Municipal, Industrial and Energy Water Demands

Indicators and Indices for the World Water Development Report

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Introduction

The World Water Assessment Programme (WWAP) was announced at the Second World Water Forum (WWF) held in the Hague in 2000 as a United Nations system-wide initiative to establish better ways of measuring progress towards targets established under Agenda 21. Eleven challenge areas were identified in the WWF that should be addressed in the WWAP (see Table 1).

Table 1. WWAP Challenge Areas

Measuring Basic Needs
Securing Food Supply
Protecting Ecosystems
Managing Risks
Sharing Water Resources
Valuing Water
Governing Wisely
Ensuring The Knowledge Base
Water And Energy
Water And Industry
Water And Cities

The Boston office of the Stockholm Environment Institute (SEI-B) was asked to propose indicators for municipal, industrial and energy water demands (note that indicators for other aspects of water are being developed as well – see Table 2). The quantities of water demanded in these sectors tie in directly with the challenge areas of Water and Energy, Water and Industry and Water and Cities, but also tie in indirectly with all of the challenge areas. For example, municipal water demands may reflect whether certain segments of society have access to adequate water supply to meet *basic needs*. The treatment, or lack thereof of pollutant loads to receiving water by these sectors can impact *ecosystem health*. Also, an understanding of the *value of water* in these sectors, from both a financial and social standpoint will be key in equitable sharing of the water available in a region. The breadth of issues that the WWAP is asked to address suggests that the indicators be broad enough in scope to provide insight for the 11 challenge areas. On the other hand, they must communicate in simple terms to help clarify the nature of the challenge and a means to address the challenges. Our approach therefore is to develop indicators that both address the three challenge areas – Water and Energy, Water and Industry and Water and Cities – and readily feed into the remaining challenge areas of the WWAP.

Table 2. Indicator Sectors for WWAP

Ecosystem Coping Capacity
Ecosystems
Extreme Events (Flood and Drought)
Food and Agriculture
Ground Water Resources
Human Dimensions of Economic Development
Institutions and Legal
Instream and Other Non-Consumptive Uses
Investment and Economic Development
Municipal, Industrial and Energy Demand
Poverty and Gender
Reservoir Data
Social and Economic Coping Capacity
Storage and Delivery
Structural Change and Economic Development
Surface Water Resources
Water and Health
Water Quality

Indicators for Municipal, Industrial and Energy Demand

Indicator Methodology

To facilitate comparability across the WWAP sectors, a taxonomy of indicator information has been established (see Strzepek, March 2001). Each sector is to be represented by a vector of key attributes. Associated with the attributes are variables that reflect a characteristic of that attribute. The values of the variable are then categorized to form an indicator with values from 1 to 5, with 1 reflecting a bad value and 5 reflecting a good value.

Previous Work

Early work on water indicators did not look at demand directly, but indirectly through the concept of water stress or scarcity a society might face. An early and widely used indictor of the potential for water stress was the water barrier concept (Falkenmark (1989), Falkenmark et al., 1989; Falkenmark and Widstrand, 1992; Gleick, 1993a; FAO, 1993; Engleman and LeRoy, 1993), which used a ratio of total water available to population on a country basis. This is compared to reference levels of 1000 m^3 per person, indicating "water stress," and 1700 m^3 per person, indicating "water scarcity." This indicator has merits in that it uses readily available data, and is simple yet meaningful. But it does not give an indication of the withdrawal requirements, which vary dramatically based on climate, the local mix of economic activities and dependency on agriculture.

To address the limitations of the water barrier method, another type of indicator was developed by the Polish scientist Balcerski, who was investigating the problems encountered by countries where water use approached the stable fraction of water supply (Falkenmark and Lindh, 1976). This approach was further developed in to the *use-to-resource ratio* concept by Raskin et al. (1995), elaborated Raskin et al. (1997). This indicator has the advantage of highlighting areas that are facing physical problems of water scarcity. This is clear when the ratio is greater than one. But those areas with ratios less than one also could face serious water constraints, depending on the variability of the supply, the nature of water demands and their potential growth, whether the supply was imported (and therefore subject to political change), and the water needs to support ecosystems. The authors suggest a ratio higher than 25% to indicate a country facing water stress, later revised to a more complex categorization of the ratios into four categories.

As a further approach to water indicators, Falkenmark and Lundqvist (1997) examined water use by sector using medians of sectoral water use as a means of comparison, based on a common unit of 100 liters per person per day, denoted by H. Falkenmark argues that this quantity represents a “decent and realistic quality of life” (Falkenmark, 1993). The quantity of water for industrial purposes is 10H, or 360 m^3 per person, and for irrigated agriculture for food self-reliance between 20H to 30H, or 720-1080 m^3 per person depending on the climate conditions. These water quantities as a function of H are essentially indicators of relative demands in the three sectors of households, industry and agriculture, and provide a means of comparing water use between countries.

A Proposed Framework for Water Demand Indicators

Previous work in water indicators, as described above, looked at water-related barriers to development, comparison of use to available resources, and cross-sector metrics. These approaches fail to distinguish two key aspects of water demand: sufficiency and efficiency. We propose an indicator framework that directly addresses these two key questions, building on previous work but separating the two aspects. The first requirement is sufficiency – whether for domestic consumption, where sufficiency means having enough water for basic survival, or for industry, where sufficiency is determined by socio-economic requirements. A second key requirement, efficiency, relates to opportunities to reduce total water demand. There are two key elements to this second requirement. The first is the array of activities for which water is used and the second is the efficiency of water use for each activity. Several factors influence efficiency, including technological choice, cultural practices, and levels of affluence. For example, domestic water use per person in a rural setting is typically much less than in an urban setting. Similarly, a person in a city in the US typically uses much more than a person in a city in India. A parallel set of comparisons can be made for the industrial and energy sector water demands. Knowledge of water use sufficiency and efficiency forms a basis for identifying areas where we might make improvements in the allocation and use of water.

We outline indicators below, first for municipal water demands, followed by a section on industrial and energy water demands, and finally a short section on water pollution for all sectors.

Indicators for Municipal/Domestic Demand

Sufficiency. An index of sufficiency in water in the municipal sector must use the attribute of water consumption per capita[1]. The mapping proposed here is based on critical levels of water use per capita given in the literature. A possible mapping of this attribute to an indicator would use the WHO criteria of 20 liters per capita per day as the worst possible condition, corresponding to a value of 1. Gleick (2000) argues that there is an essential human right to a minimum quantity of water of 50 liters per capita per day. This figure includes the physiologically necessary amount of water for drinking, as well as the minimum needed for food preparation, bathing and sanitation. This criterion of basic water needs at 50 liters per capita per day would warrant a 2. Falkenmark's measure of the water needed for a "decent and realistic quality of life" is 100 liters per capita today. Much of the world's population survives on less than 100 liters per capita per day, and would fall into category 3. Above 100 liters per capita per day would warrant a value of 4. Finally, any amount over 150 liters per capita per day would qualify as a 5, indicating that the domestic sector, on average, has sufficient water. The mapping would therefore be as shown below in Table 3.

Table 3. Index for Sufficiency of Municipal Water Use

Water Use (l/cap/day)	Assigned Value	Rationale
< 20	**1**	Minimum required for drinking water/sanitation (WHO)
>20 and <50	**2**	Minimum required for basic needs (Gleick, 2000)
>50 and <100	**3**	Level below "decent quality of life" (Falkenmark, 1993)
>100 and <150	**4**	Above "decent quality of life" (Falkenmark, 1993)
>150	**5**	Water sufficiency not an issue

The most problematic aspect of this indicator relates to the data, which are typically at the municipal level and therefore include commercial water use, which can be substantial and therefore misleading with respect to the water actually reaching households. Another problem inherent in these high level indicators is the issue of averaging – there are likely to be segments of the population with lower levels of access, and it would be advantageous to also have a measure of the portion of population without access. Knowledge of these numbers would also give a measure of the potential increase in municipal demands if access were made available.

Efficiency/Reduction Potential. The potential for water-use reduction in the municipal sector will have the opposite set of properties – as water consumption exceeds that necessary for a "decent quality of life," it may be possible to reduce consumption without reducing quality of life. Setting aside the issue of leakage, which may be a major factor in high water usage rates

[1] There is a crucial assumption that the water actually reaches people, which may not be the case with the current data available.

in low income or poorly maintained systems, higher consumption rates can be attributed to two factors. The first would be the array of water-using activities of users, such as washing machines, dishwashers, and watering lawns, and the second would be the efficiency of water use in each of those activities. Ideally an indicator of water reduction potential would separate out these factors, but the data are not available to support such an indicator.

Using available data on per capita consumption at the national level, and assuming the average consumption of municipal water in Western European nations to be a level of good quality of life, without excessive water use, establishes the high end of the indicator, a value of 5. Average Western European levels are close to 250 l/capita/day (estimated from national data, as reported in Heaps et al., 1998). National average per capita withdrawals are shown in Figure 2. As shown in the figure, only 5 countries use more than 550 l/capita/day, including the US, at 560 l/capita/day. Withdrawals above this level are assigned an indicator value of 1. Using a linear mapping of the difference results in the following mapping:

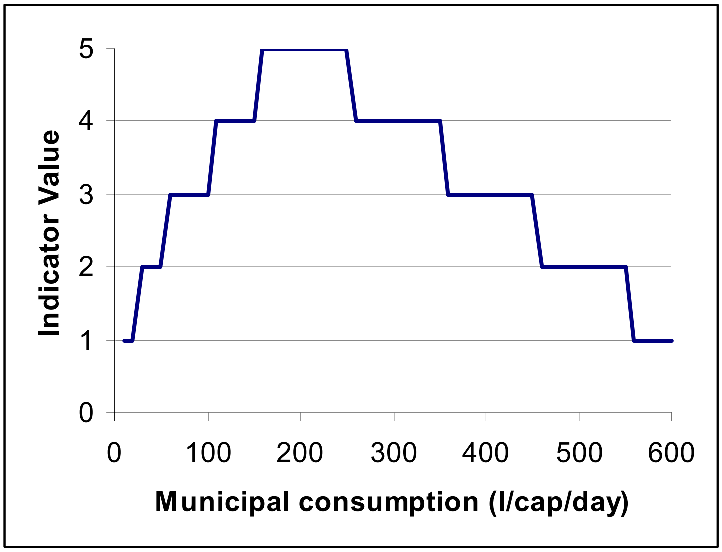
Table 4. Index for Reduction Potential of Municipal Water Use

Water Use (l/cap/day)	Assigned Value
>550	1
>450 and <550	2
>350 and <450	3
>250 and <350	4
<250	5

A Single Index for the Municipal Sector

The two indices above could be combined, giving an inverted-U-shaped behavior. The first goes up (improves) with increased water consumption, while the second declines with increased water consumption, as illustrated in Figure 1. Between the level of 150 l/capita/day and 250 l/capita/day, there is a gray area, where additional withdrawals above "sufficiency" provide some comfort and security against fluctuations, but still below a level where water use becomes wasteful and excessive. Note that because a low indicator value might reflect either insufficient or excessive water use, the two indices may be most useful viewed separately.

Figure 1. Sufficiency and Reduction Potential Indices of Municipal Water Use



For a single index of municipal water demand, a possible combined index would have the following properties (see Table 5).

Table 5. Index for Municipal Water Use

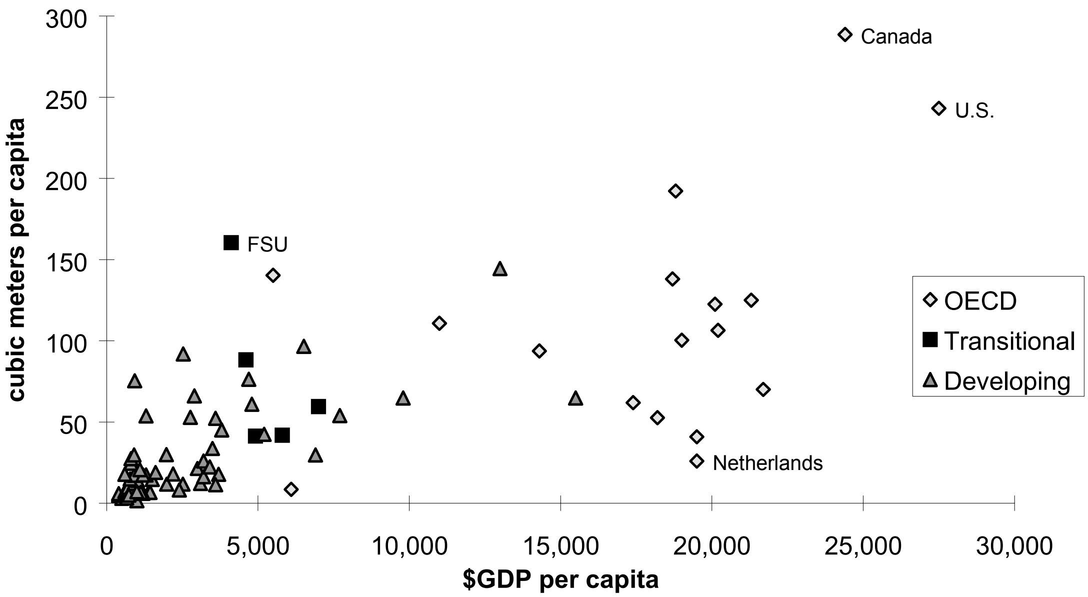
Liters per capita per day	Assigned Value
<20 or >550	1
>20 and <50 *or* >450 and <550	2
>50 and <100 *or* >350 and <450	3
>100 and <150 *or* >250 and <350	4
>150 and <250	5

The Current Availability of Municipal Demand Data Globally

Municipal water use data are given on a national basis in Gleick's annual series of reports, *The World's Water* (2000) for the globe. Data for a partial set of countries are given in FAO's AQUASTAT. In both cases, these data are complicated in that they typically include commercial water use, which can distort the assessment of how much water is used by households. Ideally, commercial use itself would be broken out into sub-categories, for example, into services, government, hospitals, and tourism sectors to better assess opportunities to reduce use in these sectors.

The problem of these aggregated numbers can be seen in Figure 2, showing current domestic water intensities varying widely between countries and regions and, while generally increasing with income, also demonstrate a wide variation, indicating the importance of other factors. For example, it is well known that domestic water intensities in a given region reflect, in addition to income levels, also water infrastructure, technology and water availability. Including commercial water use in the total further confuses the assessment. This information gives no indication of whether water use is adequate or excessive. Unfortunately, these are the data available and must form the basis for national indicators of municipal water demand.

Figure 2. Domestic withdrawals vs. income

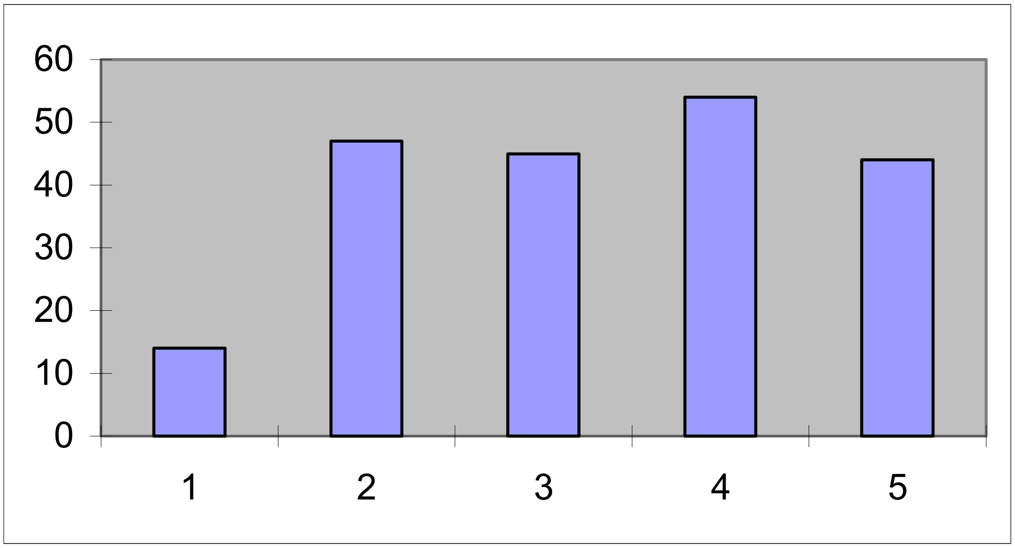


Sources: For water withdrawals, Najlis (1996); Shiklomanov (1997); Raskin et al. (1995); for GDP per capita, CIA (1997)

There is no comprehensive data set for municipal water use at the watershed level. One approach to estimating municipal demands would use geo-referenced population data, such as that available on a 5' x 5' scale through the CIESIN (Gridded Population of the World – Version 2 – 2000), which has population counts and densities for 1990 and 1995. Also, the Oak Ridge National Laboratory's LandScan 2000 Global Population Database is available at a resolution of 0.5' (1km), and uses probabilities based on a combination of census counts (sub-national), proximity to roads, slope, nighttime lights, and land cover to estimate population. Although the UN provides data on the urban/rural split and levels of access for piped water supply and sanitation for rural and urban populations (Habitat, 2001a) it is not geo-referenced: therefore, some modeling and extrapolation would be required to get an estimate of these numbers at the sub-national level.

At the city level, the Habitat database (2000a) gives per capita consumption of water for approximately 200 cities. These data could be used directly in the construction of municipal water demand indices. The frequency of distribution of index categories for these data is illustrated in Figure 3.

Figure 3. Frequency of Index Categories for 200 Cities



Relationship to WWAP Challenge Areas

Developing municipal demand indicators at the city level directly supports an evaluation of the *Water and Cities Challenge Area*, in assessing adequacy of water used in households, and opportunities to reduce use in the sector. This indicator can also be used on the *Sharing Water Resources Challenge Area*, to illustrate both adequacy of supply to the municipal sector, and whether this sector can be a source of water for other, competing sectors through water conservation.

The indicators developed above address the issues of water sufficiency and efficiency at the national, river basin and city scales, where data are available. However, other aspects of municipal water demand feature in several other challenge areas. The total water consumed by the municipal sector at the national and river basin levels is important to on the *Sharing Water Resources Challenge Area* to look at the demand relative to available supply. The percent of population with piped water supply may be a useful indicator for determining the potential for recycled water for other uses (i.e. industrial and energy). A further indicator related to municipal demand that may feed into other watershed or national level indices would be the total BOD loading from the sector, which is discussed further at the end of this paper. Both of these would relate to the *Protecting Ecosystems Challenge Area*.

These data are identified as attributes for at the national and river basin scale below.

National Level Attributes

Data are available at the national level, although domestic consumption is not given separately from commercial consumption, with the exception of the US. However there are data that can illuminate the issues of water use sufficiency and efficiency. The attributes for indicators for the municipal sector based on these data are as follows:

1. Total municipal withdrawals by country (primary), for use in the challenge areas of Measuring Basic Needs and Water and Cities;
2. Municipal withdrawals per capita (secondary), for use in the challenge areas of Measuring Basic Needs and Water and Cities;
3. Rural vs. urban population (secondary), for use in the challenge area of Measuring Basic Needs;
4. Percent of population with piped water or access to safe drinking water (primary), for use in the challenge area of Measuring Basic Needs;
5. Pollutant loading, based on average per capita loads (modeled), for use in the challenge area of Protecting Ecosystems; and,
6. Connection to treatment facilities, including composting toilets (secondary and modeled), for use in the challenge area of Protecting Ecosystems.

Basin Level Attributes

Ideally, the same dataset at the national would be available at the basin level. These do not exist with the exception of the US. The best that can be done is to use the geo-spatial data on population, delineated by watershed, and assume the population in that watershed has the same characteristics as the national average, unless that data for the river basin exist. It does not make sense to give indices at the basin level for demands, since they would simply mimic those at the national level and therefore would not provide new information.

Indicators for Industrial & Energy Demand

The issue of sufficiency of water use in industry and energy sectors is not addressed here. The nature, extent and structure of these sectors should be established in a broader socio-economic context. Therefore, only the efficiency of water use in these sectors is examined in this paper. To address the issue of the efficiency of industrial water use, we suggest using the available data on value added (VA) by sub-sector at the country level with data on water use by sub-sector using best practices.[2] These data are combined to create a normalized index, where a value exceeding one would imply an opportunity for introducing water conservation practices in the industrial water sector, and a value less than one would indicate a more efficient industrial water sector. The indicator for efficiency in industrial water demand would be calculated as follows:

$$\text{Normalized Indicator} = \frac{\text{Industrial Withdrawals}}{\sum_{\text{subsectors}} \text{VA} \times (\text{Withdrawals/VA})_{\text{BP}} \Big/ \sum_{\text{subsectors}} \text{VA}}$$

[2] The data on best practice water use by industrial sub-sector are not well established. However there are data on water use by industrial sub-sector in the US. The use of US data is based only on availability, and is problematic in that these may or may not be representative of best practice. At best, the proposed indicator would show how other countries are doing relative to US industry. Where more rigorous data are available on best available technologies, these should be used.

Unlike other industrial sectors, in the energy conversion sector a physical measure of activity – energy production – is available, and can be readily used to develop an indicator of efficiency where there are also data on energy water consumption. Water is used in thermoelectric generation principally for cooling purposes. A variety of cooling technologies is available. These include once-through systems, which have high withdrawal rates, but low consumption rates (Gleick, 1993b); cooling towers, which have low withdrawal rates but relatively high consumption rates (Gleick, 1993b); and closed systems, which have both low withdrawal and low consumption rates (Willenbrock and Thomas, 1980). Closed systems are usually introduced when little or no water supply is available, typically using saline/brackish water instead, and are not widely used.

However, most data for industrial and energy sector water use is reported combined. For the case where industrial water use includes energy water use, we propose a modified indicator:

$$\text{Normalized Indicator}_i = \frac{\text{Industrial Withdrawals (incl energy)}}{\sum_{\text{subsectors}} \text{VA} \times (\text{Withdrawals/VA})_{\text{BP}} + E_{\text{thermal}} \cdot I_i}$$

where i = 1, 2 or 3, for the different cooling technologies (see below),
$E_{thermal}$ is the thermal energy production for the country, and
I_i is the "best practice" in terms of intensity of water use for technology i.

There are three broad categories of technologies for cooling purposes in thermal energy production as discussed above in the data section. Each has different implications for consumption and withdrawal of water. We will use figures for these technologies that are considered to be "best practice." The technologies are:

1. Once-through technologies have low consumption water use, but require large withdrawals. Once-through technologies also have implications in terms of thermal pollution. (Consumptive use ranges from 0.8 to 1.2 $m^3/10^3$kWh (Gleick, 1993b and Willenbrock and Thomas, 1980).)
2. Cooling towers are the most consumptive technology, but have lower total withdrawals than once-through technologies, and are a low concern regarding thermal pollution. (Consumptive use ranges from 2.2 to 3.2 $m^3/10^3$kWh (Gleick, 1993b and Willenbrock and Thomas, 1980).)
3. "Completely" closed systems are the least consumptive, with very low withdrawals. However, they pose a problem in terms of getting rid of heat from cooling fluid, and tend to be more expensive (assumed consumption of zero).

Where information on the most common technology in a country is available, that technology will be used to calculate the indicator. Where those data are not available, we propose a range of indicators be calculated.

A Single Industrial Water Demand Index

We would propose a review of country-level data, followed by a calculation of the normalized indices and the development of a frequency diagram to establish the index of potential for response in the industrial sector.

The Current Availability of Industrial and Energy Demand Data Globally

Industrial water consumption by country, inclusive of energy demands, is given in Gleick (2000), WRI, and through AQUASTAT, but the data are not given in a common base year. Also, these data are not given by industrial sub-sector (although energy is given separately in the OECD data set), with the exception of US data, which are given by sub-sector on the USGS website for 1995.

Ideally, to address the issue of efficiency, the amount of output, both in terms of production and monetary value for each sector would also be given. This would allow for comparison of water use per unit of production or per dollar of value added (i.e. water use intensities) across geographic regions, without reliance on US data. Actual data on value added by industrial sub-sector for each country is available through UNIDO, and national accounts data. Data on sub-sectoral water consumption per dollar value added or production unit can be calculated for the US using the USGS database on industrial water consumption, national accounts data or UNIDO for value added data by industrial sector.

Data on water withdrawals for energy conversion are relatively scarce, with the exception of the OECD, which collects data on water use for thermoelectric generation from its members (OECD, 1997; 1999). In addition, data on water use for oil refining are available for the United States. Estimated thermoelectric intensities for the OECD countries, computed using the withdrawal statistics from the OECD and energy production data from IEA (1997a, b) are shown in Table 6. The values vary over a wide range, due to differences in the mix of generation and cooling technology, and in the fraction of total water requirements that are supplied from freshwater sources. For example, Japan meets much of its requirements for thermoelectric cooling using salt-water (Raskin et al., 1997), which explains the low value of 0.3 m^3/GJ.

Table 6. Thermoelectric cooling intensities in OECD countries

Country	m^3/GJ
Canada	37
United States	16
Austria	13
Finland	2
France	15
Germany	13
Italy	10
Netherlands	16
Portugal	28
Spain	11
Sweden	0.1
Turkey	24
United Kingdom	4
Japan	0.3

All of the data above are given at the national level. To get at river basin demands, ideally industrial and energy water demand data would be available in geo-referenced format. Also, such data would be broken out by sub-sector, for example: pulp and paper, iron and steel, metal refining, chemical, petroleum refining, non-metallic minerals (such as stone, glass and clay) processing, food processing, tanneries, textiles, mining, and energy, including thermal cooling. The use of wastewater, low quality (i.e. saline) or recycled water is increasing in the industrial sector, and could be explicitly accounted for in assessing the sector's water demand.

Relationship to WWAP Challenge Areas

Developing industrial and energy demand indicators directly supports an evaluation of the *Water and Industry and Water and Energy Challenge Areas*, in assessing opportunities to reduce use in these sectors. These indicators can also be used on the *Sharing Water Resources Challenge Area*, to illustrate whether these sectors can be a source of water for other competing sectors through water conservation.

The indicators developed above address the issues of water efficiency at the national, river basin and city scales, where data are available. However, other aspects of industrial and energy water demand feature in several other challenge areas. The total water consumed by the these sectors at the national and river basin levels is important to on the *Sharing Water Resources Challenge Area* to look at the demand relative to available supply. A further indicator related to industrial and energy demand that may feed into other watershed or national level indices would be the total BOD loading from the sector, which is discussed further at the end of this paper. Both of these would relate to the *Protecting Ecosystems Challenge Area*.

These data are identified as attributes for at the national and river basin scale below.

National Level Attributes

As with the municipal water demands, the ideal data are generally not available, as discussed above. Industrial and energy demands are generally available as a lumped figure at the national level, with the exception of the OECD countries, which have separate figures for industrial and energy water use. The attributes for the industrial and energy sectors, as data are available, therefore include the following:

1. Total industrial water withdrawals (primary); for use in the challenge areas of Sharing Water Resources, Water and Industry, and Water and Energy,
2. Total energy water withdrawals for OECD countries only (primary); for use in the Water and Energy and Sharing Water Resources Challenge Areas,
3. Thermal electric generation (primary); for use in the Water and Energy Challenge Area,
4. Sub-sectoral consumption per dollar value added or production unit (secondary, based on US data but ideally based on "best available technology"); for use in the Water and Industry Challenge Area, and,
5. Pollutant loading by sub-sector (secondary and modeled) for use in the challenge areas of Water and Industry, Water and Energy and Protecting Ecosystems.

Basin Level At*t*ributes

It is not possible to obtain estimates of industrial and energy water demands at the basin or watershed level with existing data, with the exception of the US.

Water Pollution

An ideal indicator of water pollutant loadings from the municipal, industrial and energy sectors would compare loadings before and after treatment to best-practice levels. However, national-level estimates of municipal and industrial water pollutant loadings are not widely available, making the development of an indicator problematic. Methods to estimate loadings for these sectors are outlined below.

<u>Municipal Loadings</u>. Ballpark estimates of pollutant loading intensity for the municipal sector can be used to generate rough estimates of total loads. These estimates could then feed into other aspects of the WWAP study. For example, estimates of pollutant loading factors for the sector for Biological Oxygen Demand (BOD) have been reported.[3] Values for the United States (Chapra (1997)), which may be representative of OECD or developed countries, and representative values for developing countries (WHO (1982)) are shown in Table 7 (drawn from Holt and Kemp-Benedict (2000)).

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[3] BOD is the amount of oxygen that bacteria in water will consume in breaking down waste. It is the most widely used measure of organic pollution because it is an overall indicator of an aquatic system's health.

Table 7. Typical loading rates for untreated domestic sewage

Region	BOD (kg/cap/year) sewered areas	BOD (kg/cap/year) unsewered population
United States (developed)	54.9	11.0
Developing countries	23.7	8.3

Industrial Loadings. Estimates of pollutant loading intensities for industrial sub-sectors are available, which can be used to generate rough estimates of total loads. These estimates could then feed into other aspects of the WWAP study. Hettige et al. (1998) used plant- and sector-level information on emissions and employment from 13 national environmental protection agencies, and output and employment data from UNIDO. Their econometric analyses showed that the ratio of BOD to employment in each industrial sector is about the same across countries. This finding allowed the authors to estimate BOD loads across countries and over time. This database may provide a starting point for developing national indicators of industrial water pollution. However, the number of countries represented is not sufficient to support such an analysis at this time. The pollutant emission coefficients provided by Hettige et al. (1998) based on the cross-country study and the coefficients provided by the World Bank's "New Ideas in Pollution Regulation" (http://www.worldbank.org/nipr/), which are based on U.S. data, can be used to estimate pollutant loadings from industry for input into other parts of the WWAP analysis.

Conclusions

A proposed framework for indicators of municipal, industrial and energy demands is presented that addresses the crucial issues of water sufficiency and water efficiency in these sectors, that directly impact the three WWAP challenge areas: Water and Energy, Water and Industry and Water and Cities. An index that combines these features for municipal demand reveals an inverted U-shaped behavior (see Figure 1). The index for industrial and water demands does not address the issue of sufficiency, which must be established through a socio-economic evaluation, but does address the issue of efficiency through the use of a normalized indicator based on value-added in industrial and energy sub-sectors relative to that of the U.S. Finally, while the lack of available data prevents the development of indicators of water pollution from the sectors, a method for estimating loadings from these sectors is given to provide input to other indicators in the WWAP, and to address the Protecting Ecosystems challenge area.

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