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Regional Reference Sites: a Method for Assessing Stream Potentials

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ABSTRACT / Field assessments of impacted streams require a control or at least an unbiased estimate of attainable conditions. Control sites, such as upstream/downstream or wilderness sites, have proven inadequate for assessing attainable ecological conditions where the control streams differ naturally from the impacted streams to a considerable degree or where different disturbances exist than those being studied. Relatively undisturbed reference sites with watersheds in areas having the same land-surface form, soil, potential natural vegetation, and land use as are predominant in large, relatively homogeneous regions are suggested as alternative control sites. These areas are considered typical of the region and therefore the sites also are considered typical of the region because their watersheds exhibit all the terrestrial variables that make that region a region. The logical basis for developing regional reference sites lies in the ability to group watersheds and common stream types into regions by integrating available maps of terrestrial variables that influence streams. Relatively undisturbed reference sites can be selected from typical areas of the regions and from transition zones where one or two of the terrestrial variables are not the predominant one(s) of the region. These reference sites are useful for estimating attainable conditions, for evaluating temporal and spatial changes in ecological integrity, for classifying attainable uses of streams, and for setting biological and environmental criteria.

The Federal Water Pollution Control Act (PL 92-500), as amended by the Clean Water Act (PL 95-217), provides the congressional mandate for the US Environmental Protection Agency (USEPA) to improve the condition of streams in the United States. The objective of both acts "is to restore and maintain the chemical, physical, and biological integrity of the Nation's waters." The regulations that the USEPA recently promulgated to enforce the acts are based on the concept of attainable uses (Federal Register 1982). Both the acts and the regulations depend on some model of attainable conditions, that is, on some measurable objectives towards which cleanup efforts are striving.

There are at least seven approaches for estimating attainable conditions of streams. In one approach, forest streams are suggested as general models (Vannote and others 1980), but such waters generally represent the mountainous or hilly regions where those forested areas exist. These forested streams certainly cannot model streams draining intensively farmed plains that naturally had entirely different vegetation, morphology, and chemistry. A second approach is to use the historical data obtained from streams before their watersheds were densely settled by humans (see, for example, Trautman 1981). Historical data of this type are lacking for most of the country but where they do exist they provide an incomplete characterization of species and their relative abundances. A third approach estimates attainable conditions in streams by examining sites upstream of a point source and downstream of the source's recovery zone (see, for example, Karr and others 1985). These types of control sites are of questionable value where diffuse pollution is a problem, where channel modifications are extensive, where point sources occur all along the stream, or where the stream morphology or flow differs appreciably among the control and impacted sites.

Hall and others (1978) review additional approaches for assessing impacts of watershed practices on streams. Thus, a fourth approach for estimating attainable conditions is the long-term, before–after study. Such an approach has limited extrapolability to different sites and requires a long-term research commitment before and after the modification. A broader perspective can be gained through a fifth approach, extensive before–after studies. This approach, examining several sites and lasting only two to three years, is vulnerable to extreme weather events coinciding with the treatment. The sixth approach, an intensive post-treatment assessment, requires a shorter time commit-

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ment than the long-term, before-after study, but has limited extrapolability and requires an assumption that the few experimental sites were once essentially identical to the control sites. The extensive posttreatment approach involves a single year of study on a large number of control and variously modified or recovered sites. This seventh approach offers the broadest spatial and temporal perspective and requires the shortest time commitment of the latter four but demands an assumption that control and experimental sites were largely the same before treatment. In all seven approaches, control sites usually are chosen subjectively, and readers must simply accept the choices as good. We believe a more objective procedure is needed.

Ideally, control sites for estimating attainable conditions should be as little disturbed as possible yet representative of the streams for which they are to be controls. Such sites may serve as reference sites for a large number of streams if the sites typify the ranges in stream morphology, substrate, and flow that are found in a region. The purpose of this article is to describe a more objective method for selecting this type of regional reference site.

All streams differ to some degree from each other, but the basis for regional reference sites is the considerable similarity among streams within definable geographic regions. Usually there is less variability among streams within one region than among streams in several combined regions. This is because streams acquire their characteristics from their watersheds (Likens and Bormann 1974, Hynes 1975), and streams draining the comparable watersheds of a region are more likely to be similar to each other than are streams draining less comparable watersheds of several different regions.

What then is a region? Hart (1982) provides an excellent discussion of this question. Among geographers, there is no standard definition of a region and no standard rule for the delineation, description, recognition, or size of regions. Regions are simply attempts to synthesize or integrate key geographic variables to reveal areas that are homogeneous in as many of those variables as is possible. In other words, a region is a relatively homogeneous area that differs from other areas and where the boundaries of several key geographic variables more or less coincide; yet all regions incorporate heterogeneous elements. Rowe and Sheard (1981) emphasize that the most useful regions are logically sound and explicitly stated expressions of ecological theory, rather than mechanical, multivariate expressions of pattern. Most geographic variables of a region are believed to be interrelated to varying degrees, and regions are used to associate phenomena that often appear disassociated. Regions are most obvious to persons with field experience in various parts of the world because the distinctiveness of one region becomes clearest when compared with others.

The delineation of regions is best done by examining patterns in the homogeneity of several terrestrial variables. This is because several watershed variables, not just one or two, are presumed to have major influences on aquatic ecosystems (Figure 1). Warren (1979) discusses the value of integrating several environmental variables to determine regions and proposes using climate, topography, substrate, biota, and culture to classify watersheds and streams. Shirazi (1984) and Jarman (1984) integrate terrestrial variables similar to those suggested by Warren to map land types of the southeastern United States and ecoregions of Oklahoma, respectively. Shirazi used his map to help select abandoned hazardous waste sites for study and Jarman proposes to use his to help refine water quality criteria.

Other stream classifications focus on specific stream variables or the streams themselves. Van Deusen (1954) and Pflieger and others (1981) base their stream classifications on fish data. Illies and Botosaneanu (1963) and Pennak (1971), respectively, propose the use of six and 13 environmental and biological criteria. The data collection necessary to classify a state's or nation's waters with such approaches is a massive and unlikely undertaking. Recognizing these limits, Vannote and others (1980) suggest stream order, Brussock and others (1985) propose channel form, and Richards (1982) describes several channel patterns to classify streams. These are useful but entirely physical classifications incorporating no chemical or biological variables in their formation.

Omernik (1985) maps aquatic ecoregions of the conterminous United States from maps of land-surface form, soil, potential natural vegetation, and land use. He analyzed these maps to distinguish their combined regional homogeneity from the heterogeneity of each geographic variable. Ecoregion boundaries were delineated by integrating the component maps and analyzing their relative accuracies. Omernik's map seems most appropriate for classifying aquatic ecoregions because of the integrative ecological, versus technological and reductionist, way it was developed (Miller 1985, Petak 1980); its level of resolution (76 aquatic ecoregions in the conterminous United States); its incorporation of mapped physical, chemical, and biological information; and because it requires no additional data collection.

Ecoregions provide a geographical basis for esti-

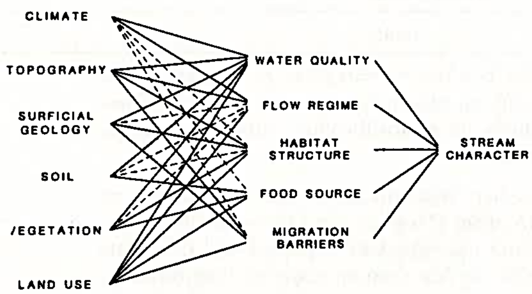

Figure 1. The influence of watershed characteristics on streams and ecological integrity. *Solid* and *dotted lines* represent greater and lesser influences, respectively. Modified from Karr and Dudley.

mating ecosystem productivity and likely responses to management action, assuming that most sites in an ecoregion will respond in a similar manner to those actions (Bailey 1983). Regional reference sites, within a setting of stream regions, offer managers and scientists examples of attainable stream conditions. The biota and physical and chemical habitats characteristic of these regional reference sites serve as benchmarks for highly disturbed streams in the same region. Such sites can be used to develop expectations about streams that are as protective of the environment as is socioeconomically and ecologically feasible. Regional reference sites provide an alternative means to help develop biological use classifications and the water quality to protect those uses. Regional reference sites make excellent locations to establish monitoring stations and they offer a different means to evaluate the impacts of pollution and pollution control.

Delineating Regions and Selecting Reference Sites

Our process of selecting reference sites is outlined in three phases. First, the boundaries of aquatic ecoregions and their typical areas are transferred to higher resolution maps, then various candidate watersheds and sites are evaluated for typicalness and level of disturbance. Finally, a number of relatively undisturbed reference sites are selected from the candidate sites. The necessary number and location of reference sites will vary with the size and variability of the region and the requirements and resources of the water resource managers.

Determining Regions and Their Typical Areas

The process of determining regions and typical areas is described in Omernik (1985). The boundaries of the aquatic ecoregions and their typical areas are transferred from the national map to 1:500,000 scale state maps and 1:250,000 scale topographic maps through the use of similarities in mapped natural and cultural features.

Where streams of interest occur in anomalous or transitional areas, where streams cross regional boundaries, or where the manager is interested in only a few sites or a single stream, the reference sites can be based on the watersheds of interest. Watersheds having the same land-surface form, soil, potential natural vegetation, and land use as the streams of interest can be determined from maps. The rest of the process is the same as outlined below. This approach was used by Hughes (1985) to examine the effects of mining wastes on trout streams and by Giattina (1985) to classify reaches of a single river that flowed from steep forested mountains through a flat agricultural plain.

Determining Candidate Watersheds and Reference Sites

After transferring regional boundaries to the higher resolution 1:500,000 and 1:250,000 scale maps, relatively undisturbed candidate watersheds and reference sites can be selected in typical and transitional areas in the regions. The process involves six steps (Table 1). Locations of candidate sites should also be discussed with knowledgeable resource managers and scientists to learn of other candidate sites, unmapped disturbances, and available data. Often district managers have considerable knowledge of sites that is otherwise unavailable.

The watersheds of most reference sites should fall almost entirely within the typical areas of a region, if those sites are to have the broadest possible applicability to that region. Some reference watersheds should be selected in transitional areas to encompass the variability among streams within a region. This is especially important in regions that incorporate watershed extremes, such as flat agricultural valleys among steep, forested mountains. The size of the typical and transitional areas will determine the maximum size of such watersheds. The smallest watersheds should include the smallest intermittent or permanent streams that support spawning or rearing of valued aquatic populations.

Selecting Reference Sites to Be Sampled

All the preceding work can be done in an office. It is then useful to view and photograph a select number of candidate sites from a small high-wing airplane flying 700–1500 m above the ground. The candidate sites should be examined over several access points to locate local and unmapped disturbances of the channel and riparian areas. The more disturbed sites

Table 1. Steps in determining candidate watersheds and reference sites.

Step	Note
1) Determine human disturbances.	Eliminate watersheds with concentrations of humans, point sources of pollution, channelization, or atypical diffuse sources of pollution (e.g., acidification, mine wastes, overgrazing, clearcuts).
2) Quantify stream size.	We suggest watershed area and mean annual discharge instead of stream order (Hughes and Omernik 1983). Watershed areas and discharges of impacted and candidate sites should differ by less than an order of magnitude.
3) Characterize stream channels.	Locate influent streams, springs, and lakes; determine drainage pattern, stream gradient, and distance from major receiving water. Retain the stream types that are most typical of the region.
4) Locate refuges.	Unless they result from local natural features that are atypical of the region, consider parks, monuments, wildlife refuges, natural areas, state and federal forests and grasslands, woodlots, and wilderness areas. For example, a gravel-bottomed stream draining a forested glacial moraine would not provide a typical reference site for the small sand-bottomed streams of the central Illinois Corn Belt.
5) Determine migration barriers, historical connections among streams, and known zoogeographic patterns.	Such information helps to form reasonable expectations of species presence and richness.
6) Suggest candidate reference sites.	Reject degraded or atypical watersheds and rank candidates by level of disturbance.

should be rejected, although the candidate sites might be moved upstream. Aerial viewing is most helpful in rapidly determining the typical appearance of candidate watersheds and sites and in characterizing relatively undisturbed conditions over broad areas.

Finally, the remaining candidate sites are assessed on the ground and ranked for disturbance. Three to four candidate sites in each stream reach are examined for typical channel and riparian characteristics and ease of access. Sites having anomalous conditions should not be used as regional reference sites. For example, sites with riffle–pool morphology and swift current would not be typical of coastal plain or swamp streams.

Several qualitative indicators of minimal disturbance exist. One indicator is extensive, old, riparian forest. Another is relatively high heterogeneity in channel width and depth (shallow riffles, deep pools, runs, secondary channels, flooded backwaters, sand or gravel bars, and islands). Abundant large woody debris (snags, root wads, log jams, brush piles), coarse bottom substrate (gravel, cobble, boulders), overhanging vegetation, undercut banks, or aquatic vascular macrophytes often characterize relatively undisturbed sites in some regions and offer concealment for fish and substrate for macroinvertebrates. Relatively high or constant discharges; relatively clear, colorless, and odorless waters; abundant diatom, insect, and fish assemblages; and the presence of piscivorous birds often suggest suitable water quality. A stream site evaluation form (Table 2) is useful for recording observations during the ground reconnaissance and for selecting final reference sites.

Discussion

The regional reference sites provide water resource managers with a series of relatively undisturbed sites that are typical of a large area. These sites may be useful for several purposes.

Managers are generally aware of the most disturbed streams in a region, but the range of attainable conditions is less apparent. A series of relatively undisturbed regional reference sites can provide examples of the attainable community structure, dominant and intolerant species, species richness, and habitat conditions and the spatial variations of those variables in each region. The ranges of these variables at these rel-

Table 2. Stream site reconnaissance form.

Date: Observer:
Stream Name: Region Code:
State: County: Ownership:
Map: Lat: Long: Alt:
Access:

Reach location:

Photographs: Roll: Frames:
Stream Stage: Width: Depth: Slope:
Riparian Veg: General:
Circle Dominant: tree, shrub, herb, absent
Overhang: Veg. Stability:
Channel Morphology: General:

Circle Dominant: pocket water, riffle, chute, run, glide, pool
Bank Angle: Bank Rock Content:
Substrate: General:
Circle Dominant: debris, mud/muck/silt, sand, gravel, cobble, boulder, bedrock/claypan
Embeddedness (%):
Concealment (%):
Water Quality: General:
Circle: clear, clouded, colored, turbid, odor, odorless
Biota: General:
Circle if abundant: algae, macrophytes, macroinvertebrates, vertebrates
Disturbance:

Comments:

atively undisturbed sites represent the attainable ecological conditions and uses of disturbed stream sites in that region if those disturbed streams and watersheds were to be restored. Relatively undisturbed sites can be found even among the channelized streams of the Corn Belt (Marsh and Luey 1982). The Ohio Environmental Protection Agency is using regional reference sites in this way to modify expectations of attainable biota and habitat conditions in northwestern Ohio (D. Dudley, Ohio EPA, Columbus, Ohio, personal communication).

The USEPA and state water quality management agencies use water quality standards to regulate discharges. The standards consist of designated desirable uses, typically "aquatic life," and water quality criteria to protect those uses. However, an "aquatic life" use designation is so vague that it can be met by generally sensitive and desirable species like cutthroat trout, *Salmo clarki*, or generally tolerant and undesirable species like common carp, *Cyprinus carpio*. Also the water quality criteria, for example, dissolved oxygen or ammonia, needed to protect such different species are considerably different. Without more explicit use designations, desirable uses will continue to be overprotected at great cost to taxpayers or underprotected with great damage to the resource.

Regional reference sites can be used to refine biological use classifications and ecological standards by providing empirical, regional examples of existing biota and habitat conditions. The differences in stream ecosystems among different regions and the similarities among stream ecosystems within a region provide a rational, ecological basis for quantifiable classifications of biological uses. Ecologically determined use classifications could help eliminate such general subjective classifications as "aquatic life" or "warmwater fish." Use classifications determined from regional reference sites might need further refinement, but they should be preferable to the present use classifications of many states. The same classification methods can be used at increasingly higher levels of resolution as more data become available.

Refined use classifications should lead to refined criteria to protect the uses. Currently, state and federal regulations only incorporate water quality criteria, ignoring the equally important biological and physical requirements of species (Figure 1, Karr and Dudley 1981). The chemical and physical conditions that support desirable biological uses in regional reference sites provide a logical basis for establishing environmental criteria for the entire region. Such conditions offer a clear alternative to nationwide water quality criteria. The Arkansas Department of Pollution Control and Ecology proposes to use regional reference sites in this way to raise dissolved oxygen criteria in some regions of the state and to lower them in others, rather than accepting a 5 mg/liter national criterion or determining an infinite number of site specific criteria (J. Giese, Arkansas Department of Pollution Control and Ecology, Little Rock, Arkansas, personal communication).

Typical, relatively undisturbed regional reference sites can be used to locate sites for monitoring stream quality or ecological integrity. Most water quality monitoring sites presently represent conditions in their immediate areas only and therefore hinder extrapolation. By sampling a small number of regional reference sites, managers and scientists could more logically extrapolate conditions throughout an entire region and monitor changes. The USEPA-Region VI and the Texas Department of Water Resources are selecting such sites from among their existing and previous monitoring stations to examine regional patterns in water quality (M. Bastian, USEPA, Dallas, personal communication).

There are, however, limitations to this regional approach. To date this approach has been tested on streams having watershed areas less than 1600 km^2. Larger rivers can be examined in the same manner, but the analysis must be at a lower resolution, and greater allowances for variability in the level of disturbance and degree of typicalness might be necessary. This is because large rivers encompass more variability, they are more likely to receive major point sources, and they are rarer to begin with.

It is more difficult to find reference sites for anomalous stream ecosystems. For example, if a high-gradient stream drains a forested watershed in Iowa, where such a system is rare, it might be necessary to seek reference sites in neighboring states. Where a stream passes through extremely dissimilar regions, reference streams should do likewise. For example, the Upper Yampa River of northwestern Colorado passes through spruce-forested mountains and the lower river passes through sagebrush tablelands. The lower river should not be compared with a river that flows through sagebrush tablelands only, because the latter is likely to have lower discharges and lower water quality than one draining the more humid mountains.

Relatively undisturbed regional reference sites do not represent pristine systems; that would require a return to presettlement conditions. Such sites do represent baseline conditions or the least altered systems that exist given the prevalent land-use patterns in the watersheds of most regions. Economic and political inertia and pressures prevent rapid or extreme change of present land-use patterns in the foreseeable future, for example, from cornfields to tall grass prairie or from rangeland to forest, although ample opportunities exist for changes in riparian land use.

A few watersheds and sites may be irreversibly and drastically degraded by dams, urbanization, mining, or erosion. Regional reference sites may not realistically represent the attainable conditions of such highly disturbed systems because of the resources required to improve them. Those resources may be more wisely invested elsewhere where the cost effectiveness ratio is more favorable.

Only certain species can be expected to reveal regional patterns at the level of resolution described here. Patterns in the distribution and abundance of rare or ubiquitous species are unlikely to correspond to regions and regional reference sites. Rare specialists (Matthews 1985) or satellite species (Hanski 1982), such as the snail darter (*Percina tanasi*), are so rarely encountered that they usually are not collected. Common generalists or core species, such as the bluntnose minnow (*Pimephales notatus*), are so abundant in such a wide variety of habitats that they are a dominant species in numerous regions. Neither type is likely to be useful for demonstrating regional patterns.

Finally, managers should not presume greater homogeneity within regions than actually exists. Regional reference sites provide attainable benchmarks within a broad spatial framework, but managers will continue to need sound biological judgments and competent stream surveillance from their scientists. Both professional personnel and citizens must be sensitive to the range and type of variations and to unsuspected anomalies within regions. For example, Larsen and others (1986) found that the number of intolerant fish species at 18 relatively undisturbed sites of the Eastern Corn Belt Plains ecoregion of Ohio varied from one to 15, with half the sites having 6–10. This variability resulted from the varying level of disturbance and from whether the sites were located in terminal or ground moraines.

Regardless of the limitations, regions and regional reference sites offer a rational, relatively objective means to compare similarities, differences, and attainable conditions in stream ecosystems over large areas. This should be preferable to the present best biological judgment or site-specific approaches.

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