TOWARD DECISION SUPPORT SOFTWARE TOOLS FOR THE ENERGY-WATER NEXUS

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ABSTRACT

Integrated Water-Energy Assessment (IWEA) has been used to quantify changes in water quality and quantity associated with thermoelectric electrical power generation. For this water-energy nexus, two indicators of IWEA are defined: the Process Change Index (PCI), which captures the changes in water quality as well as water usage within the power generation facility, and the Environmental Change Index (ECI), which quantifies changes in the surface water quality before and after the power plant is installed. The first application of our approach has been local at the Poplar River Power Plant in the Province of Saskatchewan, Canada: a thermoelectric coal-fired plant. The ECI and PCI values before and after this plant was commissioned in 1981 indicate a reduction in water quality. Separation of the data into seasonal values also allows the indices to capture the influence of high and low flows in the spring and winter months. This is the first successful step of a much larger project with the aim of developing a predictive decision support software tool to assist local governments and industry co-manage both energy and water.

INTRODUCTION

Efficient co-management of water resources and energy generation is pivotal to promote socioeconomic development. Energy and water are inextricably interdependent because large amounts of each are often needed in the production and transportation of the other (King et al. 2008). Therefore, threats to energy security have become synonymous with those to water security. Increase in global energy demand by 45% by the year 2030 is expected to be met by increases in thermoelectric output from coal, oil and gas (IEA 2008). In addition, climate change is expected to significantly increase stress on freshwater supplies (IPCC 2007). As a result, there is a need to document and communicate the relationship between water and energy.

Efficient co-management of water resources and energy generation is pivotal to promote socioeconomic development. Given the importance of energy and water policies to the world economy and human development, a variety of studies have focussed on the energy-water nexus (or the water-energy nexus). However, the focus has been mostly on the reduction of greenhouse emissions without any attempt to address the critical interconnections between energy production and water management. To date, the tools to address the energy-water nexus have not simultaneously considered water quantity and water quality. In this study, we propose an innovative pathway to consider water trends and status associated with one form of energy production; i.e., we focus solely on the water requirements for the generation of electrical energy (not considering the energy requirements for the production or transportation of water). With a case study of a coal-fired thermal power plant in the Province of Saskatchewan Canada, we develop a local-to-global approach to bridge existing gaps between indicators of environment (e.g., water quality, water quantity, aquatic ecosystem) and energy processes (e.g., electrical energy output and efficiency) to efficiently contribute to decision making within public and private policies for water and energy.

The energy-water nexus (or the water-energy nexus) stems from the dependence of much energy infrastructure to water management and vice-versa. Very often energy use is driven by water demand. Large volumes of water are necessary for extraction (e.g., oil sands) and energy generation (e.g., cooling systems in thermal or nuclear energy plants). At the same time, large amounts of energy are needed to produce safe drinking water production (e.g., water treatment and supply) for urban, industrial and agricultural activities. Water is essential for energy generation as energy is necessary to supply communities with safe water (Gleick 1993). For these reasons, the scientific community and policy makers have focused on the intersections of energy security and water scarcity. Adverse impacts from the multiple uses of water and energy on both human and aquatic systems have been broadly recognized (e.g., loss of habitat and biodiversity, occurrence of waterborne diseases, economic impacts to water-dependent infrastructures, etc). Investigations on energy development in public, domestic, industrial, and agricultural sectors should thus address water use. For the most part, water studies have followed a global hydrological discourse accounting uniquely for the quantification of water resources (Linton 2010). Quantification methodologies have been applied worldwide to determine present and future scenarios of water 'availability', 'scarcity', 'vulnerability', 'security', amongst other similar quantitative concepts. The broad picture of the water-energy nexus literature shows three main situations. First, with regards to both the economic and energy sectors much of the research dedicated to water quantification address agriculture (e.g., crop production; Hoff et al. 2010, Siebert and Döll 2010) despite sparse research on biofuels (Tan et al. 2009, Galan-del-Castillo and Velasquez 2010). Second, there are very few studies assessing simultaneously water quality and water quantity (Scanlon et al. 2007, Zimmerman, Mihelcic and Smith 2008, Vörösmarty et al. 2010). Third, to date we could not find any study assessing the water-energy interconnections by using an integrated framework to include potential changes on the human and aquatic systems.

In a world of climate change, rapid urbanization and emerging industrializing countries, water resources are under stress. Climate variability associated with population growth and economic development has influenced an increase in water demand and/or consumption and water withdrawals for energy production. Where water resources are under pressure, inadequate quality, quantity and availability reduce preparedness towards the negative impacts of climate change and expose populations to risk and vulnerability (IPCC 2007; Fisher et al. 2007; Eakin and Lemos 2010). To increase preparedness, decision making must assess the water-energy nexus, the dynamics of water bodies (e.g., lakes, river, basins, etc) and the variability in climate. It is essential thereby to develop integrated methods to examine the potential impacts of energy production on both aquatic and human systems. The present study examines changes in water quantity and water quality that could affect aquatic and human health. Within the water-energy nexus, most of methods to assess water quantity and water quality are to apply benchmarks (e.g., drinking water quality guidelines, WHO 2008) and ranking (e.g., from poor to excellent, CCME 2001). However, we could not find any study that has assessed the magnitude of change for water quantity and quality simultaneously. Our objective however is to examine the degree of change on water quality caused by thermoelectric energy production at the local scale. We believe that a magnitude of change approach can be more effective to measure water-energy interactions for water quantity, water quality and their potential environmental impacts.

We considered the Integrated Water-Energy Assessment (Silva and Dubé 2011). The IWEA evaluates whether societies have access to water in adequate quality and quantity to support their activities. To prepare and empower communities to face eventual changes on the water resources from energy generation, governments and economic sectors need to ensure safe and secure water supply to and from energy production. If on the one hand energy production, energy consumption and the development of new technologies should not affect water quantity and quality to meet human necessities; on the other hand water supply should support energy systems. The *assessment* of the possible changes in both human and aquatic systems at multiple geographic scales (e.g., national, regional/provincial, local, etc) should measure whether and how the patterns of energy production, consumption and development are affecting water resources (e.g., water scarcity and/or pollution). The core of the IWEA framework is thus to document and communicate the magnitude of these changes through a set of *indicators* capable of better informing decision makers and the public. Those expressing water resources quality, quantity and availability are surely valuable tools to evaluate and communicate the state of water health (Dunn and Bakker 2009). Indicators of IWEA must be technically relevant to water and energy policy concerns at public (e.g., governments) and private (e.g., industry) sectors. They must show to the public and decision-makers whether current water and energy policies efficiently work. The choice of indicators determines indeed how environmental conditions will be represented and their outcomes will then be transformed into political decision criteria (Joerin and Rondier 2007). Information about natural capital (e.g., water resources) is often overlooked in political decision-making processes (Tallis et al. 2008). Hence, the outcomes of water-energy nexus assessment may contribute with significant guidelines for political strategies about the use of water resources to support energy supply systems. In order to assess the trends and status from the potential changes in water resources caused by energy production, we defined indicators of IWEA: the Process Change Index (PCI), Environmental Change Index (ECI) and Human Change Index (HCI) (Table 1) (Silva and Dubé 2011).

Each index of the IWEA defines an object of change to assess a magnitude of change and examples of parameters to measure potential changes. In general, the Process Change Index (PCI) and Environmental Change Index (ECI) apply the same parameters for water quality and water quantity. Differences appear in terms of loadings and aquatic health variables. For the application of the PCI and ECI within a magnitude of change assessment two values are required for comparison. For both indices, a control index and a variable index may be developed. Figure 1 describes the application of input-output methods to the water-energy nexus to determine the water requirements of power plant processes. The PCI uses a control index based on the measurement of water quantity and water quality at the power plant process input compared to the historical site (or regional) specific objectives. Parameters should be measured at a power generation facility and at monitoring stations upstream and downstream. The choice of parameters depend on frequency of measurement and data availability for a determined energy technology (e.g., coal, nuclear, natural gas, biomass and hydroelectric). Effect assessment of environmental change (e.g., land use) based on seasonal and stream approaches has proved to be useful (Tsegaye et al. 2006). Finally, to assess the magnitude of change within the PCI, a variable index is necessary. It requires water quality and quantity at process input compared to the water quality and quantity exiting the process; i.e. "Water Quantity/Quality In – Water Quantity/Quality Out" (Figure 1). This structure follows the framework of the water reduction (WAR) algorithm developed by Young, Sharp and Cabezas (2000) to analyse the environmental impacts from energy consumption. The ECI follows the same structure of the PCI. Parameters used in the PCI and ECI must match in order to compare over changes in water quality and water quantity.

In the U.S water withdrawals for thermoelectric power generation are on par with irrigated agriculture each representing roughly 40% (Hutson et al., 2004). In 2007, the thermoelectric power industry accounted for 91% of all the energy produced in the U.S (King et al., 2008). Cooling water represents the most significant form of water use in thermoelectric power generation. In once-through cooling systems, large quantities of water are extracted for one-time use to condense turbine exhaust steam. This is the most water-intensive cooling strategy when compared to other cooling systems (EPRI, 2002). The high withdrawal rate is required to absorb the thermal load released from the condensed steam produced during power production. Large water quantities reduce the increase in the temperature differential between intake and discharge which is commonly expected to be below a regulated value. The increase in temperature is a concern as it has the potential to cause thermal pollution downstream which promotes algae growth. Discharge temperatures are regulated based on geographic location and local climate. In many parts of the U.S cooling water in once-through systems is 8 to 11 ^{o}C warmer than the inlet (IEA, 2005).

Quantifying change in water quality and water quantity in response to a thermoelectric power generating technology will enable stakeholders to make more informed decisions regarding development of technologies, policy-making, and management and operation of both systems. This should result in decreased economic and environmental risk in implementing new power generation plants. Limited investigation of the water-energy connection has been almost entirely carried out in the United States and focus primarily on water quantity with little or no attention given to water quality.

Table 1. Indices and parameters for Integrated Water-Energy Assessment

Index of IWEA	Object of change	Examples of parameters to measure change
Process Change Index (PCI)	Water quality	General chemical parameters (e.g., chloride, DOC, TOC) Physical parameters (e.g., conductivity, pH, TSS, hardness, DO) Metals (e.g., mercury, arsenic, lead)
	Water quantity	Flow path (e.g., peak flows, base flows, no flow periods and seasonality of flows) Run off timing (e.g. peak run-off timing) Baseflow (e.g., median monthly baseflow)
	Loadings	Receiving-water loading Total Maximum Daily Load (TMDL)
Environmental Change Index (ECI)	Water quality	General chemical parameters (e.g., chloride, DOC, TOC) Physical parameters (e.g., conductivity, pH, TSS, hardness, DO) Metals (e.g., mercury, arsenic, lead)
	Water quantity	Flow path (e.g., peak flows, base flows, no flow periods and seasonality of flows) Run off timing (e.g. peak run-off timing) Baseflow (e.g., median monthly baseflow)
	Aquatic health	Macroinvertebrate Fish diversity Benthic algal growth Benthic oxygen demand

Measured water quality and quantity parameters can be compared to background or benchmarks values to quantify the impact of power generating technology on the aquatic environment (De Rosemond et al., 2008). However, assessing parameters individually is a labourious task and does not generate an easily understood metric of aquatic system health. What is required is a tool that communicates to users of various backgrounds, the magnitude of change that power generating technologies have on the aquatic environment.

Current technologies exist for simplifying reporting of water quality data. In 2001, the Canadian Council of Ministers of the Environment (CCME) published a technical report which assessed existing Canadian indices to develop a Water Quality Index (WQI). A technical subcommittee of water quality experts from across Canada elected to base its index on an approach previously taken by British Columbia (Rocchini et al., 1995). The index allows a multitude of water quality parameters to be compared against objectives selected by the user and provides a summary of the complex information into a single value for easy communication to the general public.

Water quality guidelines for the CCME WQI have been proposed for drinking water, recreational and agricultural uses (De Rosemond et al., 2008). Many of the water quality indices have been applied to examine possible changes across multiple temporal and spatial scales. The Water Quality Index (WQI) (Horton 1965) was later improved into the National Sanitation Foundation Water Quality Index (NSFWQI) (Brown et al. 1970). Most studies that have improved WQI methods have been generally developed at local scales. For example, Pesce and Wunderlin (2000) reframed the CCME WQI at a river scale in Spain whereas De Rosemond, Duro and Dubé (2008) applied the CCME WQI to examine water quality changes in Canadian watersheds.

However, water quality assessment using indices have rarely been related to energy production. We propose the use of site-specific water quality objectives for the CCME WQI to quantify the change of water quality in response to power generating technologies. Historical water quality data can be used to develop numerical limits for water quality parameters for the study site. Statistical methods proposed by the CCME for statistically deriving the numerical limits include mean plus/minus one or two standard deviations or the 90 range percentile. These statistical procedures are applied to the historical water quality data to calculate the site-specific numerical limit (*objective*).

There are two changes to water quality (W_{qual}) and water quantity (W_{quant}) that occur in response to power generating technologies. The first change is in response to the specific power generating technology. This can be described as the *process change*. In thermoelectric power generation fossil fuels are combusted in the boiler to produce high-pressure steam that is subsequently used rotate the turbine blades (Elliot et al. 1998). The exhausted steam is condensed using large volumes of cooling water and is pumped to the boiler to complete the thermal cycle. Waste effluents have the potential to negatively impact water quality. This can led to harmful effects on biological health of downstream aquatic environments if released back into source waters or leached from storage ponds into ground water (IEA, 2005).

The second change in W_{qual} and W_{quant} in response to power generating technology is the change in the surrounding aquatic environment. This change can be described as the *environmental change*. It is acknowledged that power generating technology can impact both the groundwater and atmosphere in the surrounding area. However, this research focuses solely on the magnitude of change of W_{qual} and W_{quant} for surface water. Environmental change incorporates the change in W_{qual} and W_{quant} that is produced by the process change and measures that impact on a larger regional scale. In addition, the environmental change incorporates the impact of non-process related elements of power generation technologies such as reservoir building for use in cooling thermoelectric power plants.

Comparison of WQI numbers generated using the CCME WQI allows a quantifiable way of determining a change in water quality in response to power generating technologies. The magnitude of change can be measured at both the process scale and the environmental scale. We propose a combination of these measures along with a magnitude of change in water quantity that will create an index that quantifies the impact a power generating facility has on the aquatic environment.

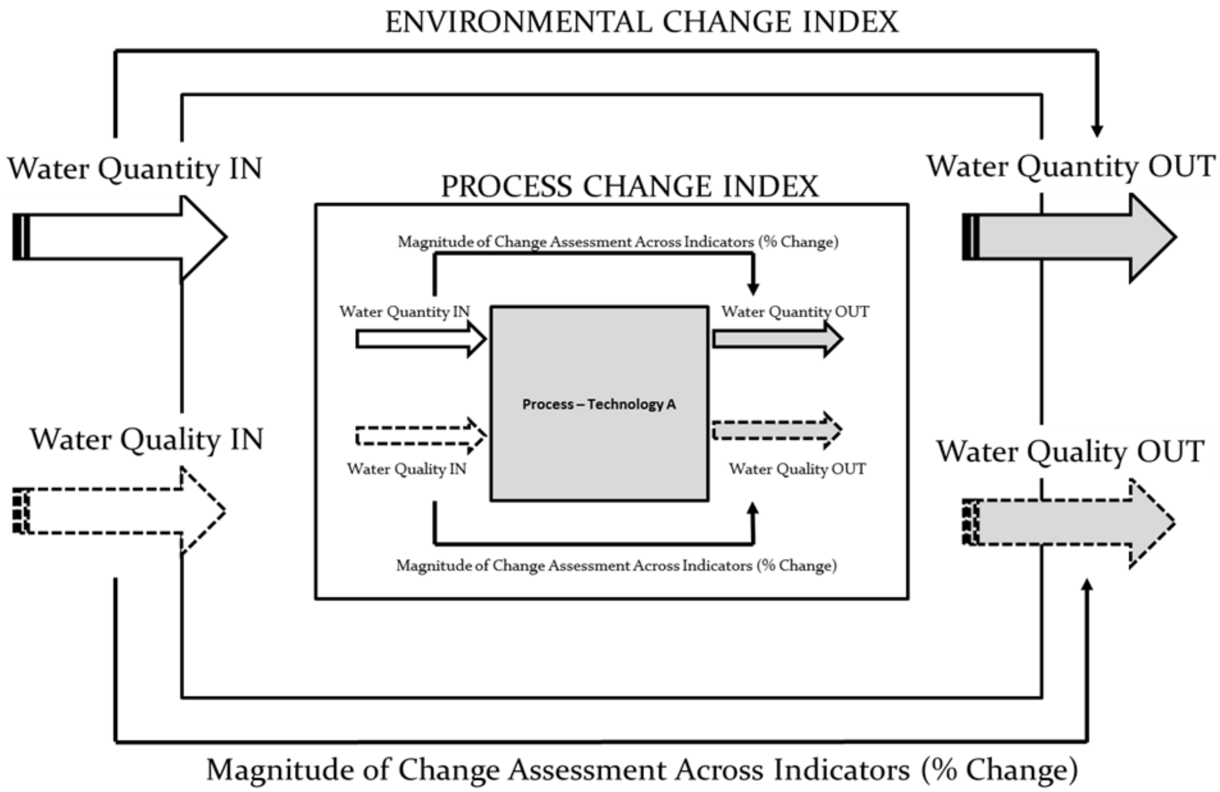

Figure 1. Construction of the Process Change Index (PCI) and Environmental Change Index (ECI)

Although the final goal of this research is to incorporate both W_{qual} and W_{quant} into the index, this paper will focus solely on the W_{qual} in the ECI and PCI. There are two objectives of this research (1) to determine whether the CCME WQI is a satisfactory tool for generating a magnitude of change value in water quality for a power generating technology in an easily understood way (2) determine whether available data is adequate for calculating meaningful water quality parameter objectives.

STUDY AREA

The Poplar River Power Plant (PRPS) became operational in 1981 and is situated in the Poplar River basin in southern Saskatchewan (Figure 2). The basin is situated in a semi-arid region. The climate is cold, dry winters with warm dry summers. The average annual precipitation in the area ranges from 300 – 400 mm with almost 30% of the precipitation supplied by snow (Gray et al. 1989). The basin is located in the prairie pothole region where the hydrology is controlled by hummocky terrain and surface depressions characteristic of retreating Pleistocene glaciers. As a result, depressions associated with knob-and-kettle landscape impound a great deal of spring melt and storm runoff (Woo, 2002).

The Saskatchewan Power Corporation built the Morrison Dam to create the Cookson reservoir which impounds 7400 dam^3 from the East Poplar River for use in cooling the PRPS. The Morrison Dam, which closed in 1975 and filled by 1979, forms the reservoir 3.5 km north of the international boundary between the United States and Canada. The Morrison Dam is an earth-fill embankment with a spill height of 757 m. The East Poplar River and the Girard Creek both contribute water to the Cookson reservoir (Figure 2). When full, the reservoir extends approximately 11 km north of the dam up the East Poplar River and the maximum depth in the lower 3 kms of the reservoir remains relatively constant at 13-14 m (International Joint Commission, 1979). Water can be discharged downstream in to the East Poplar River from the Morrison Dam.

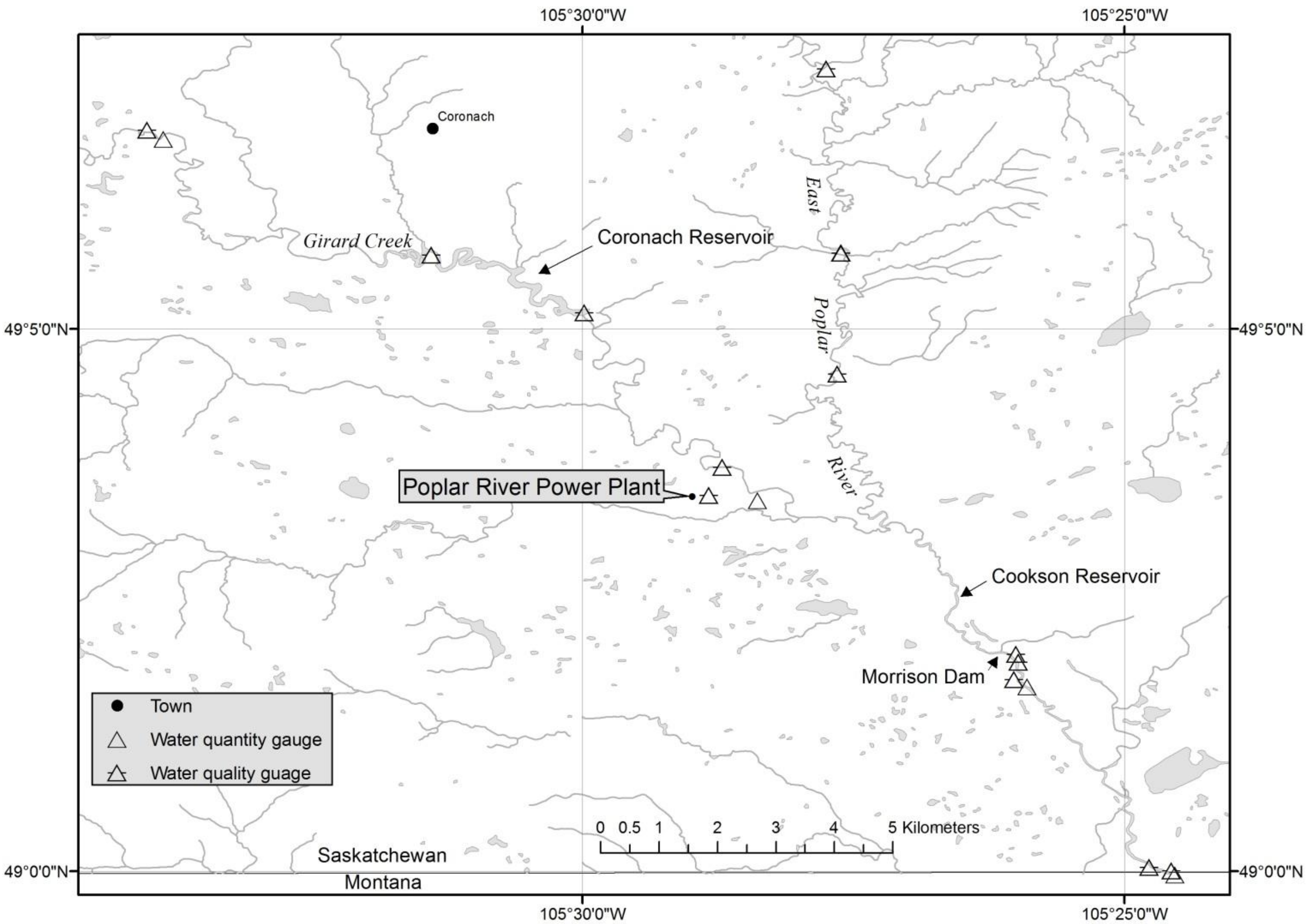

Figure 2. Poplar River Power Plant and water quality and water quality monitoring stations.

METHODOLOGY

Surface water quality data have been collected in the Poplar River basin since 1975. Environment Canada, Saskatchewan Environment and the United States Geological Survey have participated in an annual quality control program for the entire basin. As this study is concerned with only the portion of the basin that is located in Canada, only data from the Environment Canada and Saskatchewan Environment were used in the environmental change index (ECI). For the PCI, data collected by the Saskatchewan Power Corporation were also used.

Calculating reference water quality objectives for the CCME WQI was done by aggregating water quality data from stations upstream of the PRPS before its operational date in 1981. Some of these water quality stations sit within the Cookson reservoir. As a result, water quality data after the PRPS came online cannot be used as reference values as the effluent from the PRPS is discharged into the reservoir, thus affecting water quality for those stations.

Water quality parameters used in the study were chosen on the basis of whether there were sufficient data available for the parameters for the time period before the PRPS came online (before 1981), and after the PRPS came online (1981-present). Parameters also were required to have the same sampling methods and measurement techniques between the data sets. A total of nine parameters were chosen from the data sets (Table 1). The parameter values during the time period before the PRPS began operation were used to calculate the reference water quality values in the basin. Unfortunately, water quality data in the basin has only been collected since 1975. However, there are two high–flow years (1975, 1976) and a low-flow year 1977 so the available water quality data is reasonably representative of possible natural flow conditions (International Joint Commission, 1979).

Reference water quality values for each season for each parameter are calculated using a method recommended by the CCME (CCME 2003). The 90^{th} range percentile concentration of each parameter was calculated from the reference data (10^{th} percentile values were calculated for a minimum value for pH). These values were used to represent the natural or background water quality conditions before the PRPS was put into operation.

The CCME WQI is used to calculate a magnitude of change in water quality in response to the PRPS. In 2001, the Canadian Council of Ministers of the Environment (CCME) published a technical report which assessed existing Canadian indices to develop a Water Quality Index (WQI) as a tool to simplify technical reporting of water quality data (CCME 2001). A technical subcommittee of water quality experts from across Canada elected to base its index on an approach previously taken by British Columbia (Rocchini et al. 1995). The index allows a multitude of water quality parameters to be compared against objectives selected by the user and provides a summary of the complex information into a single value for easy communication to the general public. The CCME WQI includes three factors and takes the form:

$$CCME\ WQI = 100 - \frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732} \qquad (1)$$

Where,

F_1 – Scope – the number of parameters of non-compliance with selected objective

$$F_1 = \frac{Number\ of\ Failed\ Variables}{Total\ Number\ of\ Variables} * 100 \qquad (2)$$

F_2 – Frequency – the percent value of non-compliant individual tests

$$F_2 = \frac{Number\ of\ Failed\ Tests}{Total\ Number\ of\ Tests} * 100 \qquad (3)$$

F_3 – Amplitude – the magnitude by which the tests do not meet their objectives

$$F_3 = \frac{nse}{0.01nse + 0.01} \qquad (4)$$

The normalized sum of the excursions (nse) is incorporated into the equation to ensure all values calculated for F_3 fall between 0 and 100. The nse is determined as follows:

When the parameter must not exceed an objective,

$$excursion_i = \frac{failed\ test\ value_i}{objective_j} - 1 \qquad (5)$$

When the parameter must not fall below an objective,

$$excursion_i = \frac{objective_j}{failed\ test\ value_i} - 1 \qquad (6)$$

The nse is calculated by taking a ratio of the summation of the excursions and the total number of tests,

$$nse = \frac{\sum_{i=1}^{n} excursion_i}{number\ of\ tests} \qquad (7)$$

The result of the calculation is a number that ranges from 0 – 100. The CCME WQI categorizes the resultant number for ease of communication. The categories are summarized in Table 2.

Table 2. Categorization of CCME WQI index values (CCME, 2001).

Rating	**CWQI Value**	**Description**
Excellent	95 - 100	Water quality is protected with a virtual absence of threat or impairment; conditions very close to natural or pristine levels
Good	80 -94	Water quality is protected with only a minor degree of threat or impairment; conditions rarely depart from natural or desirable levels
Fair	65 - 79	Water quality is usually protected but occasionally threatened or impaired; conditions sometimes depart from natural or desirable levels
Marginal	45 - 64	Water quality is frequently threatened or impaired; conditions often depart from natural or desirable levels
Poor	0 - 44	Water quality is almost always threatened or impaired; conditions usually depart from natural or desirable levels

In the present research, we wish to identify how much the index number changes as a result of the introduction of the power generation station. If the index number changes after the power generation station is introduced, it is a quantifiable measure of the impact of the station on surface water quality.

As with any index or analytical tool the potential for misapplication if the index is not used for which it was designed my lead users to false conclusions. As such the technical subcommittee identified a few rules which should be considered in application of the index (CCME 2001):

1. Comparison of index values between water bodies can only be made if:
    a. The same sets of objectives are being applied
    b. The same sets of parameters are being used
2. Older data should be used with caution given the advancement and sensitivity of analytical techniques
3. Only parameters relevant to the water body being tested should be used
4. Only data sets of appropriate size should be used – vast spatial and temporal data sets may present false conclusions

In addition, the growing popularity and wide-spread use of the CCME WQI has driven further investigation into the sensitivity of water quality values regarding selection of guidelines, parameters, time period, sampling design (Painter et al., 2004; Gartner Lee, 2006), and evaluation of potential modifications to the index (Gartner Lee, 2006). A summary of their findings are as follows:

1. A minimum of seven water quality parameters should be used in the calculation of CWQI. Inclusion of additional parameters decreased the potential of incorrectly ranking a site.
2. Each index period should include a minimum of six observations per index period.
3. Sample periods should be selected in association with the risks of a particular guideline. For example, spring samples would be of key interest for phosphorous given its role in algae growth.

Calculating magnitude of change - Water quality - Process change index

In order to perform a magnitude of change assessment two values are required: one independent (controlled parameter) and one dependent (measured parameter). In assessing the change in water quality across a thermoelectric power facility using the CCME WQI, two indices must be calculated. The first index will assess the quality of water taken into the facility against the historical or natural conditions of the source body (objective). Similarly, the second index will assess the quality of water taken into the facility against the quality discharged into the environment. Again, only effluent streams which are returned to the source water will be included in the assessment. These two CCME WQI values will then be compared to determine if in fact there has been a change in water quality across the power generation technology providing a process change index.

Water quality data – Environment change index

Reference or objective surface water quality values are required to quantify the magnitude of change in water quality that results from the PRPS. Six water quality stations were identified as upstream of the PRPS and are used to establish a reference value for surface water quality in the Poplar River basin. Because the water quality information was obtained from two sources there were differences in the: 1) parameters, 2) time period of collection and 3) parameter sampling methods between the gauging stations. A list of parameters that had a sufficient number of observations along with similar sampling methods for both upstream and downstream stations was developed using the gauge station data. Seasonal mean values were calculated for the identified parameters to be used as objective values (Table 3).

Table 3. Parameters selected for WQI and their objective values.

Variable	Spring	Summer	Fall	Winter	Unit
ARSENIC TOTAL	10	9	6.7	3.9	µg/L
IRON TOTAL	1930	700	1040	304	µg/L
LEAD TOTAL	2	2	12.8	8.2	µg/L
NICKEL TOTAL	5	34	11.3	8.6	µg/L
NITROGEN TOTAL KJELI	1.83	5.47	3.65	1.75	mg/L
PH	8.53	9.1	9.2	8.5	mg/L
PHOSPHOROUS TOTAL	0.258	0.33	0.27	0.179	mg/L
TEMPERATURE WATER	16	17.5	8.3	0.5	DEG C
VANADIUM TOTAL	10	40	10	10	µg/L
ZINC TOTAL	10	10	94.2	84	µg/L

Water quantity data – Environmental change index

There are four water quantity gauges surrounding the PRPS. Two are located upstream and two downstream. Water quantity data were supplied by the Environment Canada HYDAT database. Because the PRPS is a once-through cooling power plant, very little water is lost during the plant process (EPRI, 2002). However, the construction of the reservoir specifically for cooling the PRPS has an impact on the water quantity on downstream aquatic environments.

RESULTS

The CCME index numbers calculated for the ECI are presented in Table 3. The seasonal WQI values for the period 1975-1980 (before the PRPS became operational) range from 44.2 in the winter season to 68.3 during the spring season. This suggests that overall water quality is good with water quality best during spring freshet and decreased during winter. Seasonal values after the PRPS became operational in 1981 range from 31.6 in the winter to 64.4 in the summer. The marked decrease in water quality during the winter season is the result of a dramatic increase in water temperature and the amount of water temperature observations that exceed the objective value (Table 4). The change between the seasonal values before and after the PRPS begins operation is negative showing a decrease in water quality downstream of the PRPS for spring (-21.7), fall (-12.8) and winter (-12.6). There is a slight increase in water quality in summer with a positive or improved water quality (4.4) in summer.

The PCI CCME WQI numbers are also presented in Table 3. As with the ECI WQI numbers, the lowest water quality pre-PRPS is in the winter season (42.5). The best water quality index numbers are in the summer and fall (65.6, 65.8). Post-PRPS, the WQI values range from 28 in the winter to a high of 62 in the summer. Like the ECI, the change between the seasonal values is negative showing a decrease in water quality downstream for spring (-4.4), fall (-9.8) and winter (-14.5). Again, like the ECI, a slight increase in water quality (2.9) is seen in the summer season.

Table 3. CCME WQI calculated seasonally. The magnitude of change calculated for the PCI and ECI from CCME WQI values is shown.

Environmental Change Index						
Water Quality	Season	Time Period	CCME WQI	Time Period	CCME WQI	Magnitude of Change
	Spring	1975 - 1980	68.3	1981 - 2004	46.6	-21.7
	Summer	1975 - 1980	60	1982 - 2004	64.4	4.4
	Fall	1975 - 1980	60	1983 - 2004	47.2	-12.8
	Winter	1975 - 1980	44.2	1984 - 2004	31.6	-12.6
Process Change Index						
Water Quality	Season	Time Period	CCME WQI - Inlet	Time Period	CCME WQI - Outlet	Magnitude of Change
	Spring	1994 - 2009	65.6	1994 - 2009	61.2	-4.4
	Summer	1994 - 2009	59.1	1994 - 2009	62	2.9
	Fall	1994 - 2009	65.8	1994 - 2009	56	-9.8
	Winter	1994 - 2009	42.5	1994 - 2009	28	-14.5

Table 4. The percentage of total water temperature observations that exceeded the objective value by season.

		Season			
		Fall	Spring	Summer	Winter
ECI		Failed variable (% of total)			
Temperature Water	1977 - 1980	63	14	60	50
Temperature Water	1981 - 2004	83	20	89	97
PCI					
Temperature Water	inlet	72	11	81	99
Temperature Water	outlet	100	84	100	100

DISCUSSION

The results show that The CCME WQI index can be used to quantify a magnitude of change in water quality in response to a thermoelectric power plant. In the Poplar River basin the main driver of decreasing water quality is water temperature. An increase in water temperature can result in eutrophication and other water quality changes. An ability to display quantifiable water quality changes in an easy to understand manner will enable better decision making by industry and government.

The research conducted on quantifying the magnitude of change in water quality in response to the PRPS was done in a drainage basin that included 17 water monitoring stations in the surrounding area. Although it appears from the quantity of monitoring stations that analysis of parameters would be straight-forward, many difficulties were encountered in the analysis.

To determine site specific water quality objectives in the basin, aggregation of multiple water quality monitoring stations was required. During the aggregation process it became apparent that as a consequence of the monitoring stations belonging to different agencies there was a difference in parameters measured, measuring techniques, and time periods monitored. Further, some of the parameters were measured monthly, some were measured three times in four days and then never again. Because of these issues, many parameters were unable to be aggregated in a meaningful way to determine an objective value and were discarded. Further problems were encountered when PCI parameters measured by the PRPS were compared against objective parameter values determined from aggregating water quality station data. Parameters were again discarded as the methods of collection, and measuring were not consistent between the PRPS and Environment Canada and Saskatchewan Environment data sets.

Objective values that represent natural water quality values that would be present without the impact of the PRPS in the basin need to be calculated before 1981 when the PRPS began operation. Unfortunately water quality data only began to be collected in 1977. This short time severely restricted the number of observations made for each parameter. Breaking the few observations in the time period down into seasonal groupings further reduced the observations used to calculate the objective values.

FUTURE WORK

As noted above, thermoelectric power plants, especially coal fired, are one of the main sources of water usage and contamination. Although previous studies have led to establishing some average water consumption tables per Megawatt hour (MWh) of electrical power produced, they can not accurately represent the differences between the water usage of different power plant configurations. Besides, power plants, especially the coal-fired plants, produce an enormous range of "waste" materials such as flue gas (including sulfur oxides, nitrogen oxides, chlorides, trace chemicals, ammonia, carbon monoxide, fine particulates, carbon dioxide, water vapor), bottom and fly ash, scrubber sludge, cooling water and boiler blowdown that may drastically decrease the quality of the water returned to the water source. The range of these contaminants is very dependent to the composition of the power plant fuel. Engineering computer simulations for various type and configurations of thermoelectric power plants are presently being constructed by our group. These simulations will form a predictive tool, able to predict the overall water withdrawal and consumption of power plants as well as the quality of different effluent streams based on the chosen configuration and fuel composition. These simulations can be an effective tool to investigate the impact of a power plant construction or retrofit on the quantity and quality of the employed water resources. In combination with the magnitude of change and process/environmental change indices described in this paper, we will have developed a predictive capability to assist decision makers on where to site a new power plant and what technology to use, given existing or anticipated water constraints. Hence our decision support tools will fill the current gap in co-management of water and energy.

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