to prevent further use. Biological impairment depends on the specific habitat under consideration. Biologically, water serves as host to aquatic ecosystems that are easily disrupted by polluted and/or an inadequate supply of waters. (Falkenmark, 1997) Certain species cannot adapt to changes in the surrounding flora and fauna or biologic food source. Chemical impairment can develop by a variety of pollutants introduced by upstream or up-gradient water uses; mercury, phosphorous and nitrogen pollution usually predominate. Unregulated underground water withdrawals near the coast can result in saltwater intrusion. Chemical impairment can also occur when specific levels of naturally occurring chemical compounds, which may have long-term effects on reproduction, feeding, physiology or metabolism, are not maintained. (Draper, 2002a) Physical impairment often results from turbidity and sediment loads, which increase to unacceptable levels due to land run-off and shoreline erosion, pollution, re-suspension of bottom sediments, dredging operations, or during high periods of fresh-water input from rivers and streams. (Minnesota DNR, 2002) Sediment from erosion can impair further use by damaging mechanical systems associated with, for instance, industrial cooling or public water supply treatment processes.

Elevated temperatures can have significant negative effects on environmental and ecological sustainability and wastewater assimilation functions. The amount of oxygen dissolved in surface waters is probably the single most important measure of habitat quality. Temperature affects the concentration of dissolved oxygen (DO) since warmer water cannot dissolve as much oxygen as colder water. (Minnesota DNR, 2002) This dissolved oxygen problem is often the result of wastewater discharges with temperatures above ambient temperature and heat loads from power plants. (CWI, 2000)

The importance of classifying water uses according to their consumptive effect cannot be overemphasized. (Dellapenna, 1997; Jackson et al., 2001; Draper, 2002c) When water use is largely non-consumptive, a significant portion of the water withdrawn is returned to the water source and is available for use by other water users downstream and by the environment.

An extreme example of the potential negative effects of excessive consumptive use is the Aral Sea Basin in Central Asia. Large river diversions for irrigation have caused the sea to shrink more than three quarters in volume and fifteen meters in depth over the past four decades. The shoreline of the Aral Sea has retreated 120 km in places, and a commercial fishery, which once landed 45,000 tons of fish a year and employed 60,000 people, has disappeared. Salinity tripled from 1960 to 1990, and the water that remains is now saltier than the oceans. (Jackson et al., 2001; de Villiers, 2000) Another example is Lake Chad in Africa, once the sixth largest freshwater lake in the world. Over the past three decades, its surface area has shrunk over 90%, from 25,000 square kilometers (9,652 square miles) in 1960 to 2,000 square kilometers (772 square miles) in 1990, as it and its tributaries have served as the sole water source for over 11 million people. (Hinrichsen et al., 2001)

Water demands

Various government and non-government agencies, both worldwide and in the United States, record water demand data, at varying times and locations. Unfortunately, there exists no standard format for reporting existing and predicted future demands. Different agencies use different categories with which to report water demands. For instance, the formats in which many estimates of global water demand are reported categorize water demands according to whether the demand is for Agricultural use, Domestic use or Industrial use. (Alcamo, 2000; NWF, 2001; Gleick. 2002) The demands are usually measured in cubic kilometers (km^3) per annum. However, others at the global scale may use the terms household, Domestic/Commercial, Municipal, Public Supply or some combination in place of Domestic use. (Postel. 1998; Cosgrove and Rijsberman, 2000; Jackson et al., 2001; Rosegrant et al., 2002) Electrical or Thermoelectric cooling may be an additional category. (Gleick, 1993) A separate category for Reservoir consumption (from evaporation) is sometimes included. These differences make direct comparison of different predictions difficult. (Shiklomanov, 1993; Cosgrove and Rijsberman, 2000; Jackson et al., 2001) In the United States, the unit of measure is normally million gallons per day (MGD). Water use in the U.S. has been reported in eight categories; Domestic, Commercial, Irrigation, Livestock, Industrial, Mining, Public Supply and Thermoelectric. (USGS, 1998) It has also been reported in four categories: Agricultural, Domestic, Industrial and Thermoelectric. (Fort, 1998; Washington Water Watch, 2002) Other variations exist.

In order to adequately compare and contrast different reports and predictions of water demands, this discussion considers the following categories of water use: Agricultural, Industrial, Public Supply and Electric Power Generation. A fifth category, Interbasin Transfer, is also proposed since such transfers can have a significant consumptive effect on water sharing. The units of measure are km^3/day and MGD. (See Table 3-2.)

A consideration for the magnitude of water use around the globe is enlightening. In the year 1995, the human population withdrew approximately 3,800-3,900 km^3 (1.00–1.03 billion gallons). (Rosegrant and Cai, 2003; Cosegrove and Rijsberman, 2000; Alcamo et al., 2000) This is equivalent to approximately 10.5 km^3/day (2,077,000 MGD) for offstream uses. Based on a definition similar to that of the U.S.G.S., the average consumption rate was 46%. (Rosegrant et al., 2002; Alcamo et al., 2000; Shiklomanov, 1998b) Industrialized countries withdrew approximately 3.0 km^3/day (790,000 MGD), with a 38% consumptive rate, and developing counties withdrew 7.5 km^3/day (1,980,000 MGD) with a 49% consumptive rate. (Rosegrant and Cai, 2002) By 2025, the average global water withdrawal is forecast to be 12.5 km^3/day (3,300,000 MGD), with an approximate 56% consumptive rate. (Raskin et al., 1998; Shiklomanov, 1998b; Alcamo et al., 2000; Rosegrant et al., 2002)

Large quantities of water are used in North America and these quantities are expected to increase. However, comparison of North American use is difficult because the withdrawals for the different nations are not collected in a consistent time frame. In 1995, withdrawals in the United States have been estimated as 1.29 km^3/day (341,000 MGD), with a 29% consumptive rate. (USGS, 1998) It has been estimated that 2025 withdrawal will increase 9.3%, with an average consumptive rate of 32%. (Shiklomanov, 1999) In 1996, Canadian withdrawals have been estimated as 0.12 km^3/day (32,530 MGD), with an average 11% consumptive rate. (Statistics Canada, 200) Withdrawals in 2025 are predicted to increase 31.1% and have an average consumptive rate of 21%. (Cross, 2001; Shiklomanov, 1999) For 1991, withdrawals in Mexico have been estimated as 0.25 km^3/day (66,118 MGD), with an average 11% consumptive rate. (UNEP, 1997) Withdrawals in 2025 are predicted to increase 22.4% and have an average consumptive rate of 50%. (Shiklomanov, 1999) (See Table 3-2) Water uses can be subdivided into those that remove water from the watercourse or aquifer for use, designated offstream uses, and those that use the water without removing it, designated instream use.

Table 3-2

Year 1995 Estimated Consumptive Water Use: Global & North America.

	Water Use		
	Consumptive		
Resolution	km^3/day	MGD (10^3)	Rate (%)
Global	10.5	2,770	46
United States	1.29	341	29
Canada [1]	0.12	33	19
Mexico [2]	0.25	66	11
	2025 Predicted Water Use		
Global	12.5	3,300	56
United States	1.41	373	32
Canada	0.16	43	21
Mexico	0.31	81	50

[1] Year 1996 data [2] Year 1991 data

Data from Shiklomanov, 1999

Offstream Water Uses

Direct water withdrawals from surface or underground sources for offstream uses are divided into five specific general categories: Agricultural, Industrial, Public Supply, Thermoelectric, Interbasin Transfer. (See Tables 3-3 and3-4)

Agriculture, primarily irrigation withdrawals, account for the largest offstream use, both globally and in North America. In 1995, worldwide irrigation consumption has been estimated as 8.45 km^3/day (2,230,000 MGD), approximately 80% of total global water consumption. (Rosegrant and Cai. 2002) In Asia, water withdrawals for irrigation account for 86% of consumption, compared to 49% in North and Central America and 38% in Europe. Rice growing in particular is a high water consumptive use; rice requires almost 7,650 cubic meters of water per hectare while wheat consumes 4,000 cubic meters per hectare, (Riceweb, 2003) Predictions for agricultural usage for 2025 are mixed, ranging to a high of 8.74 km^3/day (2,310,000 MGD) (Gleick, 1997; Shiklomanov, 1999) The average consumptive rate in 2025 is predicted to be 71%. (Shiklomanov, 1999)

In 1995, water withdrawals for agriculture in the United States have been estimated as 0.51 km^3/day (134,000 MGD). The average consumptive use for agriculture is almost 61%. Approximately 37% of withdrawals for irrigation purposes were from underground water sources and 63% were from surface water sources. It is important, however, to recognize that withdrawals for irrigation are seasonal and periodic, and not continuous like the water withdrawals needed for industrial production. (Cummings et al., 2001) Consequently, unless this anomaly is considered, a serious over-estimation of the water demands of agriculture may arise. (USGS, 1998) Livestock use is also included in the Agricultural use category. This use includes water for livestock, feed lots, dairies, fish farms and other farm demands not associated with irrigation. In 1995, water withdrawals for livestock uses in the United States have been estimated as 0.021 km^3/day (5,490 MGD), less than 2% of all freshwater withdrawals. Fifty-nine percent (59%) of withdrawals were from surface sources and 41% from underground sources. Although average consumptive use was 58% of the total, consumption rates in the various regions vary widely, from nearly 100% in Texas-Gulf and Souris-Red-Rainy regions to 4% in the Pacific Northwest. (USGS, 1998) Agricultural usage in the United States for Year 1995 has been estimated as 0.53 km^3/day (139,490 MGD) with an average consumptive rate of 61%. Agricultural usage in the continental United States for 2025 has been predicted to be 0.57 km^3/day (150,940 MGD) with an average consumptive rate of 57%. (Shiklomanov, 1999)

Agricultural withdrawals in Canada have been reported for Year 1995 as being 0.013 km^3/day (3,355 MGD) with an average consumption rate of 74%. (Statistics Canada, 2002) Predictions for 2025 estimate that agricultural usage in Canada and Alaska will increase 53% to approximately 0.0199 km^3/day (5,257 MGD) with an average consumptive rate of 79%. (Shiklomanov, 1999) Agricultural withdrawals in Mexico have been reported for Year 1991 as 86% of the total withdrawals, or about 0.215 km^3/day (56,800 MGD). (UNEP, 1997) By 2025, if there is little change to the ratio between domestic, industry, and agriculture, agriculture withdrawals will exceed 0.267 km^3/day (70,540 MGD). (Shiklomanov, 1999)

Industrial demands include process water for industrial, manufacturing and mining purposes. Internationally, the water demands for thermoelectric power generation cooling are included as a part of industrial demand. (Kemp-Benedict et al., 2002) In the United States, the water demands for thermoelectric power generation cooling are reported separately. (USGS, 1998) Worldwide industrial demand accounts for approximately 2.06 km^3/day (540,000 MGD) with an average consumptive rate of 11%. Predictions for global industrial usage show a 64% increase to 3.21 km^3/day (848,800 MGD) in 2025, with an average consumptive rate of 14%. (Shiklomanov, 1999)

In the United States, 1995 water withdrawals for industrial purposes, not including water demands associated with mining and thermoelectric power generation, totaled 0.106 km^3/day (28,000 MGD). Consumptive rates averaged 15%, although certain western regions, notably the Rio Grande and Lower Colorado, had consumptive rates above 50%. The larger industrial users, primarily in the Mississippi River Basin and East, had consumptive rates between 10% and 14%. (USGS, 1998) Mining use is included within industrial demand for this analysis. Mining use includes water for extraction of underground natural resources such as minerals, ores, and energy sources. Coal, crude petroleum and natural gas extraction is included in this category. In1995, U.S. freshwater withdrawal for mining uses was estimated as 2,560 MGD, with an average consumptive rate of 30%. However, consumptive rates vary widely among various regions, with the Texas-Gulf, Great Basin, and California regions having consumptive rates over 96%. Prediction for industrial use for 2025 in the continental United States, including mining, shows a 5.6% increase with an average consumptive rate of 6%. (Shiklomanov, 1999)

Industrial withdrawals in Canada in 1996 have been estimated as 0.039 km^3/day (10,390 MGD) with an average consumptive rate of 9%. (Statistics Canada, 2002) Industrial demands in Canada and Alaska in 2025 are projected to rise 32%. In 1991, industrial use in Mexico has been estimated as 8% of total use, or 0.020 km^3/day (5,284 MGD). (UNEP, 1997) By 2025, if there is little change to the ratio between domestic, industry, and agriculture, industrial withdrawals will exceed 0.025 km^3/day (6,560 MGD). (Shiklomanov, 1999)

Public supply includes water provided by public water supply utilities for public functions, including domestic and commercial uses. Domestic use includes household uses such as drinking, food preparation, bathing, washing clothes and dishes, flushing toilets, and watering of lawns and gardens. Globally, 1995 domestic per capita withdrawals varied from a high of 240 cubic meters in the United States to only 11 cubic meters in Sub-Saharan Africa, a level that is just over one-half of the 20 cubic meters per capita estimated to be required to meet the most basic human needs. (Rosegrant, 1997; Gleick, 1996) 1995 worldwide public supply water withdrawals have been estimated as 0.94 km^3/day (2489,000 MGD) with a consumptive rate of 15%. It has been predicted that 2025 water needs for public supply will increase 76% but that consumptive use will drop to just over12%. (Shiklomanov, 1999)

In the United States, 1995 withdrawals for public supply purposes have been estimated as 0.16 km^3/day (41,700 MGD). Sixty-three percent (63%) of the withdrawals were from surface sources and the remainder from underground sources. Overall consumptive use was just over 19%. (USGS, 1998) Public supply withdrawals in 2023 are predicted to rise 18% with a consumptive rate of 16%. (Shiklomanov, 1999) In 1996, public supply withdrawals in Canada have been estimated a 0.011 km^3/day (2,839 MGD) with an average consumptive rate of 11.4%. (Statistics Canada, 2002) Withdrawals for 2025 have been predicted to increase 20% with an average consumptive rate of 15%. In Mexico, 1991 withdrawals for public supply were 0.015 km^3/day (3,963 MGD) with an increase of 55% by 2025. (Shiklomanov, 1999)

Table 3-3

Year 1995 Estimated Offstream Water Use: Global & North America.
(Compiled from data sources described in text)

	Km^3/day	MGD	Consumptive Rate
Agricultural			
Canada	0.013	3,355	74
Mexico	0.215	56,800	86
U.S.	0.51	134,000	61
Global	8.45	2,230,000	80
Industrial			
Canada	0.039	10,390	9
Mexico	0.020	5,284	-
U.S.	0.106	28,000	15
Global	2.06	540,000	11
Public Supply			
Canada	0.011	2,839	11
Mexico	0.015	3,960	-
U.S.	0.16	41,700	19
Global	0.94	2,489,000	15
Thermoelectric			
Canada*	0.080	21,120	-
Mexico**	0.030	7,926	-
U.S.	0.50	132,000	3
Global	-	-	-

* Estimation for Canada & Alaska (1995)
** Estimation for Mexico & Latin America (1991)
- Data Unavailable

Thermoelectric power demands include water for the generation of electric power with fossil fuel, nuclear materials, or geothermal energy. The water use is primarily for cooling purposes. When used for evaporative cooling purposes, the consumption rate for water quantity purposes is less than 3% of the water removed from the water source. However, water use for thermoelectric power is primarily used for cooling purposes and has thermal effects on the returned water that may cause significant water quality concerns for reuse in the immediate vicinity of the discharge. Farther downstream, once the heat effect has dissipated, reuse normally is possible. Water withdrawn for closed water-cooling systems, however, may be considered as 100% consumptive. Globally, water withdrawals for thermoelectric power are reported as a part of industrial demands. In 1995, freshwater withdrawals for thermoelectric purposes in the United States were 0.50 km^3/day (132,000 MGD) (USGS, 1998)

Table 3-4

2025 Predicted Offstream Water Use & Consumptive Rate
(Compiled from data sources described in text)

	Km^3/day	MGD	Consumptive Rate
Agricultural			
Canada	0.012	5,260	79
Mexico	0.267	70,540	-
U.S.	0.57	150,940	57
Global	8.74	2,310,000	71
Industrial			
Canada	0.51	13,600	-
Mexico	0.025	6,560	-
U.S.	0.112	29,570	6
Global	3.21	848,800	14
Public Supply			
Canada	0.013	3,490	15
Mexico	0.019	4,920	-
U.S.	0.190	49,990	16
Global	1.65	437,090	12
Thermoelectric			
Canada*	0.100	26,335	-
Mexico**	0.049	12,840	-
U.S.	0.543	143,350	-
Global	-	-	-

* Estimation for Canada & Alaska
** Estimation for Mexico & Latin America
- Data Unavailable

The demand is projected to increase 8.6% by 2025. Thermoelectric power requirements for Canada and Alaska in 1995 were estimated as 0.08 km^3/day (21,120 MGD) while demand is expected to rise 24.6% by 2025. Thermoelectric power demands in Mexico and Central America in 1995 have been estimated as 0.030 km^3/day (7,926 MGD) with an increase of 62% by 2025. (Shiklomanov, 1999)

Interbasin Transfer (IBT) is an indirect water use that has special effects on water sharing. Under normal conditions, IBT is a consumptive demand on the waters available to users in the basin-of-origin. Unless the receiving basin's return flows are discharged back to the basin-of-origin, this demand consumes 100% of the withdrawals and may significantly reduce the future availability of water. In the case of the shared water resources, this becomes critical. Any water removed from the shared resource for use in another basin will not be available for further use by downstream parties unless the return flows from the receiving basin are back into the basin of origin. Although measurement of interbasin transfer has been made published for specific local or regional cases such as the Great Lakes and the Colorado River apportionments, no national, regional or global comparisons of the amounts of interbasin transfer has been made to date.

Instream Water Uses

Instream uses are divided into five specific general categories: hydropower, navigation, protection of human health by dilution of pollutants, recreation and environmental and ecological sustainability. (Jackson et al., 2001) These instream uses require water to remain in the watercourse in order to achieve the goals of their specific instream activity. Consequently, they compete with offstream uses, especially under conditions of water scarcity. Consideration should also be given to including reservoir evaporation as an instream use. While evaporation losses from reservoirs are not directly an instream use, the effect is a loss of water for downstream use. Water is stored for a variety of purposes, ranging from further instream use such as recreation, providing water to generate hydropower when needed, and providing storage for further offstream uses.

Hydroelectric power generation uses waterpower to generate electricity. When water moves through the turbines in a single pass, accurate estimates of the water used can be made by flow measurements and gate openings. At pumped-storage facilities, the estimate may be less accurate. Pumped-storage facilities are those that generate electricity during peak-load periods by using water that has been pumped to reservoirs at higher elevation during off-peak periods.

Navigation is an instream use that has immediate economic consequences if adequate water is unavailable to maintain an adequate channel depth. (U.S. Army, 2003) Its economic importance derives from its effectiveness in shipping bulk quantities of materials at a low cost. On U. S, waterways in 1996, over 620 million tons of coal, grain and oil and oil products were shipped by inland navigation. Over 80% of the nation's grain export, valued at over $25 billion, is shipped by barge.

(Maritime, 2003) The impact of inland water transportation on the economy of the State of Arkansas alone has been estimated as $811 million. (Nachtmann, 2002) The impact of recreational boating in a navigable watercourse is also significant. In the State of Maryland, it has been estimated that recreational boating contributed $356 million in personal income and $980 million in yearly economic activity, measured in 1993 dollars. (Chuck et al., 2000) On the European continent, the 25,000-km network of navigable canals and rivers provide the most efficient and reliable method of transporting goods. The major industrial areas in Europe depend on waterways that link them to parts of the North, the Baltic, the Black, and the Mediterranean Seas and the Atlantic Ocean. (Lyda, 2001)

Protection of human health demands adequate supplies of clean water. Globally, almost 34,000 deaths occur daily from water-borne diseases. In developing countries, 80% of illnesses are water-related. (Environment Canada, 2003; International, 2003) Such waterborne diseases include cholera, typhoid, bacillary dysentery, polio, meningitis, hepatitis A & E, and diarrhea among others. (Gleick, 2001; International, 2003) Other than fecal-oral diseases, the most important category of water related disease is water related insect vector. Malaria, filariasis, yellow fever, and dengue fever are all classified as water related diseases because their vectors breed in water. Malaria alone kills an estimated 1-2 million people annually and there are up to half a billion new cases every year, second only to diarrheal and respiratory infections. (Kjellen and McGranahan, 1997) Industrialized nations are increasingly at risk from water-related diseases that may increasingly be imported by travelers and visitors to these countries and from diseases that may establish themselves. (Gleick, 2001) Growing threats to the environmental and ecological integrity of the world's watersheds come from rising populations, water pollution, deforestation, withdrawals of water for irrigation and municipal water supply and the regulation of water flows resulting from the construction of large reservoirs. (WCD, 2000)

One of the most significant water resource issues facing the various states within the United States is Total Maximum Daily Load (TMDL) compliance, which derives from the Federal Clean Water Act, 33 U.S.C. §§ 1251 *et seq* (CWA), requiring that states identify waters not meeting water quality standards and develop specific plans to bring the waters into compliance. While discharge from point sources, i.e., specific pipes and devices that discharge pollutants at a specific point, are regulated and should treat discharges to meet TMDL compliance, other sources of pollution (non-point sources) are not so regulated. These other sources, often erosion and sediment particles to which are attached various pollutants, are not treated. Unless strict local regulations are effective in sediment and erosion control, dilution of these non-point pollutants can be accomplished only with sufficient quantities of water in the watercourse. The exact quantification of what sufficient quantities of water are required to meet TMDL requirements remains a much-debated question and is, in many respects, requires a site-specific examination of the existing and potential future pollutant loads. (NDEP, 1994; USGS, 2002b; USEPA, 2003)

In many regions outside of the United States, such standards do not exist, however. In this case, the parties should consider establishing biological, health, physical and chemical quality criteria for all significant water bodies in the shared water resource to continually improve water quality where necessary. The parties should establish minimum standards both for discharge of effluents and for receiving waters and institute standards for land use management such as limits on agrochemical use, deforestation, and wasteful irrigation practices. (ASCE, 2001a) Such rational land use standards should prevent land degradation, erosion and siltation of lakes and other water bodies. (Draper, 2002a)

Recreation, and environmental and ecological sustainability are two separate water demands but they are closely related since, in most cases, both uses depend on adequate supplies of clean water remaining in the watercourse. They are related because they are both instream uses that are related since, in most instances, water-based recreation is based on a sustainable environment and ecological systems. Hunting and fishing depend on a stable population of game animals or birds, or game fish. The two uses often compete, however, with respect to water quality. If recreational use unreasonably pollutes the watercourse, through the discharge of heavy metals, or oil and gas from boat engines, or introduced species are predatory for instance, environmental and ecological sustainability becomes threatened.

Environmental and ecologically sustainable use of water is a fundamental element of sound water resources management. Environmental and ecological flow requirements are important components of water use and they should be incorporated in allocation procedures. (WCD, 2000; Hirji and Ibekk, 2001) Watersheds, aquifers, and wetlands provide natural storage besides serving other functions. (Hirji and Ibekk, 2001) It is emphasized that a goal of ecosystem sustainability is necessary for more than purely aesthetic or philosophical reasons. Economic prosperity as well as adequate public health depends on a healthy environment as does significant industrial and commercial activities. Recreational activities depend on adequate supplies of water and a healthy environment. Hunting and fishing are among the largest recreational activities and both depend on clean water. One-tenth of the total world fish yield is caught on inland waters, not including subsistence fishing. (Covich, 1996) Environmental and ecological degradation of water resources exacts its own costs in human terms. Degraded watersheds and recharge areas result in reduced and unreliable water supply. Destabilized wetlands result in uncertain food supplies and altered hydrological and ecological functions. Declining productivity of commercial and subsistence game animals and birds, fish, shellfish, or waterfowl populations carries economic costs and severely affects indigenous peoples and fishing communities. Likewise, recreation and tourism may diminish. If wetlands are no longer available to provide storm-surge protection, local and downstream areas may sustain more frequent and severe flood damage. Underground water recharge patterns may be altered. To safeguard the productivity of water resources, it is essential to protect watersheds, recharge areas, and ecosystems from irreversible degradation.