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METHODS FOR EVALUATING WETLAND CONDITION

#17 Land-Use Characterization for Nutrient and Sediment Risk Assessment

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#17 Land-Use Characterization for Nutrient and Sediment Risk Assessment

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Prepared jointly by:

The U.S. Environmental Protection Agency
Health and Ecological Criteria Division (Office of Science and Technology)

and

Wetlands Division (Office of Wetlands, Oceans, and Watersheds)

Notice

The material in this document has been subjected to U.S. Environmental Protection Agency (EPA) technical review and has been approved for publication as an EPA document. The information contained herein is offered to the reader as a review of the "state of the science" concerning wetland bioassessment and nutrient enrichment and is not intended to be prescriptive guidance or firm advice. Mention of trade names, products or services does not convey, and should not be interpreted as conveying official EPA approval, endorsement, or recommendation.

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This entire document can be downloaded from the following U.S. EPA websites:

http://www.epa.gov/ost/standards

http://www.epa.gov/owow/wetlands/bawwg

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Foreword

In 1999, the U.S. Environmental Protection Agency (EPA) began work on this series of reports entitled *Methods for Evaluating Wetland Condition*. The purpose of these reports is to help States and Tribes develop methods to evaluate (1) the overall ecological condition of wetlands using biological assessments and (2) nutrient enrichment of wetlands, which is one of the primary stressors damaging wetlands in many parts of the country. This information is intended to serve as a starting point for States and Tribes to eventually establish biological and nutrient water quality criteria specifically refined for wetland waterbodies.

This purpose was to be accomplished by providing a series of "state of the science" modules concerning wetland bioassessment as well as the nutrient enrichment of wetlands. The individual module format was used instead of one large publication to facilitate the addition of other reports as wetland science progresses and wetlands are further incorporated into water quality programs. Also, this modular approach allows EPA to revise reports without having to reprint them all. A list of the inaugural set of 20 modules can be found at the end of this section.

This series of reports is the product of a collaborative effort between EPA's Health and Ecological Criteria Division of the Office of Science and Technology (OST) and the Wetlands Division of the Office of Wetlands, Oceans and Watersheds (OWOW). The reports were initiated with the support and oversight of Thomas J. Danielson (OWOW), Amanda K. Parker and Susan K. Jackson (OST), and seen to completion by Douglas G. Hoskins (OWOW) and Ifeyinwa F. Davis (OST). EPA relied heavily on the input, recommendations, and energy of several panels of experts, which unfortunately have too many members to list individually:

- Biological Assessment of Wetlands Workgroup
- Wetlands Nutrient Criteria Workgroup

More information about biological and nutrient criteria is available at the following EPA website:

http://www.epa.gov/ost/standards

More information about wetland biological assessments is available at the following EPA website:

http://www.epa.gov/owow/wetlands/bawwg

List of "Methods for Evaluating Wetland Condition" Modules

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2	Introduction to Wetland Nutrient Assessment
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Summary

The condition of and potential threats to a given wetland are often largely determined by surrounding land use. Land use, especially the percent of the watershed that has been cleared of natural vegetation, can affect the amount of water, sediment, pesticide, and nutrients entering a wetland as well as the composition of its plant and animal communities. A rapid and inexpensive assessment of the land use around a wetland and its implications for nutrient and sediment inputs can be made using readily available maps and aerial photographs, including county soil maps, USGS quadrangle maps, land-use maps, and aerial photographs. These are used to delimit the watershed or drainage basin around a wetland and to classify land use within this watershed. These land use data are used to calculate an index of potential nutrient loading to the wetland and a sediment risk index. Their intended use is to identify quickly, easily, and cheaply those wetlands that are at greatest risk from nutrient and/or sediment inputs.

Purpose

The purpose of this module is to suggest procedures for assessing the relative risk to a given wetland of nutrient and sediment loads from its watershed.

Introduction

All wetlands are influenced by a number of flow systems that bring materials into and out of them. The most important flow systems are usually atmospheric flows, surface water flows, and subsurface water flows. Many natural flow systems have been altered by human activities, especially surface and subsurface water flows into wetlands. The amount of water (Luo et al. 1994, Euliss and Mushet 1996), nutrient (Omernik 1977), sediment (Martin and Hartman 1987, Gleason and Euliss 1998), and pesticide entering a wetland is largely a function of land use in the watershed. Inputs into wetlands, especially sediment from surrounding areas, can affect the recruitment, growth, and even survival of many plant and animal species (Dieter 1991, Euliss and Mushet 1999, Jurik et al. 1994, Martin and Hartman 1987, Newcomb and MacDonald 1991, Waters 1995).

The characterization of land use around a wetland is essential for evaluating wetlands for water quality purposes. Data from maps and aerial photographs can be used to estimate the potential for inputs of nutrients and sediments into wetlands. Many factors determine the movement of nutrients and sediments within most landscapes, including vegetative cover (land use), soil type (erodibility), slope length, slope angle, and frequency and intensity of rainfall. A variety of models and equations exist for estimating the potential loads of nutrients and sediments to a wetland from its surrounding watershed. The data requirements of these models generally make them unsuitable for preliminary evaluations of the risk of nutrient or sediment inputs to a wetland. Nevertheless, when reduced to its simplest terms, the more a wetland's watershed has been altered by human activities the more likely it is at risk. Consequently, a quick-and-dirty assessment of land use in the watershed should provide a crude estimate of potential risks from nutrient and sediment loadings to a wetland.

Methods

Geographic information systems (GIS) are primary tools in analysis of landscapes, and their use has significantly changed how spatial data and related nonspatial data are collected, stored, and analyzed. State, regional, and local GIS facilities will often have on file in digital form all the information needed to characterize landscapes around a given wetland. Appropriate State, county, and municipal agencies should be consulted to see if their GIS facilities can be utilized for this purpose. If a GIS facility is not available, the work needed to characterize the landscape in which a wetland is found can be easily done by hand. The methods outlined in this module presuppose that a GIS will not be used. All of the proposed steps suggested in this module, however, can be done utilizing existing GIS software packages or simple modifications or extensions of them. Although the proposed method is simple, it will quickly become prohibitively time-consuming if extended to a statewide assessment of risks to wetlands. For large-scale projects, a GIS should be used.

A very useful and practical manual that provides detailed methodology for collecting the kinds of information needed to characterize lands use around wetlands is *Landscape Planning: Environmental Applications*, 3rd Edition, by William M. Marsh. Much of what follows is based on Marsh (1998). Guidelines for selecting wetlands to sample are found in Study Design for Wetland Monitoring.

There are many kinds of wetlands, including fringing wetlands along lakeshores, rivers, and oceans, and palustrine wetlands that cover their entire basin (see module on Wetland Classification for details). These wetlands vary greatly in size and shape and in inputs and outputs of water. To simplify this module, the methods described are applied to the evaluation of the watershed of a palustrine wetland within a well-defined watershed. This is an idealized situation. To apply this methodology to other wetland types, suitable adjustment will need to be made. In some cases, watershed boundaries will be difficult or impossible to establish. In such cases, an arbitrary zone of influence around the wetland can be substituted. This zone's width needs to take into account known surface and subsurface flow patterns into the wetland. For large wetland complexes, e.g., riverine or estuarine wetlands, only portions of the complex may be of interest. Again, suitable adjustments will need to be made to determine the zone of influence. In many cases, significant nutrient and sediment inputs may come from other sections of the complex.

Sources of Maps, Aerial Photographs, and Other Data

The Internet has made finding and acquiring relevant maps and other data simpler and more efficient than ever before. Increasingly, digitized maps can be downloaded directly. Below is a list of some major sources of maps and aerial photographs. These Websites often have links to other sites with relevant information. Only the URLs for their home pages are listed because these are less likely to change. See also the module on Wetland Classification for additional sources of information.

Topographic maps are published by the U.S. Geological Survey (USGS) at a variety of scales. The most useful topographic maps are the 7.5-minute quadrangle maps. These maps contain information on topographic relief, drainage systems, and some land use features. The USGS Web site **(www.usgs.gov)** provides a list of all topographic maps and all other maps produced by the USGS. It also describes several ways of ordering these maps. Current and historic stream-flow data can also be obtained from this site.

National Wetland Inventory (NWI) 7.5-minute quad maps can be downloaded from their Website **(www.nwi.fws.gov)** and are also available through the USGS Earth Science Information Centers.

A list of all county soil maps in the United States is available through the National Resources Conservation Service (NRCS) Website **(www.nrcs.usda.gov)**, as is a list of State NRCS offices from which these county soil surveys can be obtained. Information about regional soil erosion patterns can also be obtained from this site.

Information about aerial photographs that are part of the National Aerial Photography Program (NAPP) can be obtained from the USGS Website **(nsdi.usgs.gov/products/aerial.html)**. Aerial photographs taken by State agencies and local governments are also usually available. Recent aerial photographs and land-use maps can usually be obtained from State agencies such as the State Geological Survey and map and aerial photography collections at major universities.

A National Land Cover Data Base (NLCD) based on satellite imagery from the early 1990s is being developed as part of the Federal Multi-Resolution Landscape Characterization (MRLC) initiative. The NLCD is a joint project of the USGS and the U.S. Environmental Protection Agency (USEPA). Its aim is to produce a consistent land cover data layer for the conterminous U.S. based on 30-meter Landsat thematic mapper (TM) data. Information about available NLCD products can be obtained from both USGS (edcwww.cr.usgs.gov/programs/lccp/nationallandcover.html) and EPA Websites **(www.epa.gov/mrlc/Regions.html)**.

Flood hazard maps from the Federal Emergency Management Agency **(www.fema.gov)** can often be used to delineate the boundaries of floodplain wetlands along rivers and streams.

Map Limitations

All maps have a minimum resolution level that is determined by their scale. This establishes the smallest area or unit that can be mapped. For USGS 7.5-minute quadrangle maps, whose scale is 1:24,000 or 1" = 2,000 ft, the smallest units that can be mapped are 10 or more acres. Because many wetlands, especially palustrine wetlands, are often much less than 10 acres and their watersheds are equivalently small, USGS quadrangle maps may not have the resolution needed to delineate their watershed boundaries. In flat landscapes, there is an additional limitation of USGS 7.5 quadrangle maps, i.e., their vertical resolution. In short, for small wetlands or wetlands in very flat landscapes, maps with a better resolution than USGS quadrangle maps may be needed. Unfortunately, county soils maps, which typically have a 1:20,000 scale, have only a slightly better resolution than USGS quadrangle maps. When no suitable maps are available, low-level aerial photographs may be the only way to collect the data needed to characterize the watershed in which the wetland is found.

Watershed or Drainage Basin Delineation

Establishing the boundaries of a watershed around a given wetland is done by finding drainage divides on a topographic map. In landscapes with well-developed drainage systems, this process begins with mapping the drainage network to establish the order of its various branches. The results of this exercise will largely be a function of the resolution of the topographic map. One of the simplest ways to identify drainage divides is to demarcate patterns of overland flow with arrows drawn perpendicular to contour lines. Where the arrows are divergent, i.e., point in opposite directions, there is a drainage divide. By inspection, first-order basins can be identified and aggregated into second-order watersheds and so forth.

Identifying watersheds, as described above, may not be feasible in some landscapes. In flat, poorly drained landscapes, drainage divides are often hard to determine using topographic maps. In such situations, soils maps may be more useful for identifying both wetland basins and intermittent, interconnecting drainage channels. In these landscapes, groundwater inputs into wetlands are often very important. When this is so, watershed delimitation using surface flow patterns may greatly underestimate the effective size of the area around a wetland whose runoff enters the wetland. In both urban and agricultural areas, the effective watershed of a wetland includes the area drained by storm sewers or drainage networks, respectively, which discharge into the wetland. The area covered by these storm sewer or drainage networks generally is not congruent with the wetland's surface runoff watershed. Maps and other information about storm sewer and drainage networks are often available from local governments or from organized drainage districts. These can be used to establish the effective watershed for wetlands in such altered landscapes, and these effective watersheds should be used to estimate potential loading rates of nutrients and pollutants to the wetland.

Land Use in Watershed

Nutrient and sediment inputs into a wetland are due to both point and nonpoint inputs. To a large extent land use in the watershed will determine the load of sediment and nutrients that a wetland will receive. It will also determine how much of this input is the result of point and nonpoint sources. The more a watershed has been altered by human activities, the greater the potential for the movement of sediments into a wetland. The first step in characterizing the watershed is to classify each recognizable area in the watershed by its predominant land use:

- Natural vegetation (>75% forest and/or grassland)
- Mostly natural vegetation (50 to 75% forest and/or grassland)
- Agriculture (>75% cropland)
- Mostly agriculture (50 to 75% cropland)
- Mostly urban (>40% developed)
- Mixed (doesn't fall into one of the previous categories)

Because land use is changing constantly, up-to-date information on current land use is needed. This can most readily be obtained from recent aerial photographs of the watershed. In some States, land use maps may be available, but the classification system used will undoubtedly be more sophisticated than the simple system proposed above. Converting the classes on existing land-use maps to the land-use classes proposed above is usually very easy and may not be necessary at all if local estimates of annual nutrient loss for different classes are available. In agricultural areas, USDA crop compliance maps may be ready-made land-use maps. For wetlands with large watersheds, the MRLC National Land Cover Data Base may also be a useful source of digital land-use data.

The area of the watershed in each land use class then needs to be determined. This can be done in a variety of ways with paper maps using a dot grid or planimeter. If a digital version of the land use map is available, a GIS can be used to calculate the area of each land use class in the watershed.

Dot grids are transparent overlays with a regular pattern of dots. With a dot grid, the number of dots that fall on each land use class in the watershed is counted. Each dot represents a certain area. To determine the area represented by a dot, the following formula is used:

$$Area/dot = [area\ on\ map/(1\ linear\ unit)^2]/[number\ of\ dots/(1\ linear\ unit)^2]$$

For example, if 1 cm on the map is equivalent to 100 m, then 1 cm^2 = 10,000 m^2 or 1 ha.
If 1 cm^2 on the dot grid contains 10 dots, then

$$Area/dot = (1\ ha/\ 1\ cm^2)/(10\ dots/\ 1\ cm^2) = 0.1\ ha/dot.$$

If 40 dots on the grid fell in areas that were covered with natural vegetation, the total area in natural vegetation is estimated to be 40 dots x 0.1 ha/dot or 4 ha. To improve the precision of area estimates using dot counts, several random drops of the dot grid can be made on the watershed map and the dots counted for each land-use class. The average dot count per class is then used to calculate the area of each land-use class.

A planimeter is a device that is used to convert the boundary or perimeter length of a polygon to its area. Prolonged use of a planimeter is tedious, and it takes skill and practice to trace the boundaries of complex polygons. For occasional use, dot grids are simpler to use and probably more reliable. If large number of wetlands are going to be evaluated, scanning land use maps to create digital versions and using a GIS to calculate total watershed and land use class areas is strongly encouraged.

Nutrient Loading Index

A simple index of potential nutrient loadings can be used to characterize the nutrient environment of a wetland. This index is the ratio of the potential loss of nitrogen (N) or phosphorus (P) from the watershed with its current land use divided by the potential losses if the entire watershed were covered with permanent natural vegetation. Operationally, potential nutrient loadings are calculated by multiplying the area of each upland land use class by the amount of N or P that is estimated to leave this land use class (Table 1 or comparable local data set) and then adding up the total annual estimated output of N or P for the watershed. (See also the Vegetation-Based Indicators of Wetland Nutrient Enrichment section of this manual for additional sources of information on nutrients in runoff.) This approach to estimating total annual loads of nutrients from watersheds into lakes has been used for many years in the limnological literature (Reckow et al. 1980). The total estimated annual loss of P or N is then divided by the estimated output of nutrient if the entire watershed were covered in permanent natural vegetation (forests or grasslands).

Table 1: Potential nutrient loss rates (kg/ha/yr) for different upland land-use classes

Land Use (LU)	Nutrient loss rate (NLR)	
	Nitrogen	Phosphorus
Natural vegetation	0.44	0.0085
Mostly natural vegetation	0.45	0.018
Agricultural	0.98	0.031
Mostly agricultural	0.63	0.028
Mostly urban	0.79	0.030
Mixed	0.55	0.019

Source: Adapted from Omernik (1977) and Marsh (1998)

(1) Nutrient Loading index = (Total Watershed Loss)/(Natural Watershed Loss)

where

(2) Total Watershed Loss = $S(LU_i \text{ x } NLRX_i)$

LU_i = area of watershed in upland land use class i;

$NLRX_i$ = nutrient loss rate for upland land use class i for nutrient X (Table 1);

and

(3) Natural Watershed Loss = TUWA x NLRNVX

TUWA = total upland watershed area; and

NLRNVX = nutrient loss rate of nutrient X for the natural vegetation land use class (Table 1).

The higher the index value, the larger the potential nutrient loading into the wetland. This index provides a measure of the relative threat to the wetland from nutrient inputs from the current upland landscape.

The index does not give a realistic estimate of the actual annual loadings of nutrients to a wetland. It only provides a crude way of ranking wetlands based on the likelihood that they are receiving nutrient loadings from the surrounding watershed. Other sections of this manual discuss methods for estimating actual loadings of nutrients to wetlands.

If there are point sources of nutrients within the watershed, the index needs to be adjusted appropriately. Annual inputs of nutrients from storm sewers or agricultural drainage networks will be highly site specific and can best be obtained from local sources. In areas where septic tank fields are within 100 m of a wetland, the number of septic tank fields in the watershed needs to be estimated. The input load to the wetland needs to be adjusted by determining the potential inputs of nitrogen (11 kg per drainage field per year) and phosphorus (0.28 kg per drainage field per year) as suggested by Marsh (1998). Many other point sources of nutrients may be present in a watershed, e.g., feedlots, golf courses, sewage treatment plants, etc. In short, estimates of point sources are simply added to those from nonpoint sources. The Nutrient Loading Index is then calculated as above with estimated inputs of nutrients added to the numerator.

Sediment Risk Index

The simplest method for assessing potential sediment-related impacts to wetlands is to do an erosion risk assessment of the watershed. The major factors that influence soil erosion rates are climate, soil properties, topography, soil surface conditions, and human activities. Within a given region, it is soil surface conditions and human activity in close proximity to the wetland that will largely determine the potential sediment load. Potential risk of sediment inputs increases with the amount of land in the watershed that is classified as agricultural. It further increases if this agricultural land has steeper and longer slopes, i.e., is classified as highly erodible land (HEL), and/or if it is adjacent to the wetland. The amount of the watershed classified as HEL can be obtained by contacting the nearest NRCS Office. How much of the land that is classified as agricultural land is adjacent to the wetland can be determined with a planimeter. In many watersheds, recent clearing of natural vegetation due to road building, construction, mining, lumbering, etc., can also cause significant short-term erosion problems. The potential impact of these activities is assessed by estimating the total percentage of the watershed recently cleared of natural vegetation.

Sediment Risk Index = (Percent of agricultural land classified as HEL x percent of agricultural land) / 100 + Percent of wetland boundary adjacent to agricultural land + Percent of watershed disturbed by land-clearing activities.

As with the Nutrient Loading Index, the Sediment Risk Index is a quick-and-dirty way to identify wetlands that have a greater risk of having high sediment loadings. There are many sophisticated methods for estimating sediment losses from watersheds (see Boardman and Favis-Mortlock 1998, Morgan 1986, Schmidt 2000). These should be used to confirm that a given wetland is actually at risk from sediment inputs.

Final Comments

In this module, overland flow and agricultural drainage networks, if present, are assumed to be the major sources of nutrients and sediments into a wetland. For wetlands in watersheds where stormwater sewers are a significant or predominant source of nutrients and sediments, appropriate changes in the methods for estimating nutrient and sediment loadings will need to be made. Likewise, better estimates of annual nutrient loss rates for areas with different land uses may be available locally. Because these rates are a function of local soil types, fertilizer application rates, and precipitation patterns, these should be substituted for those in Table 1 when available. In short, this module presents some simple methods for gauging the overall risk to a wetland of various human impacts on watershed land use. Users are encouraged to adapt the proposed methodology to the realities of local landscapes in order to improve its reliability.

Case Study

Land-use data adapted from data supplied by the NRCS Office in Spirit Lake, IA, for three watersheds around the Iowa Great Lakes are presented in Table 2. Land use classes in the NRCS data have been converted into the land-use classes

Table 2: Land uses (ha) in the watersheds of wetlands W1, W2, and W3 in the Iowa Great Lakes Region of NW Iowa

Land Use	Watershed of W1	Watershed of W2	Watershed of W3
Natural vegetation	87	69	349
Mostly natural vegetation	88	0	44
Agriculture[a]	132	43	2,797
Mostly urban	0	67	0
Mixed	12	26	57
Total Upland Watershed Area (TUWA)	319	206	3,247
Wetlands and aquatic systems	80	87	276
Total watershed area	399	293	3,523

Note: Data adapted from land-use data provided by the NRCS Office in Spirit Lake, IA.
[a] Agricultural land is all in row crops, mostly corn and soya beans.

presented in Table 1. W1 and W3's watersheds had land in the Conservation Reserve Program (CRP). This CRP land was mostly planted to various kinds of perennial prairie grasses. In Table 2 CRP land has been classified as mostly natural vegetation. Based on percent of the upland area of each watershed in agricultural land (41%, 21%, and 86% for the watersheds for wetlands W1, W2, and W3, respectively), wetland W3 has the highest risk of inputs of nutrients and sediments from the surrounding uplands, followed by W1 and W2.

The estimated annual loadings of nitrogen and phosphorus to each wetland calculated using Equation 2 are presented in Table 3, as is the Nutrient Loading Index for each wetland. Of the three wetlands, wetland W3 has the highest potential nutrient loadings. This is largely because so much of its watershed is in agricultural land. Wetlands in W1 and W2 have identical Nutrient Loading Indices. For W1, however, the largest potential source of nitrogen and phosphorus is agricultural land while for W2 it is runoff from urban areas.

Data used to calculate the Sediment Risk Index are given in Table 4, as is the Index. Wetland W2 has the highest Sediment Risk Index (56%), although it is nearly identical to that for W3 (53%). Wetland W2 is primarily at risk because so much of it (42% of its shoreline) is adjacent to agricultural land and because there is a lot of recently cleared land in its watershed (10%). On the other hand, wetland W3 is at risk primarily because so much of the watershed is agricultural land (86%) and about 22% of this land is classified as HEL

Collectively, the four indicators of the potential risk of wetlands to nutrient and sediment inputs (percent of agricultural land in the upland portions of the watershed, Nutrient Loading Indices for N and P, and Sediment Risk Index) suggest that wetland W3 overall is at greatest risk, followed by W2 and W1.

Table 3: Estimated current annual nitrogen and phosphorus loadings (Total Watershed Loss), presettlement loadings (Natural Watershed Loss), and Nutrient Loading Index for three wetlands (W1, W2, and W3) in the Iowa Great lakes region

Land Use	Nitrogen			Phosphorus		
	W1	W2	W3	W1	W2	W3
Natural vegetation	38	30	154	0.74	0.59	2.97
Mostly natural vegetation	40	0	20	1.6	0	0.8
Agricultural	129	42	2,741	4.1	1.3	86.7
Mostly urban	0	53	0	0.0	2.0	0.0
Mixed	7	14	31	0.2	0.5	1.1
Wetland and aquatic systems	0	0	0	0.0	0.0	0.0
Total watershed loss	214	140	2,946	6.6	4.4	91.6
Natural watershed loss	140	91	1,429	2.7	1.8	27.6
Nutrient loading index	1.5	1.5	2.1	2.4	2.4	3.3

Table 4: Percent of the watersheds for wetlands W1, W2, and W3 classified as agricultural land, percent of agricultural land classified as highly erodible (HEL), percent of wetland boundary adjacent to agricultural land, and percent of watershed disturbed by recent land clearing for three watersheds in the Iowa Great Lakes region as well as the Sediment Risk Index for each wetland

Landscape Characteristics	W1	W2	W3
Percent in agricultural land	41%	21%	86%
Percent of agricultural land that is HEL	9%	18%	22%
Percent of wetland boundary adjacent to agricultural land	25%	42%	29%
Percent of watershed disturbed by land clearing	0%	10%	5%
Sediment Risk Index	29%	56%	53%

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