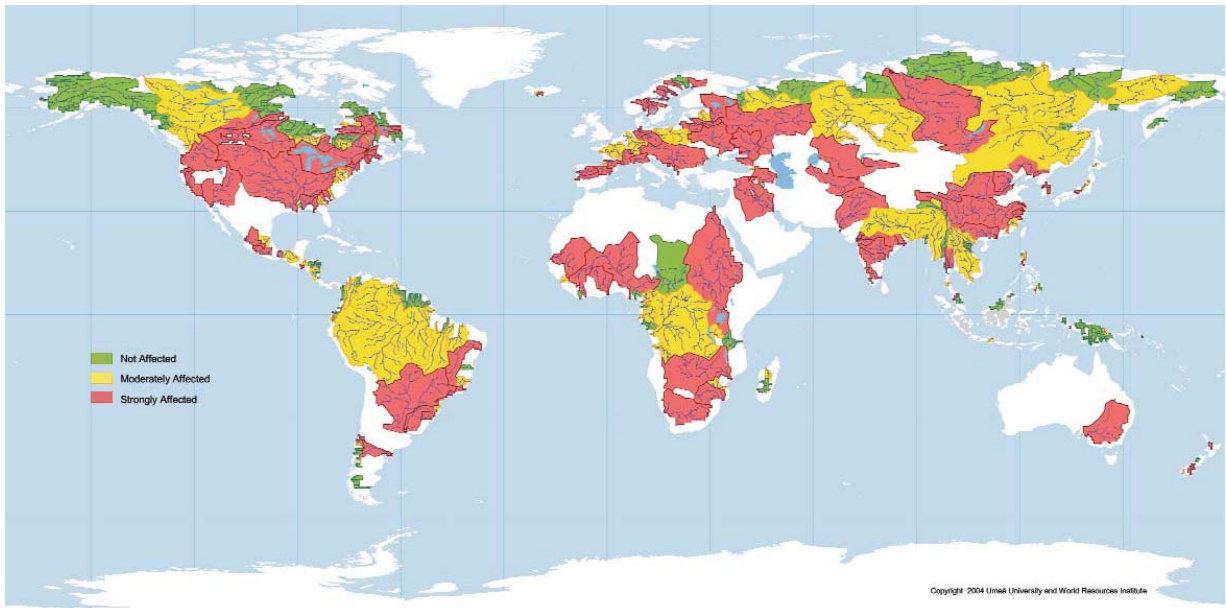


Indicator name	Fragmentation and flow regulation of rivers
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Prepared by	UNEP
Example	WWDR2, Chapter 5, Map 5.3 and Figure 5.4 WWDR3, Chapter 8, Figure 8.2
Rationale	The negative impact on ecosystems of altering waterways by dams, water transfers and canals must be considered when managing water resources in a sustainable way. It is no longer acceptable to draw water from nature for use in agriculture, industry, and everyday life without taking into account the role that ecosystems play in sustaining a wide array of goods and services, including the water supply. Ecosystems, such as wetlands and riparian habitats in particular, play a critical role in maintaining the integrity and proper functioning of freshwater and coastal ecosystems.
Position in DPSIR chain	State, Impact
Definition of indicator	Degree of environmental impact at the river basin level resulting from flow regulation, channel fragmentation and other stresses associated with dams, withdrawals and diversions.
Underlying definitions and concepts	<p>Virgin mean annual discharge (VMAD): river system discharge (m^3s^{-1}) for the most water-rich river segment, before any significant direct human manipulations.</p> <p>River system (RS): network of stream and river channels interconnected by surface freshwater, from the headwaters to the sea.</p> <p>Flow regulation: degree to which VMAD is regulated by dams or other diversions. This is described as the sum of reservoir capacity within a river system, irrespective of a reservoir's location within the catchment, expressed as the percentage of river system VMAD which can be contained by the reservoirs.</p> <p>Channel fragmentation: degree to which the river system is spatially fragmented by dams. This is classified according to the longest segment of the main river channel without dams (but that frequently includes reservoir water tables), and whether dams exist in the major tributary, minor tributaries, or both.</p> <p>Irrigation pressure: the amount of basin runoff which is available per square kilometre of irrigated land within the catchment.</p> <p>Ecoregions or Biomes: relatively large units of land or water containing a distinct assemblage of natural communities and species, with boundaries that approximate the original extent of natural communities prior to major land-use change. [Following classification under: D. M. Olson et. al. BioScience. 51, 933 (2001) and current work by R.</p>

	<p>Abell et al. (WWF-US).]</p> <p>Per discharge gross RS product (GRP): the sum of US dollars assigned to each river-system inhabitant according to his/her nationality and corresponding 2003 per-capita gross domestic product, divided by VMAD.</p> <p>Development pressure (DP): the additional GRP needed by a river system to reach the economic development stage represented by the average OECD nation.</p>																																															
Specification of determinants needed	<p>VMAD</p> <p>Flow regulation</p> <p>Channel fragmentation</p> <p>Irrigation pressure</p>																																															
Computation	<ol style="list-style-type: none"> Individual river systems are delineated on topographic maps, and VMAD data collected (see section on data sources for more detail). All dams within a river system are located and storage capacities identified. Flow regulation is calculated as the sum of reservoir live storage capacities within the system as a percent of the VMAD. Channel fragmentation is ranked into five classes describing the longest main-channel segment without dams (but frequently including reservoir water tables) in relation to the entire main channel (0 = 100%; 1 = 75-99%; 2 = 50-74%; 3 = 25-49%; and 4 = 0-24%). For the tributaries, fragmentation is described by three classes (0 = no dams; 1 = dams only in the catchment of minor tributaries; 2 = dams also in the catchment of the largest tributary). Presented below are the principles for constructing the indicator, comprised of classes of river system impact (not affected, moderately affected, and strongly affected) from the combination of fragmentation and flow regulation assessments. <table border="1" style="margin-left: auto; margin-right: auto;"> <thead> <tr> <th rowspan="2">Fragmentation (Main channel + tributaries)</th> <th colspan="3">Flow regulation (%)</th> </tr> <tr> <th>Not affected</th> <th>Moderately affected</th> <th>Strongly affected</th> </tr> </thead> <tbody> <tr> <td>0 + 0</td> <td>0</td> <td></td> <td></td> </tr> <tr> <td>0 + 1</td> <td>≤ 2</td> <td>> 2</td> <td></td> </tr> <tr> <td>0 + 2</td> <td>≤ 1</td> <td>> 1</td> <td></td> </tr> <tr> <td>1 + 0</td> <td></td> <td>≤ 30</td> <td>> 30</td> </tr> <tr> <td>1 + 1</td> <td></td> <td>≤ 25</td> <td>> 25</td> </tr> <tr> <td>1 + 2, 2 + 0</td> <td></td> <td>≤ 20</td> <td>> 20</td> </tr> <tr> <td>2 + 1</td> <td></td> <td>≤ 15</td> <td>> 15</td> </tr> <tr> <td>2 + 2, 3 + 0</td> <td></td> <td>≤ 10</td> <td>> 10</td> </tr> <tr> <td>3 + 1</td> <td></td> <td>≤ 5</td> <td>> 5</td> </tr> <tr> <td>3 + 2, 4 + 0, 1, 2</td> <td></td> <td></td> <td>≥ 0</td> </tr> </tbody> </table> <ol style="list-style-type: none"> Irrigation pressure is VMAD divided by irrigated area in the basin ($m^3 s^{-1} km^{-2}$). The basin's irrigation pressure is applied to both minimum and maximum expected irrigation consumption rates to provide a range of probable additional withdrawals from the system. These values can then be interpreted as additional flow regulation, and assessed to identify systems which most likely belong in a higher impact class. 	Fragmentation (Main channel + tributaries)	Flow regulation (%)			Not affected	Moderately affected	Strongly affected	0 + 0	0			0 + 1	≤ 2	> 2		0 + 2	≤ 1	> 1		1 + 0		≤ 30	> 30	1 + 1		≤ 25	> 25	1 + 2, 2 + 0		≤ 20	> 20	2 + 1		≤ 15	> 15	2 + 2, 3 + 0		≤ 10	> 10	3 + 1		≤ 5	> 5	3 + 2, 4 + 0, 1, 2			≥ 0
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3 + 2, 4 + 0, 1, 2			≥ 0																																													
Units of measurements	<p>Degree of river fragmentation and altered flows rated in three categories:</p> <p>Strongly affected, Moderately affected, and Not affected.</p>																																															
Data sources, availability and quality	<p>WWDR3 figure data: WWF, Living Planet Report 2006, http://assets.panda.org/downloads/living_planet_report.pdf (Accessed 2 March 2009)</p> <p>River system delineation: Data sources include:</p> <ul style="list-style-type: none"> Operational Navigation Charts 1:1,000,000, Defense Mapping Agency, USA additional topographic maps/data provided electronically by national governments communication with regional authorities for confirmation and/or clarification of 																																															

delineations.

VMAD data: The vast list of potential and existing data sources include international, national and subregional hydrologic databases; personal correspondence with agency personnel, academics and/or non-governmental staff working with a particular river system; and published literature. Some examples of commonly cited sources include:

- Global Hydrology Research Group, University of New Hampshire, USA
<http://www.wsag.unh.edu/> (Accessed 2 March 2009)
- The Global Runoff Data Centre, D - 56002 Koblenz, Germany
<http://www.rivdis.sr.unh.edu/maps> (Accessed 2 March 2009)
- J.D. Milliman, C.M. Rutkowski and M. Meybeck. "River Discharge to the Sea, A Global River Index (GLORI)" (LOICZ Reports & Studies No. 2., 1995)
- F. van der Leeden, Water resources of the world (Geraghty & Miller, Inc., New York, 1975)
- State Hydrological Institute, Russia and UNESCO, World Water Resources and Their Use, St. Petersburg, Russia, 1999
<http://webworld.unesco.org/water/ihp/db/shiklomanov/> (2 March 2009)

Dam data: Starting points for collection of dam data may include:

- World Register of Dams (International Commission on Large Dams; ICOLD)
- World Atlas (International Journal on Hydropower and Dams)
- International Rivers Network (IRN).
- WRI's Rivers at Risk from dams planned and under construction database – compiled from multiple sources.

The usefulness of national or subregional government sources varies dramatically, and avenues of personal communication may require much persistence and patience. Many basins have conservation groups set up (such as the Mekong River Commission), and these organizations can be extremely informative. Internet searches may result in anything from an email address from which a lengthy search for someone informative ensues, to direct acquisition of reliable data.

Irrigation data: Surface area under irrigation within a basin comes from:

- S. Siebert, P. Döll, and J. Hoogeveen. "Global map of irrigated areas version 2.0" (Center for Environmental Systems Research, University of Kassel, Germany / Food and Agriculture Organization of the United Nations, Rome, Italy, 2001).

The range of expected irrigation consumption rates for use in interpretation of irrigation pressure will be based on data from various sources, including but not limited to:

- R.L. Thompson. "Selection of crops for drought conditions" (The Department of Land Resources and Environmental Sciences, Water Quality and Irrigation Management, Montana State University)
- <http://waterquality.montana.edu/docs/irrigation/cropselection.shtml> (Accessed 2 March 2009)
- Frank and D. Carlson. "Colorado's net irrigation requirements for agriculture, 1995" (Colorado Department of Agriculture, December 1999).
- P. Chauvelon, A. Sandoz, V. Heurteaux and A. Berceaux in Remote sensing and hydrology 2000, M. Owe, K. Brubaker, J. Ritchie and A. Rango, Eds. (IAHS Publication no. 267, August 2001).
- L.K. Heng, P. Moutonnet and W.A. Baethgen. "Optimization of fertilizer application for irrigated wheat systems based on an integration of crop simulation models and nuclear techniques" (International Consortium for Agricultural Systems Applications, August 2001) <http://www.icasa.net/applications/fertilizer.html> (Accessed 2 March 2009)

Biome and ecoregional data will be primarily derived from D. M. Olson et. al. BioScience. 51, 933 (2001) and current work by R. Abell et al. (WWF-US). Other biodiversity related information will come from environmental organizations such as Conservation International, The Nature Conservancy, and IUCN.

Scale of application	Global to river basin, sub-catchments within a given river basin depending on size. Data is too coarse for smaller river basins.
Geographical coverage	Global – by major river basin.
Interpretation	<p>Indicator as it relates to conservation of global biodiversity: This indicator can be spatially related to the world’s biomes or ecoregions (freshwater or terrestrial depending on data availability). Biomes that are threatened by river fragmentation and flow regulation can be identified. This is crucial in order to preserve the greatest global biodiversity possible. Second, we will know which river systems are the most biologically diverse (some river systems span as many as ten biomes), and thus be able to target specific basins for conservation priorities.</p> <p>The indicator can also be spatially related to economics. To provide an understanding of the future fate of undeveloped river systems or reaches, we can look at the relationship between economics and river impact by employing a basin-scale equivalent of gross domestic product, or a gross RS product (GRP; see “definitions” section). We can examine both the current relationship between GRP and RS impact, and this relationship in conjunction with development pressure.</p> <p>Dams are promoted as a means of meeting water and energy needs and of supporting economic growth, contributing to the fact that now approximately two thirds of the world’s existing dams are in developing nations. Economic theory holds that societies progress through three stages of development, beginning with primarily agrarian economies, followed by a rise in industry, and finally shifting to service or knowledge-based economies. Following this, we can anticipate that demand for large dam benefits will continue growing in basins with primarily agrarian and industrial economies, whereas demand for dam benefits in knowledge-based economies has likely tapered. Of course, population size also affects how strong demand for dam benefits is in any basin. We can use the following equation to help assess whether impact could be expected to increase within LRSs according to current conditions:</p> $[(OECD_{pc} - GRP_{pc}) * RS_{pop}] / VMAD = DP$ <p>Where: OECD_{pc} = average per capita GDP (in US dollars) of nations included in the Organization for Economic Co-Operation and Development (OECD), GRP_{pc} = per capita gross RS product (in US dollars), RS_{pop} = population within RS, and DP = development pressure (in US dollars per m³ of discharge).</p> <p>A DP value of zero or below would indicate that the tertiary stage of economic development has likely been reached, and that the system will likely not increase in impact given the current amount of water and population in the basin. OECD nations function within predominantly tertiary stage economies, and thus the mean OECD GDP is chosen as a useful benchmark against which to compare RS economies.</p> <p>Limitations on the indicator:</p> <ol style="list-style-type: none"> 1. Additional dams for which no data are available may exist, inclusion of which would possibly alter the impact classification for a given RS. Therefore, impact classes represent the minimum level of impact. 2. VMAD may need to be estimated using environmental models for systems with unavailable data. 3. Both reliable discharge and environmental data (from which to estimate discharge) are largely unavailable for RSs in Indonesia and Malaysia, forcing these regions to be excluded from the study despite the fact that they are recognized as hot spots for freshwater and terrestrial biodiversity.

	<p>4. Although the effects of channel fragmentation and flow regulation do permeate entire river systems to some extent, sizeable tracts of large river systems may remain relatively unaffected even though the RS as a whole is classified as impacted.</p> <p>The rate of dam construction is so high in some regions that the indicators may change faster than our ability to update the study.</p>
Linkage with other indicators	Indicators related to freshwater ecosystem degradation; species abundance and habitat extent indicators; and freshwater ecosystem restoration trends as well as indicators on food production (irrigation dependent) and water stress at the global level.
Alternative methods and definitions	We are not aware of an alternative method to develop this indicator.
Related indicator sets	Rivers at risk from dams planned and under construction (WRI indicator) Land-use change by basin (WRI indicators) WWF's Global 200 indicators that show priority sites in terms of biodiversity IUCN List of Threatened species (national level)
Sources of further information	<p>Dynesius, M. and C. Nilsson. 1994. "Fragmentation and Flow Regulation of River Systems in the Northern Third of the World." <i>Science</i> 266: 753–762.</p> <p>Ward, J. V. and J. A. Stanford. 1989. "Riverine Ecosystems: The Influence of Man on Catchment Dynamics and Fish Ecology," pp. 56–64 in D. P. Dodge, ed. <i>Proceedings of the International Large River Symposium</i>, Canadian Special Publication of Fisheries and Aquatic Sciences 106. Ottawa, Canada: Department of Fisheries and Oceans.</p> <p>Nilsson, C., M. Svedmark, P. Hansson, S. Xiong and K. Berggren. 2000. River fragmentation and flow regulation analysis. Unpublished data. Umeå, Sweden: Landscape Ecology, Umeå University.</p> <p>Revenga, C., J. Brunner, N. Henninger, K. Kassem, and R. Payne. 2000. <i>Pilot Analysis of Global Ecosystems: Freshwater Systems</i>. Washington DC: World Resources Institute. http://earthtrends.wri.org/datatables/index.php?theme=2 (Accessed 2 March 2009)</p> <p>WRI (World Resources Institute) in collaboration with United Nations Development Programme, United Nations Environment Programme, and the World Bank. 2000. <i>World Resources 2000-2001: People and Ecosystems: the Fraying Web of Life</i>. Washington DC: World Resources Institute.</p> <p>WCD (World Commission on Dams). 2000. <i>Dams and Development: A new Framework for Decision-making. The Report of the World Commission on Dams</i>. London, U.K.: Earthscan Publications Ltd.</p> <p>Abell, R.A., D.M. Olson, E. Dinerstein, P.T. Hurley, J.T. Diggs, W. Eichbaum, S. Walters, W. Wettengel, T. Allnutt, C.J. Loucks, and P. Hedao. 2000. <i>Freshwater Ecoregions of North America: A Conservation Assessment</i>, World Wildlife Fund-United States, Washington, DC, U.S.</p> <p>Nilsson, C. and K. Berggren. 2000. "Alterations of riparian ecosystems caused by river regulation." <i>BioScience</i> 50(9): 783–792.</p>
Other institutions involved	UNDP; UNDESA; UNEP-WCMC; University of Umeå, Sweden World Resources Institute (WRI), WWF