Fresh Waters

Extent of Freshwater Ecosystems

The Data

Wetlands, Lakes, Reservoirs, and Ponds

Data Source: Data for wetlands are from Dahl (2000). Data used here are from Figure 35 (p. 56) and Figure 42 A–C (p. 62). Data for lakes, reservoirs, and ponds come from Dahl (2000) and also from Frayer et al. (1983); Dahl and Johnson (1991); and unpublished data from the U.S. Fish and Wildlife Service.

Data Collection Methodology/Definitions: The data shown here are derived from the U.S. Fish and Wildlife Service's National Wetlands Inventory (NWI), which produces periodic reports of changes in wetland area. For this report, decadal estimates are presented as the midpoint of the decade. For example, "1980s" data are presented as "1985." The historic estimate for 1780 is based on the estimate of 221 million acres of coastal and freshwater wetlands at that time (see Dahl 1990) minus an estimate of 10 million acres of coastal wetlands in 1922, which should approximate the historical area of coastal wetlands because most of these were converted to other land cover types after World War II (see Gosselink and Baumann 1980). Estimates of wetland extent in the 1780s are based on colonial or state historical records plus land use records, drainage statistics, and information on the extent of hydric soils (i.e., drained and undrained).

NWI counts all wetlands, lakes, reservoirs, and ponds, regardless of land ownership, but recognizes only wetlands that are at least 3 acres, and ponds that are at least 1 acre. A permanent study design is used, based initially on stratification of the 48 conterminous states by state boundaries and 35 physiographic subdivisions. Within these subdivisions are 4375 randomly selected 4-mi^2 (2,560-acre) sample plots. These plots were examined with the use of aerial imagery of varying scale and type; most images were 1:40,000-scale, color infrared, from the National Aerial Photography Program.

The wetland types selected for reporting here were recommended as the most relevant and most reliable for long-term reporting by the NWI (see Dahl 2000, p. 62). For wetlands, they include forested, shrub, and emergent wetlands. Ponds include the category of open-water ponds and non-vegetated palustrine wetlands (i.e., palustrine unconsolidated shore, which are mud flats and the shorelines of ponds); ponds are generally less than 6 feet (2 m) deep and less than 20 acres in size. Lakes and reservoirs are generally larger than 20 acres and deeper than 6 feet, although smaller bodies are included if they are deeper than 6 feet or have a wave-formed or bedrock shoreline.

Data Quality/Caveats: Field verification was conducted to address questions of image interpretation, land use coding, and attribution of wetland gains or losses, and plot delineations were completed. For example, for the 1980s-to-1990s analysis, 21% of the sample plots were verified.

Ephemeral wetlands and effectively drained palustrine wetlands observed in farm production are not recognized as a wetland type and are not included. Wetlands that are farmed during dry years but that normally support hydrophytic vegetation were classified as freshwater emergent wetlands.

The U.S. Geological Survey's (USGS) National Hydrography Dataset (NHD) also has information on lake, reservoir, and pond area (at least 6 acres in size). Considerably higher total acreage (26.8 million acres) is found using this resource. NWI was used because time trends are possible; the cause of the disparity between datasets is not known.

Data Access: *The Status and Trend of Wetlands in the Conterminous United States 1986 to 1997* is available on the Web at http://wetlands.fws.gov/bha/SandT/SandTReport.html.

Riparian Areas

Note: This indicator uses a distance of roughly 100 feet from the edge of a stream to define its "riparian" area. This is based on the availability of remote-sensing data, as described below. We are cognizant that the definition of riparian areas is a complex one, and that no single value for the width of this feature will be appropriate in all situations.

Data Source: Data reported here for the classification of riparian areas along streams and rivers were provided by the U.S. Environmental Protection Agency's National Exposure Research Laboratory, Environmental Sciences Division, and are based on the NHD. The NHD is a comprehensive set of digital spatial data that encodes information about naturally occurring and constructed bodies of water (see http://nhd.usgs.gov/). The NHD was developed based on EPA's River Reach File 3 (RF3), which itself was based on digitization of streams from USGS topographic quadrangle maps. The dataset does not provide information on very small streams, and the lower limit of stream size that is reported in the database is unclear. Data on the vegetation cover within 100 feet of streams and rivers were produced by EPA from remote-sensing imagery and the NHD. The remote-sensing imagery is from the National Land Cover Dataset (NLCD; see the technical note for the national extent indicator for further details, p. 207).

Data Manipulation: For this study, EPA combined these datasets to identify the land cover along streams and rivers (and the shores of ponds, lakes, and reservoirs—see the altered freshwater ecosystems indicator). For each stream reach described in the NHD, land cover was characterized, using the NLCD, in a band approximately 100 feet wide on either side of the stream. NLCD land cover classes were aggregated to produce four general categories (forested; agricultural; urban; and grasslands, shrublands, and woody and emergent wetlands). In one instance, the text describes this latter category as "other natural vegetation," despite the fact that some of these land cover types may not be the historical (i.e., natural) vegetation for that site, or may have been altered in other ways. This terminology is used to highlight the contrast with the highly altered land covers (urban, agricultural). Estimates of the riparian area in each of these different land cover classifications were derived by overlaying stream reaches and land cover.

Data Caveats/Limitations: The NLCD and the NHD are currently the most comprehensive datasets available for land cover and freshwater resources, respectively. However, both of these contain inaccuracies that could affect the calculations presented here. The NLCD is known to contain approximately 20% error in land cover classification; some of the known misclassifications that occur randomly in the dataset include suburban areas or tree farms classified as forest; grasslands classified as agriculture, or vice versa; and fallow agricultural fields classified as barren lands. The NHD is a relatively new dataset and is known to contain numerous errors and inconsistencies. Strahler first- and second-order streams (a method for ranking stream order, which is related to size) are poorly represented in the NHD as well as in the RF3 that serve as the base data. It appears that dry lake beds in the west may have occasionally been included as lakes in the NHD. Additionally, the architecture of the NHD results in some lakes being represented by numerous polygons with different identifications, thus being counted as separate lakes in this analysis. Numerous inconsistencies exist in the NHD attribute data. The designation of stream segments as perennial or intermittent is particularly problematic; in at least one case, this designation can be shown to follow USGS topographic quadrangle boundaries. In addition, many errors can be found in the attribution of ponds, lakes, and reservoirs. Although these inconsistencies were noted, it was not possible given the scope and scale of this analysis to provide across-the-board corrections, nor was it possible to coregister the datasets for all locations. Therefore, the most current versions of both datasets were used as is.

The Data Gap

Information on the number of small, medium, and large streams and rivers is not available. In general, the number of stream miles can be derived from sources such as the NHD; however, there is no universally accepted approach for categorizing streams and rivers based on size (i.e., small, medium, and large). Potential approaches include basing categories on flow rate, drainage area size, or stream order. USGS will soon incorporate a tool within the NHD dataset to allow determination of stream order, which can be determined from maps. Flow rate is a much more difficult parameter to determine.

In addition, there is concern that use of the NHD may understate the extent of small streams. Since the NHD is based upon historic mapping conducted for the USGS, there may be inconsistencies in the degree to which small streams were mapped. Since the rate of conversion and alteration of small streams is believed to be higher than for larger streams, it is important to ensure as great a coverage of small streams as is feasible.

For a discussion of the effects of human activities on small streams, see Meyer and Wallace (2001).

References

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Altered Freshwater Ecosystems

The Indicator

This indicator would report the percentage of each of the major freshwater ecosystems (rivers and streams, riparian areas, wetlands, and lakes, ponds, and reservoirs) that are altered. "Altered" is defined differently for each of the following:

- ***Rivers and streams*** (all flowing surface waters) are altered if they are leveed, channelized, or impounded behind a dam. There are other types of alterations to streams that may be important; these include changes in sedimentation and temperature, and barriers to movement between stream reaches. Such changes can be caused by dams or other alterations to the river or its surroundings. As monitoring and reporting technology and understanding evolve, it may be possible to report on these and other alterations. At present, identifying such changes requires detailed site-specific analyses, which have not been done on a widespread basis (see also The Heinz Center 2002). Both the stream habitat quality and changing stream flows indicators provide important complementary information on stream conditions.
- ***Riparian areas*** along rivers and streams are considered altered if they have a predominance of urban or agricultural land use.
- ***Lakes and ponds*** are considered altered if the area immediately adjacent to the shoreline has land cover that is predominantly urban or agricultural. Since there is no agreed-upon proportion of shoreline that must be in these land use categories in order for individual lakes to be classified as "altered," this indicator reports the overall percentage of lake shoreline in agricultural or urban use. This indicator focuses on "natural" waterbodies, that is, those that are not created by impoundment behind a dam. While reservoirs provide habitat, the prevalence of large and frequent fluctuations and associated poor development of the riparian/littoral zone reduces this value. In this case, the number or percentage of natural lakes whose waterflow has been altered by damming would also be reported. Some

impounded lakes are not subject to such fluctuations, but until it is possible to distinguish between different impoundment types, this indicator will be limited to natural waterbodies.

- *Wetlands* are considered altered if they are excavated, impounded, diked, partially drained, or farmed. These categories are used by the U.S. Fish and Wildlife Service's National Wetlands Inventory; they are defined in Cowardin et al. (1979). Wetlands fragmentation (subdivision into smaller and more isolated patches by filling, roads, or other alterations) is also important, but measurement of this change requires detailed site-specific information.

The Data

The methods used to produce the data reported here for altered riparian areas are described in the technical note for the Extent of Freshwater Ecosystems, which immediately precedes this one. The extent indicator describes methods used to characterize riparian areas; the same method could be used to classify the shorelines of ponds and lakes, but the relevant database does not distinguish between natural and impounded lakes/reservoirs.

The Data Gap

There is no nationally aggregated database of the number of impounded river miles or the number of leveed river miles. There is also no method for calculating the extent of downstream effects of dams, other than by conducting site-specific investigations for each dam.

No nationally aggregated database distinguishes impounded waterbodies from natural ones, or identifies which natural lakes are dammed at their outlets. It is possible that existing databases on dam locations, such as those maintained by the U.S. Army Corps of Engineers, could be merged with other datasets, such as the National Hydrography Dataset, to derive this information.

Data on altered wetlands are available through the U.S. Fish and Wildlife Service's National Wetlands Inventory (see http://www.nwi.fws.gov/). At present, these data are not available in electronic form for the entire United States. Further, these data are available only on a quad-sheet-by-quad-sheet basis. The Fish and Wildlife Service is in the process of integrating these data more fully, and it is likely that they will be available in the near future. However, they will be from different time periods in different states, and there is no plan for periodic updating. In addition, there are no plans to produce regional or national reports comparing any updates with past data.

References

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Phosphorus in Lakes, Reservoirs, and Large Rivers

The Indicator

A variety of nutrients are needed for plant growth in aquatic systems: nitrogen, phosphorus, carbon, sulfur, iron, manganese, and various trace metals (e.g., copper, cobalt, molybdenum, and zinc). Silica is required by some kinds of algae (e.g., diatoms) because it is the main component of the shells that surround the cells. However, nitrogen (N) and phosphorus (P) are by far the most common nutrient elements that limit or control the amount and rate of plant growth in aquatic systems and, thus, define their trophic status and corresponding "water quality." Of these two elements, phosphorus is widely considered to be the element that most commonly limits aquatic plant growth in fresh waters under natural conditions (i.e., minimal impacts from human activity). Total phosphorus (TP) includes all forms of phosphorus present in a water sample—dissolved and particulate, inorganic and organic; adsorbed onto suspended clays and hydrous oxides; present in planktonic organisms and in organic detritus; and phosphorus in dissolved natural organic matter. Phosphorus in macrophytes, fish, and bottom sediments generally is not included.

TP was selected for reporting because it is a comprehensive measure of the many operationally defined and chemical forms of phosphorus, most of which are directly or indirectly available for plant growth. Excess phosphorus can contribute to algal blooms, poor water clarity, and other symptoms of eutrophication.

TP levels are a measure of trophic state (Carlson 1977) and general water quality in lakes, reservoirs, and large rivers. (Large rivers typically behave as lakes; water residence times in stretches of large rivers are sufficiently long that substantial phytoplankton growth can occur in them.) The concentrations of TP that contribute to symptoms of eutrophication are poorly understood for flowing waters, but generally they are thought to be higher than the critical levels in lakes. Consequently, TP is reported separately for lakes and rivers. (The effects of phosphorus enrichment are different for lakes and rivers in tropical areas than they are for temperate zones; this discussion relates to temperate zones only.)

TP measurements are straightforward; TP in lakes should be reported as an average over the growing season (e.g., April to September), which will require several (e.g., 4–6) samples over the course of the period. Consideration was given to the appropriate number of samples each year (e.g., Knowlton et al. 1984), and complications of sampling in areas with minimal seasonal influence, such as Florida (Brown et al. 1988).

TP measurements in rivers are restricted to those large rivers with flows exceeding 1000 cubic feet per second (cfs). To ensure proper characterization of average values for each river, only sites that had at least 30 samples over the course of 2 years were included.

Information on the 1986 phosphorus recommended goal for preventing excess algae growth can be found in EPA 440/5-86-001 (see references). Information on regional nutrient (phosphorus) criteria can be found at http://www.epa.gov/waterscience/criteria/nutrient/ecoregions.

The Data

Data for river phosphorus are from sites operated by the U.S. Geological Survey (USGS) National Water Quality Assessment (NAWQA) and National Stream Water Quality Accounting Network (NASQAN). Data were available from 140 sites, with data collection from 1992 to 1998; 116 of these sites were either NAWQA or NAWQA and NASQAN joint sites.

NAWQA is described generally in the technical notes for the core national indicator for contaminants (p. 210) and for nitrate in farmland streams (p. 232). While that note describes data collection from streams with relatively homogenous land cover (and often relatively low discharge volumes), the data used in this indicator are from larger rivers, with both larger discharge volumes and watersheds with generally more diverse land uses. Thus, these samples represent the integrating influences of many different land uses. The methods for processing and summarizing these data for large rivers, such as computing annual-weighted discharge concentrations, also have been described in the technical note for the Farmlands nitrate indicator.

NASQAN is a USGS program that is focused on four major river basins: the Mississippi, the Rio Grande, the Colorado, and the Columbia River. NASQAN stations are located on major tributaries in the four river basins, along the mainstem of rivers where there is a large increase in flow, and upstream and downstream from large reservoirs. The program generally measures both stream flow and a broad range of chemical constituents. An extensive quality-assurance/quality-control program enables constituents present in very low concentrations (micrograms per liter, roughly parts per billion) to be measured with definable accuracy and precision. See http://water.usgs.gov/nasqan/progdocs/index.html.

Because there was concern over the use of STORET data for this indicator (see below) with respect to the possibility that sampling locations might be strongly influenced by virtue of being located near outfalls from wastewater treatment plants, this question was also raised with respect to the NAWQA/NASQAN data. These programs collect data using procedures that ensure that the sample is representative of the entire stream cross-section. So, even if the stream at the point of collection were not well mixed, the samples would still be representative of the entire stream flow. In addition, the measure that is being reported—annual discharge-weighted average concentrations—addresses the potential concern that samples might be overly representative of summer low flows when wastewater effluent can comprise a large fraction of the flow in some rivers.

The Data Gap

In assessing the availability of data for reporting on phosphorus in lakes and rivers, we reviewed two major datasets in addition to the one reported here (NAWQA/NASQAN). These were STORET, maintained as a data repository by the Environmental Protection Agency (http://www.epa.gov/storet/), and within STORET, data from the National Water Information System (NWIS), a USGS-maintained data system (http://water.usgs.gov/nwis/).

Under contract to The Heinz Center, Procter & Gamble's Miami Valley Laboratory undertook an assessment of the quality and spatial and temporal variability of the data from these two sources. They concluded that phosphorus data were likely to be comparable in terms of reporting thresholds; that is, there were few if any problems related to the use of different reporting thresholds in different states or jurisdictions.

The second step was to determine whether either data system had sufficient numbers and geographic distribution of sampling sites. It was apparent from inspection of a map of lake phosphorus sampling sites that neither NWIS nor STORET as a whole has sufficient coverage across the country. STORET has phosphorus concentration data from a large number of river sampling sites, and this record extends into the 1980s.

However, there was significant concern among workgroup members regarding the fact that STORET data are derived from studies undertaken for many reasons and using many methods for selecting sampling sites. For example, some sampling was undertaken specifically as part of before-and-after effectiveness studies relating to phosphorus removal in publicly owned sewage treatment works (POTWs). Other studies may have been undertaken to determine the nature and extent of known phosphorus contamination problems, while others may have been located randomly as part of efforts to characterize nutrient concentrations in both "clean" and "dirty" areas.

STORET has very little information that can be used to determine the rationale for sampling-site selection. Thus any determination of the appropriate subset of STORET results to use would have to be based on a complex analysis of the proximity of sampling sites to POTWs, urban areas, and the like, which could be used to determine if the sampling was biased to inclusion or exclusion of such sites. Unfortunately, this analysis has not been done and could not be accomplished within the time and resources of this project. Therefore, given the significant potential for STORET data to be unrepresentative, we have decided that it is inappropriate to rely on it for this indicator until such studies can be completed.

References

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Changing Stream Flows

The Indicator

This analysis is based on changes between flow characteristics of a 20-year period beginning about 1930 and three 10-year periods (1970s, 1980s, and 1990s). All stream gauges used here had a 20-year record for the reference period and a 10-year record for the later comparison period. Some of these 20-year records began in 1930 and ended in 1949, while some began in 1931, 1932, and 1933, and ended correspondingly later. Twenty years was selected as a reasonable period that would allow characterization of hydrologic regimes, and 10 years as the minimum period to use to determine changes.

Data from the earlier period are being used here as a practical baseline for historical comparison, even though many dams and other waterworks had already been constructed by this time, and even though this period was characterized by low rainfall in some parts of the country. This decision means that it is more useful to focus on decade-to-decade changes in the number of streams with major changes in flow, rather than on the number or percentage of streams with such changes, compared to the baseline period.

The indicator assesses changes in magnitude and timing of low-flow events and high flows, extreme events that are ecologically important in riverine ecosystems. Four subindicators were included in the analysis:

- *Average 7-day low flow (% change):* assesses the degree of alteration in low-flow magnitude, a parameter of importance to aquatic life. Minimum flows determine habitat availability for aquatic organisms and can influence condition of riparian vegetation. Regulated streams are often required to maintain a minimum flow for aquatic life.
- *Timing of the 7-day low flow (Julian day):* describes how timing of low-flow conditions may have changed. A substantial change in seasonal timing of low flow can influence many ecological processes.
- *Average 1-day high flow (% change):* assesses the degree of alteration of the average annual peak flow. High flows are significant ecological and geomorphic events for streams and rivers, and a large change in the 1-day high flow is expected to have important ecological consequences.
- *Timing of the 1-day high flow (Julian day):* assesses the change in the timing of maximum annual high flow, an event of substantial ecological relevance. A substantial change in seasonal timing of peak flow can influence many ecological processes.

The Data

Data Source: Data reported here are from the U.S. Geological Survey (USGS) stream gauge network. USGS has placed stream gauges and maintained flow rate records throughout the United States since the end of the 19th century. These records are available on the Internet in the form of daily streamflow values reported as the average volume of water per second over a 24-hour period (http://water.usgs.gov/nwis/discharge).

Table 4. Values for Minimal, Moderate, and Large Change

	Minimal Change	Moderate Change	Large Change
Percent Change	<25%	25-75%	>75%
Time	<30 days	30-60 days	>60 days

Data Collection Methodology: Stream gauging data are collected using standard USGS protocols.

Data Manipulation: Queries of the USGS Web site were used to identify 867 sites that had 20-year continuous records within 4 years of the target dates of 1930–1949 and 10-year continuous records for the decades of the 1970s, 1980s, and 1990s. The data for these 867 sites were then put into a format compatible with the Indicators of Hydrologic Alteration (IHA) software package produced by The Nature Conservancy with Smythe Scientific Software (http://www.freshwaters.org/iha.html), which was used to perform all subsequent analyses. The IHA software package compares the values for each subindicator (see list above) for the early 20-year period and the three later 10-year periods for each gauge. Each gauge is classified according to the degree of change of each of the four subindicators (see Table 4). Data analysis was conducted by David Raff, Department of Civil Engineering, Colorado State University.

Data Quality/Caveats: Although the sites analyzed here are spread widely throughout the United States, gauge placement by the USGS is not a random process. Gauges are generally placed on larger, perennial streams and rivers, and changes seen in these larger systems may differ from those seen in smaller streams and rivers. In addition, the USGS gauge network does not represent the full set of operating streamflow gauges in the United States. The U.S. Army Corps of Engineers, for example, operates gauges, and those data are not available through the USGS; they were not used in this analysis.

Data Access: Stream gauge data are available through the USGS Web site at http://water.usgs.gov/nwis/discharge. Analysis results are available through The Heinz Center.

Water Clarity

Two approaches for measuring water clarity are measurements of Secchi depth and satellite-based estimates. Since 1994, the U.S. Environmental Protection Agency (EPA) has supported an impressive program that aggregates Secchi disk measurements made by volunteers during July across parts of the United States and Canada (The Great North American Secchi Dip-In; see http://dipin.kent.edu). In 2000, lakes in 43 states were sampled, but the coverage varied considerably from state to state—in Minnesota, Michigan, and Maine, large numbers of lakes were tested, while in West Virginia and Wyoming, no lakes were sampled, and in states such as Pennsylvania and the Dakotas, relatively few lakes were sampled. In order to make the data nationally representative, this program should be expanded to include more lakes in more states. Because clarity is greatly affected by algal blooms, measurements of clarity should be carried out at the height of the growing season (mid-July to mid-September) in each ecoregion, which may or may not fit with the July observations of the Dip-In program. In addition, scientists are developing ways to measure water clarity from satellite data, which could greatly improve our understanding of how water clarity varies across the country and over time.

The Indicator

This discussion assumes that water clarity will be measured in lakes and reservoirs by the Secchi-disk method, although a satellite-based method may become the preferred approach. Secchi depth measurements of water clarity (or transparency) will be reported in three ranges: low (<3 ft), medium (3–10 ft), and high (>10 ft). The Secchi disk is a white plate with a diameter of 8 inches with black lines radiating from the center. The disk is lowered into the water until it can no longer be seen. The depth at which this occurs is called the Secchi disk transparency or Secchi depth (SD). It is a simple but effective way to measure water clarity.

Water clarity values for lakes and reservoirs will be reported in two ways: by lake area falling into the low, medium, and high categories, and as averages for freshwater ecoregions. (Ecoregions are areas that are similar in climate, geography, and ecological conditions and are defined in Ricketts et al. 1997.) Measurements should be made annually during an "index" period near the height of the algal growing season, which generally corresponds with the height of the recreational use season. In lakes of the Upper Midwest, for example, the index period is mid-July to mid-September, when Secchi-disk transparency is relatively constant and at annual minimum values. The appropriate length of the index period in other parts of the country needs to be determined, but the mid-July to mid-September period should be suitable for all lakes in temperate climate zones. One measurement during this period should be adequate to define ecoregional growing-season minimum values, although one measurement is not sufficient to define the minimum transparency for an individual lake.

Humic-colored lakes and reservoirs are found in many areas of the country (e.g., in northern forests of Minnesota, Wisconsin, Michigan, New York, and New England and in wetland forests throughout the Southeast, from Virginia to Florida). Clay turbidity is a dominant factor in water clarity in lakes and reservoirs of the central plains and the Piedmont region of the Southeast. Humic color and clay turbidity tend not to have a strong seasonal pattern in lakes, so a mid- to late-summer sampling period designed to capture the peak influence of algal growth on transparency should also be appropriate for these lakes and reservoirs.

Ponds have been excluded from this indicator, mostly because the hydraulic properties of ponds are quite different from those of lakes. Because of their shallow nature (typically less than 2 meters, or 6.5 feet), ponds can readily be completely mixed by strong winds. Such mixing can suspend sediments in the water column, which would decrease clarity. Lakes (and reservoirs) typically have a warm layer of water at the surface (epilimnion) that does not easily mix with deeper, colder waters (hypolimnion). Full wind-driven mixing of lakes typically occurs only during the fall and spring when temperatures are fairly uniform across all depths.

The Data Gap

The Great North American Secchi Dip-In program has been evolving since 1994. Supported by the EPA in cooperation with the North American Lake Management Society, the Dip-In is the largest-scale program for collecting SD data in the United States. The program relies upon volunteers who measure the Secchi depth of lakes in their area over a 2-week period in the beginning of July. Data are collected and maintained at http://dipin.kent.edu. While the data do not cover the whole country, they are substantial. In 2000, lakes in 43 states were sampled, but coverage varies considerably from state to state. Several states (Minnesota and Wisconsin in particular) have extensive volunteer monitoring programs coordinated by state agencies, and some state agencies have extensive collections of historical data.

Using satellite imagery is promising as a way of obtaining essentially complete coverage of lake water clarity. This approach is being tested by a NASA-funded consortium involving the Universities of Minnesota, Wisconsin, and Michigan. The consortium is applying a recently developed protocol using Landsat satellite images from the early 1990s and from 1999 to all lakes over 50 acres in the three-state region (see resac.gis.umn.edu/lakeweb/index.htm and Kloiber et al. 2000).

References

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At-Risk Native Species

See the technical note for the core national at-risk species indicator, (p. 214).

Non-Native Species

The Indicator

This indicator reports the percentage of all hydrologic units (simplified here to represent watersheds; see below) having one of several ranges of established non-native species. Introduced species are those that are not native to the watershed in which they are found. These species may be from outside North America, or they may be from another part of this continent. Established species are those that have established persistent breeding colonies. In general, watersheds with higher numbers of non-native species are subject to higher levels of ecological and economic disruption.

Some non-native species become established at low population levels; other species are "invasive"—that is, they spread aggressively, creating ecological and economic disruption. Ideally, this indicator would track only invasive species, perhaps by reporting on a selected group of problematic or potentially problematic species, as identified by recognized experts. However, it is not now possible to identify potentially problematic species, and thus we have chosen to report on all non-native species. But changes can signal the emergence of an invasive species. Some become invasive quickly; others do so only after long lag times.

It is important to note that hydrologic units, which are represented by hydrologic unit codes (HUCs), can be loosely thought of as watersheds. However, only at the finest resolution is this accurate. Thus, the HUCs shown in the figure may include multiple watersheds in whole or in part, or they may actually represent a single watershed.

The Data

Data Source: Nonindigenous Aquatic Species Database, Biological Resources Division (BRD), U.S. Geological Survey (USGS). Roughly 90% of the data are derived from the published literature. Data are collected for the most part by federal and state biologists, although the public does contribute by reporting sightings.

Data Manipulation: Data for introduced species are maintained in a database whose units are 6-digit HUCs (there are 352 6-digit HUCs across the 50 states). The only necessary manipulation was to compute the indices as described above.

Data Quality/Caveats: Although the BRD database (Web site listed below) is widely known about throughout the professional community, in some cases new discoveries are not reported by state and federal biologists.

Data Access: While these types of data are available on BRD's Nonindigenous Aquatic Species (NAS) Web site (http://nas.er.usgs.gov/), the actual data presented here were prepared for this report by USGS.

The Data Gap

NAS includes information on a host of vertebrates, invertebrates, algae, and plants. At this time, however, the database managers do not feel that these data have matured adequately to be presented at the national level.

Animal Deaths and Deformities

The Indicator

This indicator describes unusual mortality among fish, aquatic mammals (such as otter or beaver), waterfowl (i.e., ducks, geese, and swans), and amphibians, along with the incidence of deformities among amphibians. Unusual mortality generally involves the death of multiple animals in a relatively small area over a relatively short period of time. That is, one dead bird would not be considered an "unusual mortality event," but if one dead bird was found every day for a week, in the same location, it might be. In addition, a single death might be considered for inclusion here if the particular circumstances warranted it—for example, if the bird was part of a flock that was known to have fed at a contaminated site.

This indicator reports mortality events according to the number of individuals killed. When data for different species groups become available, it may be necessary to use categories (such as serious, severe, catastrophic) rather than numbers of individuals. This would facilitate comparison of mortality events affecting different species. For example, an event affecting 100 individuals would be viewed with different levels of seriousness if it affected 100 waterfowl, 100 fish, or 100 mammals such as otters.

The Data

Data Source: Data on waterfowl are collected by the Department of the Interior, U.S. Geological Survey, Biological Resource Division, National Wildlife Health Center (NWHC). They were supplied especially for this report.

Data Collection Methodology: NWHC is a research and diagnostic laboratory, with a primary focus on disease prevention, detection, and control in free-ranging wildlife. NWHC maintains a database of outbreaks of wildlife disease and unusual mortalities, usually affecting multiple animals at the same time. The database covers all 50 states, Puerto Rico, and the U.S. Virgin Islands, and covers wildlife disease and mortality events over the past 25 years. The database contains information on avian, mammalian, and amphibian mortality events. Information in the database is provided by various sources, such as state and federal personnel, diagnostic laboratories, wildlife refuges, and published reports.

Data Quality/Caveats: As noted, the NWHC database covers mammalian and amphibian mortality events, as well as avian events. For freshwater reporting, the avian component was selected as the most complete and most likely to provide representative information at this time. Even for birds, however, the database may not accurately reflect all causes or cases of mortality since NWHC is not informed of every mortality event. Smaller events, in particular, may be handled locally and may not be reported to NWHC. The decision whether or not to include a reported event in the database is made by NWHC specialists. The data reported mortality events primarily affecting anseriformes (ducks, geese, and swans); however, other types of birds that died in an event would have been counted. In addition, the database was not developed as a tool for reporting on national trends; it was intended for use by NWHC as a tool for tracking epidemiological information over time. The information is generally not from specifically defined surveillance and monitoring systems; rather, information is provided as events are discovered or reported.

Data Access: Data are reported quarterly in NWHC online reports. See http://www.nwhc.usgs.gov/pub_metadata/qrt_mortality_report.html. These reports also include information on mammal and amphibian mortality. Data reported here were prepared by NWHC staff specifically for this project.

The Data Gap

Mammal and Amphibian Mortality: As noted, the NWHC collects data on amphibian and mammal mortality. These data are less complete than for waterfowl. Reporting on these groups would be possible if additional resources were available to ensure that reports of amphibian and mammal deaths were reported to NWHC on a regular basis from all regions of the country.

Fish: There is no program in place to collect information about freshwater fish die-offs.

Amphibian Deformities: The North American Reporting Center for Amphibian Malformations (NARCAM; see http://www.npwrc.usgs.gov/narcam/) is a project of the U.S. Geological Survey's Northern Prairie Wildlife Research Center. The NARCAM database receives data from a wide variety of sources. NARCAM is not part of a structured monitoring system, but it cooperates with and receives information from several such monitoring programs, among them NAAMP (North American Amphibian Monitoring Project), Frogwatch USA, ARMI (Amphibian Research and Monitoring Initiative), and A Thousand Friends of Frogs. Wildlife refuge personnel, state fish and game agency staff, university students and researchers, and others who have conducted field surveys of amphibians also submit reports, as do members of the general public, who are able to use NARCAM's Web site to submit their reports directly online. Unless the reporter is thought to have sufficient expertise, the submission is forwarded to a verifier (a professional herpetologist or other expert) who can go to the original site and confirm the report.

As of July 2001, more than 2,000 verified reports, from 47 states and 4 Canadian provinces, had been included in the NARCAM database (see http://www.npwrc.usgs.gov/narcam/reports/reports.htm and http://www.nwhc.usgs.gov/amph-dc.html). However, reports are not evenly distributed among the states: Minnesota, where large numbers of malformed amphibians were first reported, accounts for 21.7% of all reports, Wisconsin for 12.2, and Vermont for 12.0. Another nine states account for 26% of all verified reports. According to NARCAM, it is often difficult to find trained volunteers (and funds) for amphibian surveying programs.

Status of Freshwater Animal Communities: Fish and Bottom-Dwelling Animals

This technical note also supports the urban/suburban indicator Animal Communities in Urban/Suburban Streams.

The Indicator

Biological integrity has been defined as "the capacity of supporting and maintaining a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of the natural habitat of the region" (Karr et al. 1986).

Ecosystems that are "healthy," or show high integrity, are more likely to withstand disturbances imposed by natural and anthropogenic stressors. Biological integrity is a broad term that typically refers to measures of structural elements, such as genetics, individuals, populations, and assemblages (communities).

Quantitative methods for assessing biological integrity (generally called "indices of biotic integrity") have been developed for fish and benthic macroinvertebrates. Benthic macroinvertebrates comprise a heterogeneous assemblage of animal groups that inhabit the sediment or live in or on other bottom substrates in the aquatic environment. Macroinvertebrates are defined as organisms that cannot pass through a No. 30 sieve (0.6-mm, or 0.023-inch openings). The major taxonomic groups of freshwater benthic macroinvertebrates are the insects, annelids (worms), mollusks, flatworms, and crustaceans. They are important members of food webs, and their well-being affects the well-being of higher forms, such as fish.

The Data Gap

Most methods for assessing biotic integrity were developed for streams and wadeable rivers. A seminal step was the development of the Index of Biotic Integrity (IBI) for fish, described briefly at http://www.epa.gov/bioindicators/html/ibi-hist.html.

IBIs for fish and macroinvertebrates are based on reference conditions, which are usually determined by comparison to undisturbed or relatively undisturbed areas believed to be representative of conditions in an ecoregion (an ecoregion is "a relatively large area of land or water that contains a geographically distinct assemblage of natural communities" [Abell 2000]). Most IBIs consist of several metrics that can be organized under three major groupings: species richness and composition, trophic structure, and abundance and condition. Each metric is scored from low (1) to high (5), with low values corresponding to the worst condition and high values representing the reference condition. This approach means that all IBIs must be tailored to the specific species makeup in a specific region. At present, there are no national criteria for assessing biological integrity, but the U.S. Environmental Protection Agency has published guidelines for the development of such criteria, and methods and criteria for several regions and states are under development (see U.S. Environmental Protection Agency 1996 and 1998).

Thirty-two states are developing quantitative tests for fish or bottom-dwelling animals or both: Alabama, Alaska, Arizona, Arkansas, California, Connecticut, Delaware, Georgia, Hawaii, Idaho, Illinois, Indiana, Iowa, Maryland, Massachusetts, Minnesota, Mississippi, Montana, Nebraska, New York, North Carolina, North Dakota, Oklahoma, Oregon, Pennsylvania, South Carolina, Tennessee, Texas, Washington, West Virginia, Wisconsin, and Wyoming. Five states (Florida, Kentucky, Maine, Ohio, and Vermont) already have active quantitative testing programs in place, and 10 states (Colorado, Kansas, Louisiana, Michigan, Missouri, New Hampshire, New Jersey, New Mexico, Rhode Island, Virginia) and the District of Columbia have or are developing some type of fish or benthic community assessment program (generally not a quantitative test, as is proposed here). Only South Dakota, Nevada, and Utah have no active or planned program (http://www.epa.gov/ost/biocriteria/States/streams/streams.html, 06/28/01).

In order to develop a nationally consistent set of observations, there must be consistency in key aspects of the monitoring in different states. For example, some states currently use an "average" condition for the basis of their reference, whereas others use "minimally impaired" (e.g., closer to "natural" or "undisturbed"). The result is that states using the former approach appear to be in good shape (on average), while those that compare their sites to a "minimally impaired" reference show a wide range of IBIs (exceptional to poor). Without a common reference condition, IBI rankings will not be comparable from state to state.

In addition, comparing testing results from different places requires some consistency in scoring methods. For instance, EPA's current Environmental Monitoring and Assessment Program (EMAP; http://www.epa.gov/emap/) uses an IBI scaled to 100, while some state programs use a scale of 1 to 60. Aggregation will require knowledge of the linearity of the scoring method. That is, is an EPA score of 50 the same as a state score of 30? Clearly, rules for classification to establish "ranks" will need to be developed.

Finally, consistency is important with regard to the intensity of sampling. Regions that are more heavily sampled are more likely to reflect the "true" aggregated condition than areas that are not. Criteria for the number of observations per region should be developed to screen out results that do not adequately describe the condition of a body of water.

References

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U.S. Environmental Protection Agency. 1998. Lake and reservoir bioassessment and biocriteria technical guidance document. U.S. Environmental Protection Agency, Office of Water, Washington, DC. EPA-841-B-98-007. http://www.epa.gov/owow/monitoring/tech/lakes.html.

At-Risk Freshwater Plant Communities

The Indicator

For purposes of this report, wetlands are defined using the dominant vegetation (including all rooted aquatic species) and hydrologic properties of the National Wetlands Inventory (NWI; for information about the NWI program, see http://wetlands.fws.gov/; for information on the wetlands classification system, see http://wetlands.fws.gov/Pubs_Reports/Class_Manual/

class_titlepg.htm). Wetland plant communities are defined according to the association concept, which is a plant community type of a specific floristic composition resulting from certain environmental conditions and displaying relatively uniform physiognomy. These communities form part of the U.S. National Vegetation Classification System (NVCS), which was adopted as the federal standard for vegetation information by the Federal Geographic Data Committee in 1997. The classification covers uplands as well as wetlands (see http://www.fgdc.gov/standards/status/sub2_1.html for information about this classification system). The conservation status assessment for each association is called a global rank and is based on the relative rarity and degree of imperilment of the association across its entire geographic range. Tracking wetland plant communities at the association level is a way of measuring wetland diversity and provides a tool to assess conditions affecting specific types of wetlands across the entire country.

Riparian areas are the margins of streams, rivers, or lakes. Riparian areas include a range of plant communities, including both upland vegetation communities (often thriving on the increased moisture available near the stream or river) and wetland plant communities on the floodplain. Because riparian vegetation is a mixture of upland and wetland habitats, classification is difficult. In 1997, the U.S. Fish and Wildlife Service developed a classification scheme for the western United States (http://wetlands.fws.gov/Pubs_Reports/Riparian/Riparian.htm), but this system has only begun to be used for collecting data on riparian habitats in that region of the country. As the Service uses this classification to expand its natural resource mapping to riparian habitats, it should be possible to use the resultant inventory to document the status of riparian habitats and their trends in the future. Meanwhile, NatureServe (a nonprofit organization; see www.natureserve.org) and the Natural Heritage Network, which provides status information on wetlands (see below), are developing an approach for reporting on riparian area condition (see "Data Quality/Caveats" below).

The Data

Data Source: NatureServe and its Natural Heritage member programs develop and maintain information on each association in the NVCS. The regions were defined by The Heinz Center and collaborators, using vegetation-based and climate-based ecological regions, the regional boundaries developed by federal land and resource management agencies, vegetation data from remote sensing, and a common-sense approach to regional differences and similarities.

Data Collection Methodology: NatureServe ecologists gather, review, and integrate available information about vegetation pattern from Natural Heritage program databases, published and unpublished literature, and ecology experts in each state. They then assess conservation status using standardized Heritage ranking criteria (see http://www.natureserve.org/explorer/ranking.htm). Heritage ranks range from 1 to 5, with 1 meaning critically imperiled; 2, imperiled; 3, vulnerable to extirpation or extinction; 4, apparently secure; and 5, demonstrably widespread, abundant, and secure.

Data Manipulation: The global ranks are summarized into "rounded ranks." For example, an actual rank may express substantial uncertainty about whether the community is "critically imperiled" or "imperiled." In all such cases, the rank has been rounded to the more imperiled one.

Data Quality/Caveats: Conservation status ranks are continually reviewed and revised by Natural Heritage program biologists. In addition, as development of the system of classifying plant communities evolves (http://www.fgdc.gov/standards/status/sub2_1.html), more communities will be recognized in geographic areas that are currently "underclassified." Such revisions could affect the proportion of communities considered at-risk.

Some variability exists across the country in how the wetland plant community types were defined and in the amount of survey work done, and the definitions of community types are still under review by ecologists with the NatureServe and Natural Heritage programs.

Data Access: Detailed, periodically updated information on each wetland plant community type, including its status, is available at http://www.natureserve.org/servlet/NatureServe?init=Ecol.

The Data Gap

In the near future NatureServe hopes to augment the associations used in this analysis with an "ecological systems" approach. Ecological systems are biological communities found within a geographic region that share similar ecological processes and gradients (e.g., fire regime, elevation, climate, hydrologic regime), biological dynamics (e.g., succession), and other driving environmental features (e.g., soils, geology). Wetland areas defined by such an approach will bear a more direct relationship to major ecological settings (e.g., riparian types, peatlands, marshes) and thus may be a better basis for this kind of analysis.

This ecological systems approach may help in dealing with the fact that riparian areas are not specifically described in the NVCS and are not assessed by NatureServe. A holistic approach could include the entire moist upland–wet lowland zone as part of the riparian area, facilitating mapping and documentation of these systems across a region.

Stream Habitat Quality

See the technical note for the Farmlands Stream Habitat Quality indicator, p. 237.

Water Withdrawals

The Indicator

Five mutually exclusive categories of water use are reported: "Municipal" supply is water withdrawn by public and private water suppliers and delivered to homes and businesses for drinking, commercial, and industrial uses. "Rural" water use is self-supplied water for domestic use and for livestock. Water used for "irrigation" includes application to crops, pastures, and recreational lands such as parks and golf courses. "Thermoelectric" is water used for cooling in the generation of electric power. "Industrial" water use includes self-supplied water (i.e., water not drawn from the municipal supply) for fabrication, processing, cooling, and washing. The industrial category includes commercial and mining uses of water.

The Data

Data Source: Using raw data collected by states and other sources, the U.S. Geological Survey (USGS) compiles estimates of water use for each use category and then aggregates the estimates for each state, Puerto Rico, and the U.S. Virgin Islands and for each of the 21 water-resources regions. The data have been published every 5 years since 1950 in the USGS Circular series "Estimated Use of Water in the United States." More recent compilations are available electronically at http://water.usgs.gov/watuse/. Some state and federal agencies also publish reports on water use for specific states or categories of use.

Data Collection Methodology: Sources of information and accuracy of data vary by state and by water-use category. Most public-supply water withdrawals and deliveries are metered. In some states, large irrigation and industrial users are required to have water meters to measure the amount of water withdrawn. For other categories, such as self-supplied domestic (e.g., "rural") and small industries (e.g., self-supplied commercial), estimates of water use are derived from population or product output. Energy production data obtained from the Department of Energy are used in making water-use estimates for the thermoelectric power category. Information on acres irrigated is obtained from the Department of Agriculture's Census of Agriculture and its Farm and Ranch Irrigation Survey and from state universities. Information on public water supplies is obtained from the Environmental Protection Agency, state agencies, and individual water suppliers.

Data Manipulation: The steps required to transform the raw data into final form vary with the category of use and with the level of detail of the available raw data. Guidelines used for preparing the most recent estimates are available at http://water.usgs.gov/watuse/. In addition, sources of information and accuracy of data are discussed in the USGS circulars published every 5 years.

Data Quality/Caveats: Because the sources of data and the level of detailed information vary for each state, it is difficult to apply an error analysis to the national aggregate water-use estimates. As part of the compilation effort, each USGS compiler is required to provide justification when estimates change by more than 10% from the previous water-use compilation. Once the data are compiled at the state level, they are peer-reviewed by USGS regional water-use specialists and again by USGS national water-use specialists.

Data Access: The data used here are available in the regular USGS Circular series "Estimated Use of Water in the United States" (for historical data) and at http://water.usgs.gov/watuse/ (for more recent data).

Groundwater Levels

The Indicator

This indicator would describe changes in water levels in major regional aquifers by reporting the fraction of the total area of regional aquifers that declined, increased, or remained stable in comparison to a previous period, and would be reported every 5 years. An example of the kind of data that are available for some major aquifers, and which would be used to develop a national indicator, can be seen in a series of maps depicting changes in the High Plains aquifer, which underlies eight states in the central United States (see McGuire et al. 1999).

The Data Gap

This indicator would require significant data on water levels in major regional aquifers (see below). It would also require a scheme for classifying changes in aquifer level as "significant increase," "significant decrease," or "no significant change." Changes in groundwater level have unique levels of significance in different aquifers; a change of a few feet in a shallow coastal aquifer may be quite important in terms of susceptibility to saltwater intrusion, while a change of 10 feet on a very large aquifer may not be as significant. Logically, the values for "stable" will be different in different aquifers (e.g., the High Plains case defined –5 feet to +5 feet as "no significant change"). Therefore, definitions of significant increase or decrease (and thus, no significant change) should be determined on an aquifer-by-aquifer basis.

Water-level data are available for all or parts of every state, but these data cannot be aggregated to provide national coverage because of limited coverage of most aquifer systems and lack of electronic availability of much of the monitoring data. The High Plains aquifer is one of the few multistate aquifers with systematic and coordinated water-level monitoring. States or areas with good water-level-monitoring programs include parts of Florida, Long Island (NY), Pennsylvania, and Utah. To ensure national coverage, the following points must be addressed:

- Data must be collected from areas that represent the full range of topographic, hydrogeologic, climatic, and land use environments within the major aquifers.
- Data must be collected using standardized methods from monitoring wells or other wells not affected by local pumping. Procedures for well selection and data collection are available in Chapter 2 of the USGS's 1980 *National Handbook of Recommended Methods for Water-Data Acquisition*.
- There must be agreement on timing of water-level measurements across the country so that the status of major aquifers in a region or in the entire country can be presented as a snapshot in time.
- Plans must be in place to ensure long-term viability of observation-well networks and data collection programs, including plans for a combination of data collection at long-term monitoring wells and periodic synoptic measurements.
- There must be agreement among the agencies or other sources of data on electronic data storage, access, and dissemination. The agencies that will be responsible for leadership in compiling and publishing the data must be identified.

References

McGuire, V.L., C.P. Stanton, and B.C. Fischer. 1999. Water level changes, 1980 to 1997, and saturated thickness, 1996–97, in the High Plains aquifer. U.S. Geological Survey Fact Sheet. FS-124-99. http://ne.water.usgs.gov/highplains/hp97_web_report/97fs.pdf.

Waterborne Human Disease Outbreaks

The Data

This indicator reports the number of waterborne disease outbreaks (WBDOs) reported to the Centers for Disease Control and Prevention (CDC) through a network of doctors and state and local public health officials. In addition, the U.S. Environmental Protection Agency (EPA) and the Council of State and Territorial

Epidemiologists assist with collection and reporting of WBDOs. CDC generally reports only cases involving at least two individuals with a similar illness, and only where epidemiological evidence implicates water as the probable source of the illness. (Data from 1920 to 1936 include outbreaks that affected more than five people. These early data also include some cases related to contamination of reservoirs and cisterns, which are not included in the 1973–1998 dataset.) This indicator does not report outbreaks due to distribution system problems of unknown origin, nor does it include outbreaks caused by contamination of water or ice at the point of use (e.g., a contaminated water faucet). Outbreaks associated with recreational fresh surface waters are included here; outbreaks associated with marine water, spas, whirlpools, hot tubs, and the like are not reported.

Data Collection Methodology: State and territorial and local public health departments are primarily responsible for detecting and investigating WBDOs and voluntarily reporting them to CDC. CDC requests annual reports from state and territorial epidemiologists or from persons designated as WBDO surveillance coordinators. EPA collects additional information on water quality and treatment as needed from state drinking water agencies.

Data Manipulation: Information from CDC was sorted to identify only those outbreaks that are clearly linked to contamination in lakes, streams, ponds, and the like. Thus, outbreaks linked to contamination at the point of use and those linked to marine waters, hot tubs, spas, and swimming pools were deleted. Outbreaks associated with untreated and inadequately treated drinking water were aggregated.

Data Quality/Caveats: Various factors can affect the chances of an individual illness being linked to a water source. These include public awareness, the likelihood that ill people will consult the same health care provider, availability and extent of laboratory testing, local requirements for reporting cases of particular diseases, and the surveillance and investigative activities of state and local health and environmental agencies. Recognition of WBDOs is also dependent on certain outbreak characteristics; large interstate outbreaks and outbreaks involving serious illness are more likely to receive the attention of health authorities. Outbreaks associated with private water systems that serve a small number of residences or farms are the most likely to be underreported because they generally involve only a few people.

Data Access: Current WBDO data are reported by CDC, Public Health Service, U.S. Department of Health and Human Services, in CDC Surveillance Summaries for Waterborne-Disease Outbreaks, *Morbidity and Mortality Weekly Report*. The 1985–1999 Surveillance Summaries are available at http://www.cdc.gov/mmwr/sursumpv.html; see Volumes 37, 39, 40, 42, 45, 47, and 49. Data from 1978 to 1984 are from CDC's Water-Related Disease Outbreaks Annual Summaries (1980–1985), and data from 1973 to 1977 are from CDC's Foodborne and Waterborne Disease Outbreaks Annual Summaries (1974–1979).

Freshwater Recreational Activities

There is no technical note for this indicator.