yet actions may vary upon whether the immediate goal is active restoration, rehabilitating a current degraded condition or facilitating natural recovery.

Assessment

A number of channel form assessment and design approaches have been developed (Skidmore et al, 2001[9]). Using a combination of design approaches is appropriate for restoration of channels, especially high quality, large or unstable streams. For less critical projects and lower quality, yet vertically stable streams, more generic channel design may be adequate. Some projects may even involve only floodplain construction with no work done to the bankfull channel.

Commonly used sources of assessment and design information (design approaches) include:

1. **Regime equations (Empirical Design)** The large databases of channel geometry have a statistical advantage in that they are based on many streams and rivers. Their disadvantage is that they provide typical values within a large acceptable range without defining the character of a specific reach. Some resources may found at (www.dnr.state.oh.us/soilandwater/docs/streammorphology).
2. **The Rosgen Classification of Natural Streams** The Rosgen classification of natural streams (Rosgen, 1996[10]) allows a level of refinement, where typical channel geometry is provided for stable channels in a range of valley conditions. Perhaps even more valuable is the Rosgen classification's geometries that are characteristically unstable.
3. **Regional curves** Regional channel geometry curves provide another type of refinement. Like regime equations, which generally provide only a description of a typical stream without accounting for the variability in channel character, regional curves describe channels typical of a region. Typically only three values are provided: bankfull cross sectional area, width, and mean depth. (Since mean depth is defined as area/width, this is really only two variables.) Regional curves are useful for evaluating size as well as width to depth proportions, which may both having regional variability. A regional curve for the Eastern United States is often used for reference in Ohio (Dunne, 1978[11]). It should be noted that proper identification of bankfull stage is critical to the development of regional curves. Additional regional channel geometry resources may be available by contacting the ODNR-DSWC Stormwater and Streams section.

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9 Skidmore, P.B., F.D. Shields, M.W. Doyle, & D.E. Miller. 2001. A Categorization of Approaches to Natural Channel Design. Wetlands Engineering and River Restoration Conference 2001. Available at https://fs.ogm.utah.gov/PUB/MINES/AMR_RELATED/NAAMLP/StrmRest/Skidmore.pdf

10 Rosgen, D.L. (1994). A classification of natural rivers. Catena, Vol. 22, 169-199. Elsevier Science, B.V. Amsterdam.

11 Dunne, T. and L.B. Leopold, 1978. Water in Environmental Planning. W.H. Freeman, New York, 818p.

4. **Measured local reference channel (Analog Design)** A reference channel reach near the reach to be designed has the best potential for illustrating and defining the channel variability and character resulting from local climate and geology. Additionally, there is no end to the detail that may be gleaned from a local reference reach. This also highlights a disadvantage – these particular local reaches of interest are most likely reference sites no one has yet published, let alone surveyed. Perhaps the most valuable (and time consuming) design task is surveying a local reference reach, its longitudinal profile, representative cross sections, bed materials and, to a lesser extent, its meander pattern. Numerous references provide descriptions of methods and uses of reference reach information (Harrelson, 1994; Rosgen, 1998; Hey, 2006[12]). The weaknesses of measured local or on-site channel geometry are that a quality reference channel might not exist and it represents a small sample. Thus this approach must be used in conjunction with the prior three approaches for determining stable channel form.

Actions

Actions promoting best potential channel form require understanding of and to varying degrees designing the appropriate bed form, cross-sectional dimension, and the plan form that fit the stream discharge and valley conditions. Types of constructed channel forms can be generally based on the slope of the proposed stream and the valley conditions as: step-pool channels that are generally over 4% slope; top dressed rip-rap channels (equates to B channel in Rosgen Classification System) that are generally 2-4% percent slope; and compound channels for streams generally less than 2% slope. Compound channels are by far the most common to Ohio and are characterized by a smaller channel within a wider active floodplain, which receive flows during large events. Actual channel designs will contain numerous measures related to channel form such as riffle slope, pool depth and other stream features as well as bed material and appropriate bank protection necessary to maintain the form during establishment of vegetation.

Some actions promote the natural recovery of improved channel form. Channel recovery, sometimes called passive restoration (Brookes, 1996[13]), eventually improves each of the 4 prioritized objectives. However the time required for recovering vertical stability is very long. As discussed earlier, recovery of floodplains has significant potential and channels with the greatest potential for recovery in acceptable time frames and with manageable impacts will be those that have simply been straightened without being lowered. Thus facilitating recovery in these channels may be the most realistic approach to improving channel form. Steps include identifying areas where meander pattern is redeveloping, planning for it through set aside, stream setbacks, easements and perhaps even compensating landowners for it, since this usually means immediately adjacent land uses will be threatened. In some streams it may even be possible to initiate channel recovery with selective tree removal or construction of deflectors.

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12 Harrelson, C.C., C. Rawlins, and J. Potyondy, 1994. Stream Channel Reference Sites: An Illustrated Guide to Field Techniques. USDA Forest Service Rocky Mountain Forest and Range Experiment Station General Technical Report RM-245, 67 p. Available at http://www.ohiodnr.com/soilandwater/docs/streammorphology/RM245E.pdf

Rosgen, D.L. 1998. The Reference Reach - a Blueprint for Natural Channel Design. From proceedings of the ASCE Wetlands and Restoration Conference, March, 1998, Denver, Co. Available at http://www.wildlandhydrology.com/assets/The_Reference_Reach_II.pdf

Hey, R.D. 2006 Fluvial Geomorphological Methodology for Natural Stable Channel Design
AWRA No. 02094, Volume 42, Issue 02, pages 357-374

13 Brookes, A. (1996) Floodplain restoration and rehabilitation. In: Anderson, M., Walling, D. and Bates P. (eds.),

Floodplain processes. John Wiley, Chichester. pp. 553–576.

Objective 4: Habitat

Habitat quality is largely dependent on the ability of natural stream characteristics to develop over time. Thus improvements to habitat should not be attempted unless the proceeding objectives have been met. Because habitat is dependant upon the proceeding objectives, it can serve as a valuable indicator of the overall stream morphology. Drawbacks to using habitat as an indicator are that it does not typically identify the underlying problem or help to choose appropriate remediation, nor does it always identify which elements are critical for protection. Yet for many stream projects, providing immediate good quality habitat is an important objective that follows planning for the appropriate stream form.

Assessment

Ohio's Qualitative Habitat Evaluation Index (QHEI, see Rankin, 1989[14]) and Headwater Habitat Evaluation Index (HHEI[15]) offer valuable tools for assessing habitat quality. It should be noted that just as channel morphology is dependent on the characteristics of a particular watershed, the potential for some aspects of habitat are limited by the watershed characteristics and underlying morphological characteristics. For instance, some watersheds do not supply the bed material that will help to raise that portion of the QHEI score. Another example: Excavating pools on a particular reach of stream that are significantly deeper than the range of pool depths from a quality reference channel should not be expected to be maintained over time. Thus habitat should be assessed in the context of the geomorphic factors and the watershed conditions and utilize the best conditions of the watershed as a point of reference.

Actions

At a minimum, sites must be stabilized sufficiently that the previous objectives are not compromised. Ideally if objectives 1-3 have been met, then quality habitat should develop over time (though substantial time may be required). Although this is true, stream projects differ substantially from natural sites that have established vegetation and other features. Some situations may be appropriate for allowing habitat to develop overtime, such as where existing degraded morphology is being rehabilitated or restored. Ultimately this may be determined by the permitting authority. Ideally, each stream project should plan for quality habitat features, even if they are to be gained through natural development and succession.

14 Rankin, Edward T. 1989. The Qualitative Habitat Evaluation Index (QHEI): Rationale, methods and application. Ohio Environmental Protection Agency, Division of Water Quality Planning and Assessment, Ecological Assessment Section, Columbus, Ohio. At http://www.epa.state.oh.us/dsw/bioassess/BioCriteriaProtAqLife.html

15 Anderson, P., R. D. Davic, and S. Tuckerman. 2002. Field Evaluation Manual for Ohio's Primary Headwater Habitat Streams. Ohio EPA, Division of Surface Water, Columbus, Ohio. 66 p. Available at http://www.epa.state.oh.us/dsw/wqs/headwaters/PHWHManual_2002_102402.pdf

Where immediate habitat quality is desired, such as areas of particular ecological importance, habitat structure must be part of construction. Promoting high quality habitat may include actions like utilizing placed boulders, particular substrates, root wads, large woody debris, brush layering and vegetative cover appropriate for the watershed. Constructing appropriate habitat will also involve planning for appropriate aquatic species and native vegetation. Some resources help fit habitat applications to particular stream and flow conditions (Newbury, 1993; Rosgen, 1996[16]). Numerous references[17] discuss habitat structures, but do so with varying degrees of appreciation of the importance of tying the habitat features to stable morphology and projected hydraulic conditions. Streams are dynamic and even the best laid plans require monitoring and perhaps adjustment and maintenance. For this reason, easements may be required.

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16 Newbury, R.W. and Gaboury, M.N. 1993 Stream analysis and Fish Habitat Design: A Field Manual. Newbury Hydraulics Ltd. Manitoba Habitat Heritage Corporation and Manitoba Fisheries Branch.

Rosgen, D.L., 2002. Applied River Morphology. Second Edition. Wildland Hydrology, Pagosa Spring, Colorado.

17 Federal Interagency Stream Restoration Working Group (FISRWG)(15 Federal agencies of the US gov't). 1998. Stream Corridor Restoration: Principles, Processes, and Practices. GPO Item No. 0120-A; SuDocs No. A 57.6/2:EN 3/PT.653. ISBN-0-934213-59-3.

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