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Modeling of Water Quality Dynamics Using Indigenous Knowledge

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Abstract

Unavailability of western-laboratory-type data on water quality for the areas where the aboriginal people live requires developing special evaluation and prognosis-making methodologies. To determine the key parameters of the water quality we interviewed the experts (aboriginal elders). Basing on the determined key parameters we formed the key questions and developed the questionnaires. The questionnaires were distributed among the households of the Peepeekisis and Kahkewistahaw aboriginal communities (Saskatchewan, Canada). According the developed model we can conclude that within next 15-25 years the negative dynamics of the water quality in both of the communities will be held. However if the positive factors (construction of water treatment facilities, restriction of chemical use, etc) regarding the water quality are maintained at least at the current level, in 15-25 years we may observe dominating of positive trends in water quality in both of communities.

Keywords: environment evaluation, indigenous knowledge, mathematical modeling, temporal dynamics.

1. Introduction

The Calling Lakes consist of Pasqua, Echo, Mission, and Katepwa Lakes which are part of the Qu'Appelle Valley drainage system in Saskatchewan. The Qu'Appelle Valley drainage system supplies water to nearly a third of the population in the western Canadian prairies. It is, however, characterized by poor water quality, blooms of toxic cyanobacteria, excess plant growth, and significant fish kills. Temperature and the level of dissolved oxygen are especially important as these parameters are believed to cause the large numbers of fish deaths seen over these past years in small and shallow lakes in Southern Saskatchewan (Canada). A significant summer fish kill was observed in July 2007, on Pasqua and Echo Lake due to a number of factors including; summer heat, little wind, shallow water and low oxygen levels [1].

Recreational water may be contaminated from a variety of sources including sewage, industrial effluents, agricultural runoff (manure, fertilizers and pesticides), and oil and gasoline spills from boats and marinas. While these chemical contaminants may be detrimental to human health, exposure to disease-causing microorganisms from sewage poses the greatest risk [2] and swimming in fecally contaminated waters has consistently been associated with gastrointestinal illness [3]. In the Qu'Appelle Valley drainage system, the poor water quality is explained by the increase in cropland area, livestock biomass, and urban nitrogenous wastes since the European settlement [4].

2. Methodology

Our research project has attempted to use the aboriginal people's environment evaluation skills to develop a model for describing water quality dynamics in the aboriginal communities. Studies of Indigenous knowledge often make comparisons with scientific knowledge in an effort to determine the "accuracy" of Indigenous knowledge as measured on a scale that is intended to be objective. However, the idea of validating Indigenous knowledge is a foreign concept to most aboriginal people. In fact, Indigenous populations throughout the world have been described as those with a social and cultural identity distinct from the dominant society where they live, who have a close attachment to their ancestral lands. Indigenous societies represent cohesive systems of life, imbued with a shared world view. Every aspect of Indigenous life is governed by sets of rules and values and sustained by a sound knowledge base. Indigenous peoples have achieved harmonious integration with the environment and have sustained this relationship over the centuries [5]. Here, we argue that mathematical modeling is compatible with Indigenous knowledge.

To apply Indigenous knowledge to environmental research and management, consideration must be given to the ways in which it is acquired, held, and communicated. Indigenous knowledge is the synthesis of innumerable observations made over time [6]. Added weight is often given to anomalous occurrences, in order to be better prepared for surprises and extremes. It is typically qualitative; when quantities are noted, they are more often relative than absolute. Indigenous knowledge evolves with changing social, technological, and environmental conditions, and thus observations of change over time can be influenced by these as well as by the vagaries of memory. Within the presented research project we used Indigenous environmental memory and community survey information as statistical data. Based on the analysis of the collected statistical data we developed a mathematical model of the temporal dynamics for the water quality in Peepeekisis and Kahkewistahaw communities.

As it is mentioned above aboriginal people identify themselves as a part of the nature, and they have their own evaluation principles and scale, which they use for determining the current state of the Nature as a whole as well as its components. In general, the evaluation principles are based on believes of the aboriginal people. However some principles have quite materialistic sense, and can be represented quantitively. For developing the mathematical model we needed to determine the key parameters, which are used by aboriginal people for evaluating the conditions of the water systems.

Analysing the expert (Elder) interviews we determined the parameters to evaluate the water quality in the communities, and developed the following Key questions,

1. How would you evaluate the taste of fish caught in your community water in comparison with our days?
2. How would you evaluate the overall quality of water in your community in comparison with our days?

3. How would you evaluate the quality of birds hunted in your community in comparison with our days?
4. How would you evaluate the number of bird nests in the shore in comparison with our days?
5. How would you evaluate the level of chemicals in the water of your community in comparison with our days?
6. How often do your family members swim in the water in your community in comparison with our days?
7. How would you evaluate the transparency of the water in your community in comparison with our days?
8. How do you think the quality of the water in your community will become?

It is typical for the households of the aboriginal communities to usually represent two-three generations living together. Therefore, each household saves in their environmental memories the information regarding the water quality for the last 20 – 30 years. Considering this potential of the aboriginal community households we decided to address the questionnaires to the households, not to individual community members. This idea was supported by the experts (Elders).

In the developed questionnaires the participants were asked to evaluate the water quality in the past (30 years ago, 20 years ago, 10 years ago, and 5 years ago), and make a prognosis for the future (in 5 years, in 10 years, in 20 years) using the Key parameters. The digitalization scheme of the answers is presented in the Appendix 2.

The questionnaires along the Consent Forms were distributed in Peepeekisis and Kahkewistahaw households. The response rate was 35-37%.

The average marks of each parameter for each time period were evaluated using the following formula,

$$Average\ Mark = \frac{\sum The\ Mark \times Number\ of\ Respondents\ Chosen\ this\ Mark}{Total\ Number\ of\ Respondents}$$

3. Results

Below we represent the time dependence of the Key parameters determined for Peepeekisis and Kahkewistahaw communities,

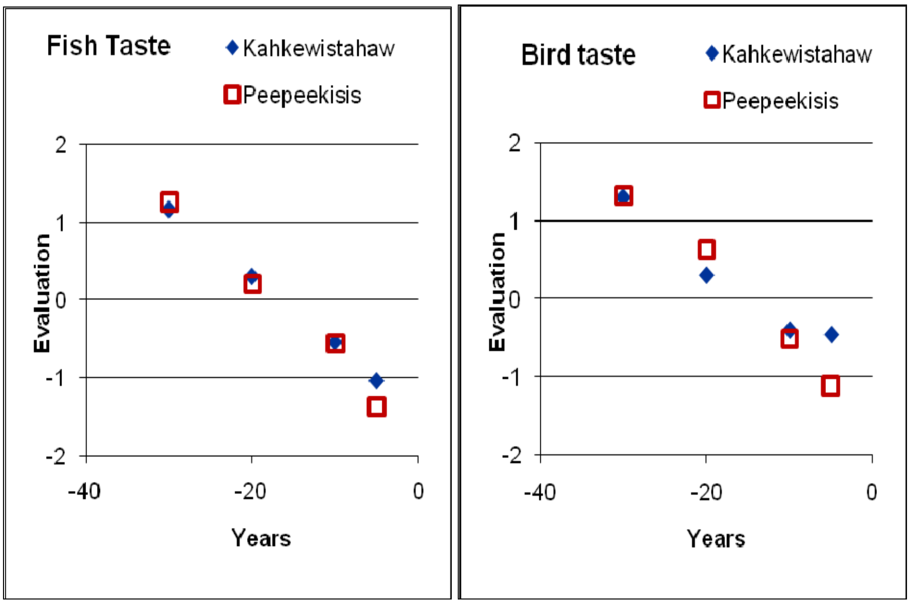

Figure 1. Temporal dynamics of a. Fish taste and b. Bird taste

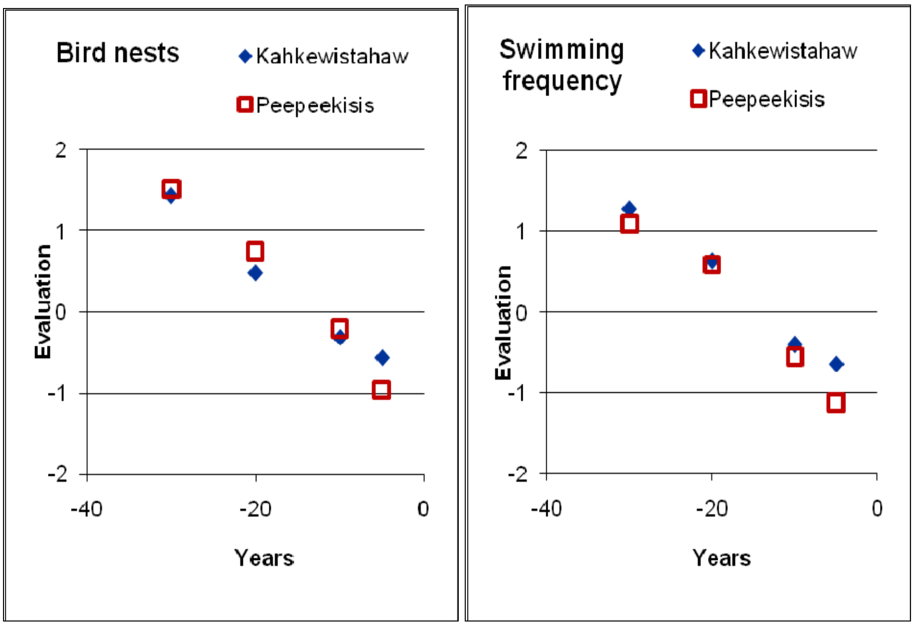

Figure 1. Temporal dynamics of c. Bird nests numbers and d. Swimming frequency

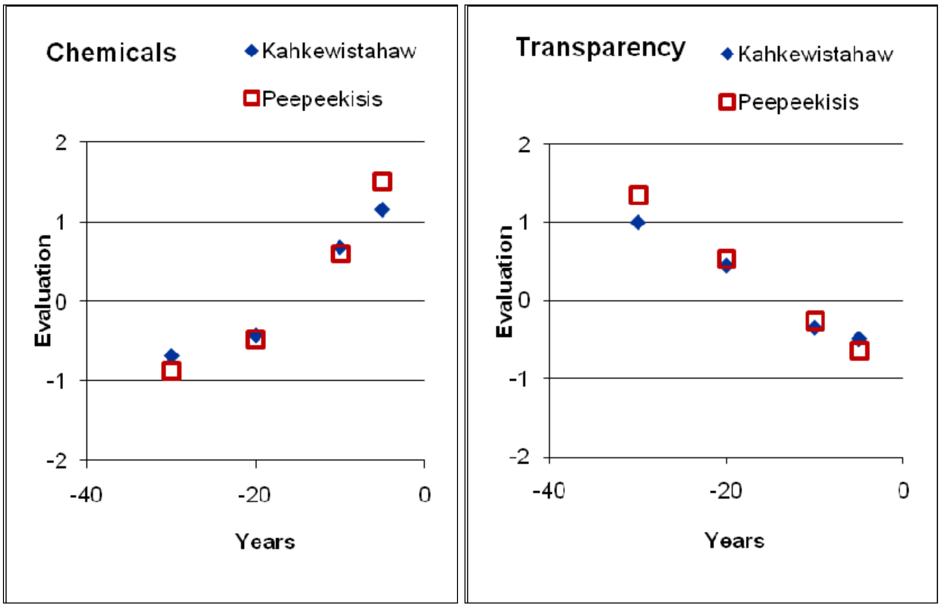

Figure 1. Temporal dynamics of e. Chemical use and f. water transparency

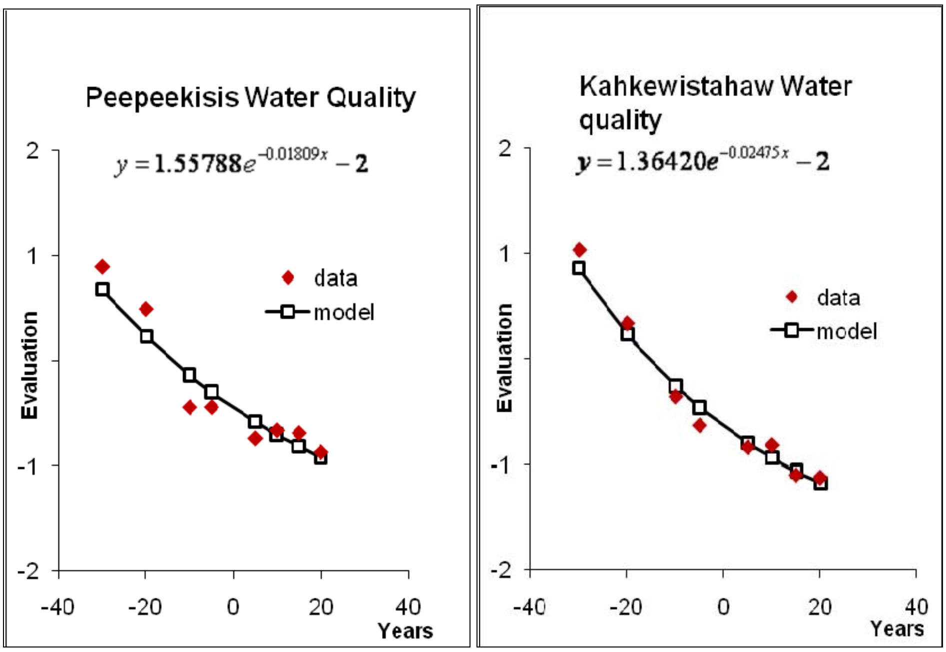

Figure 2. Overall temporal dynamics of the water quality; Exponential model for a. Peepeekisis and b. Kahkewistahaw.

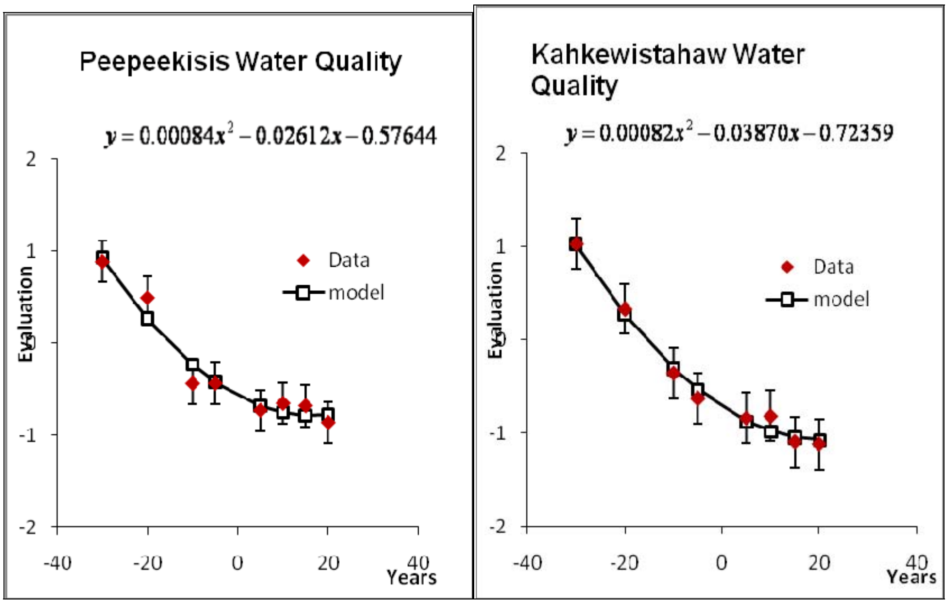

Figure 2. Overall temporal dynamics of the water quality; Polynomial model for a. Peepeekisis and b. Kahkewistahaw.

4. Statistical Analysis

4.1 Spearman Rank Correlation Coefficient for Peepeekisis Water survey

1. Test the hypothesis of the relationship between how individuals rated the level of chemicals in the water 30 years ago vs. 5 years ago. (Question 5.1 vs. 5.4).

H_0: $\rho_s = 0$

H_1: $\rho_s > 0$

We will use a significance level of $\alpha = 0.05$.

d.f. = n-2 = 37-2 = 35. Therefore, we reject H_0 in favor of H_1 if the test statistic t > 1.691. Otherwise fail to reject H_0.

$$r_s = 1 - \left[\frac{6\sum D^2}{n\left(n^2-1\right)}\right] = 1- \left[\frac{6\left(267\right)}{37\left(37^2-1\right)}\right] = 0.968$$

$$t = r_s\sqrt{\frac{n-2}{1-r_s^2}} = 0.968\sqrt{\frac{37-2}{1-0.968^2}} = 22.952$$

Since t = 22.952 is greater than 1.691, the null hypothesis is rejected. We can conclude that there's a strong positive relationship between respondents' evaluations of the level of chemicals in the water 30 years ago versus his/her evaluation of the level of chemicals 5 years ago. The majority of respondents rated the level of chemicals in the water lower 30 years ago in comparison to 5 years ago.

2. Test the hypothesis of the relationship between how individuals rated the water quality 30 years ago vs. 20 years into the future. (Question 2.1 vs. 8.4).

H_0: $\rho_s = 0$

H_1: $\rho_s > 0$

We will use a significance level of $\alpha = 0.05$.

d.f. = n-2 = 37-2 = 35. Therefore, we reject H_0 in favor of H_1 if the test statistic t > 1.691. Otherwise fail to reject H_0.

$$r_s = 1 - \left[\frac{6\sum D^2}{n\left(n^2-1\right)}\right] = 1- \left[\frac{6\left(204\right)}{37\left(37^2-1\right)}\right] = 0.976$$

$$t = r_s\sqrt{\frac{n-2}{1-r_s^2}} = 0.976\sqrt{\frac{37-2}{1-0.976^2}} = 26.411$$

Since t = 26.411 is greater than 1.691, the null hypothesis is rejected. We can conclude that there's a strong positive relationship between respondents' evaluations of the water quality 30 years ago versus his/her evaluation of the water quality 20 years into the future. The majority of respondents rated the quality of water healthier 30 years ago in comparison to 20 years into the future.

4.2 Spearman Rank Correlation Coefficient for Kahkewistahaw Water survey

1. Test the hypothesis of the relationship between how individuals rated the level of chemicals in the water 30 years ago vs. 5 years ago. (Question 5.1 vs. 5.4).

H_0: $\rho_s = 0$

H_1: $\rho_s > 0$

We will use a significance level of $\alpha = 0.05$.

d.f. = n-2 = 38-2 = 36. Therefore, we reject H_0 in favor of H_1 if the test statistic $t > 1.689$.

$$r_s = 1 - \left[\frac{6\sum D^2}{n\left(n^2-1\right)}\right] = 1 - \left[\frac{6(267)}{38\left(38^2-1\right)}\right] = 0.971$$

$$t = r_s\sqrt{\frac{n-2}{1-r_s^2}} = 0.971\sqrt{\frac{38-2}{1-0.971^2}} = 24.274$$

Since t = 24.274 is greater than 1.689, the null hypothesis is rejected. We can conclude that there's a strong positive relationship between respondents' evaluations of the level of chemicals in the water 30 years ago versus his/her evaluation of the level of chemicals 5 years ago. The majority of respondents rated the level of chemicals in the water lower 30 years ago in comparison to 5 years ago.

2. Test the hypothesis of the relationship between how individuals rated the water quality 30 years ago vs. 20 years into the future. (Question 2.1 vs. 8.4).

H_0: $\rho_s = 0$

H_1: $\rho_s > 0$

We will use a significance level of $\alpha = 0.05$.

d.f. = n-2 = 38-2 = 36. Therefore, we reject H_0 in favor of H_1 if the test statistic is t > 1.689.

$$r_s = 1 - \left[\frac{6\sum D^2}{n\left(n^2-1\right)}\right] = 1 - \left[\frac{6\left(206\right)}{38\left(38^2-1\right)}\right] = 0.977$$

$$t = r_s\sqrt{\frac{n-2}{1-r_s^2}} = 0.977\sqrt{\frac{38-2}{1-0.977^2}} = 27.779$$

Since t = 27.779 is greater than 1.689, the null hypothesis is rejected. We can conclude that there’s a strong positive relationship between respondents’ evaluations of the water quality 30 years ago versus his/her evaluation of the water quality 20 years into the future. The majority of respondents rated the quality of water healthier 30 years ago in comparison to 20 years into the future.

5. Discussion

The comparisons of the corresponding plots indicate that the opinions of Peepeekisis and Kahkewistahaw community members regarding the key parameters of the water quality differ slightly. The respondents from both of the communities recognise the negative temporal dynamics of the local water quality. This solidarity looks reasonable considering the fact that the communities are situated around the same water area.

The community members also notice the rise of chemicals in the water. This result allowed us to conclude that the chemicals are considered as the main factor causing negative trend in the water quality. As it was mentioned above the elders also noted this consequence in their interviews. The phase diagram Water quality vs. Chemicals represents the influence of chemical use on the water quality (Fig. 3).

Respondents were asked to evaluate overall water quality for the proposed time periods (Questions 2 and 8). One can see that the respondents are more optimistic about the future of the water quality. Elders explained this by the fact that for last years' governmental institutions take more care on the water quality in the aboriginal communities. In particular, the aboriginal community members are aware about the government programs developed for constructing new water treatment facilities, and this fact has affected on their answers.

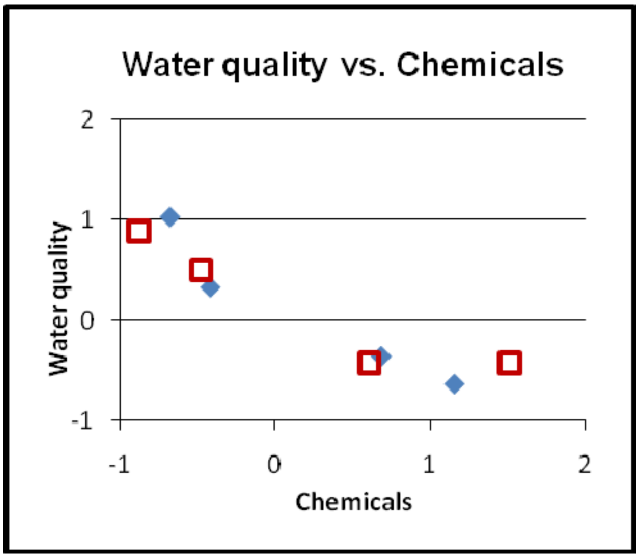

Figure 3. Phase Diagram

By inspection we have found two types of functions (exponential and polynomial) reasonable for best fitting to the plots on the Fig. 2. Using the least squares method and Excel program we determined the functions and the deviations for both of the communities (Table 1).

Table 1. Best fitting functions for the temporal dynamics of the water quality.

Community	Function	Deviation	Minima
Peepeekisis	$y = 1.55788 e^{-0.01809 x} - 2$	0.08	-
	$y = 0.00084 x^2 - 0.02612 x - 0.57644$	0.11	15 years
Kahkewistahaw	$y = 1.36420 e^{-0.02475 x} - 2$	0.13	-
	$y = 0.00082 x^2 - 0.03870 x - 0.72359$	0.18	24 years

The mathematical analysis polynomials reveal the points of minima in 15 years (in 2024) and in 24 years (in 2033) for Peepeekisis and Kahkewistahaw respectively.

The analysis of exponential functions shows that they approach -2 as x approaches infinity. For instance, now the functions are decreasing at the rate of 2.8% per year and 3.3% per year for Peepeekisis and Kahkewistahaw respectively. In 25 years (in 2034) the decreasing rates will be 1.8% per year for both of the communities.

Basing on the results of the mathematical analysis of the best fitting functions one can consider two possible scenarios for the temporal dynamics of the water quality in the Calling Lakes.

Polynomial Scenario:

If this scenario takes place, within the next 15-25 years the negative dynamics of the water quality will be observed in both of the communities. However if the positive factors (construction of water treatment facilities, restriction of chemical use, etc) regarding the water quality are stimulated at least at the current level, in 15-25 years we may observe dominating of positive trends in water quality in both of the communities. The community water is expected to reach the lowest level of quality in 15 (Peepeekisis) – 24 (Kahkewistahaw) years. Then due to the water treatment activities some improvement in the water quality may be evident.

Exponential Scenario:

If this scenario takes place, the community water quality will decrease exponentially in spite of water treatment activities until it reaches the natural saturation. Though the current rate of decreasing the water quality in different communities differs, in 25 years the water quality decreasing rates for the communities will become equal.

It is very important to emphasize that the relatively positive scenario may take place only if the water treatment programs will be carried out at the regular base.

6. Conclusion

The presented project is one of the pioneer works where the aboriginal peole's unique observation and environment evaluation skills are used as a scientific tool for modeling the water quality temporal dynamics in the local area. Within the presented project we have developed a methodology for converting the aboriginal people's empiric information into the mathematical language.

We have determined the key parameters for evaluating the water quality. We have developed a conversion scale, which allowed us to determine the quantitative equivalent of the qualitative description of the water quality and its temporal dynamics. The opinions of the Peepeekisis and Kahkewistahaw community members regarding the key parameters of the water quality in the same water area differ slightly. This accordance in evaluation indicates the reliability of the developed methodology.

Based on the statistical and mathematical analysis we have developed two possible scenarios for the temporal dynamics of water quality.

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Appendix 1

1. How would you evaluate the taste of fish caught in your community water in comparison with our days?

30 years ago	**20 years ago**	**10 years ago**	**5 years ago**
much better	much better	much better	much better
Better	better	better	better
about the same	about the same	about the same	about the same
Worse	worse	worse	worse
much worse	much worse	much worse	much worse

2. How would you evaluate overall quality of water in your community in comparison with our days?

30 years ago	**20 years ago**	**10 years ago**	**5 years ago**
much better	much better	much better	much better
better	better	better	better
about the same	about the same	about the same	about the same
worse	worse	worse	worse
much worse	much worse	much worse	much worse

3. How would you evaluate the quality of birds hunted in your community in comparison with our days?

30 years ago	**20 years ago**	**10 years ago**	**5 years ago**
much better	much better	much better	much better
better	better	better	better
about the same	about the same	about the same	about the same
worse	worse	worse	worse
much worse	much worse	much worse	much worse

4. How would you evaluate the number of bird nests in the shore in comparison with our days?

30 years ago	**20 years ago**	**10 years ago**	**5 years ago**
much more	much more	much more	much more
more	more	more	more
about the same	about the same	about the same	about the same
less	less	less	less
much less	much less	much less	much less

5. How would you evaluate the level of chemicals of the water in your community in comparison with our days?

30 years ago	**20 years ago**	**10 years ago**	**5 years ago**
much more	much more	much more	much more
more	more	more	more
about the same	about the same	about the same	about the same
less	less	less	less
much less	much less	much less	much less

6. How often have your family members swimming in the water in your community in comparison with our days?

30 years ago	**20 years ago**	**10 years ago**	**5 years ago**
much more often	much more often	much more often	much more often
more often	more often	more often	more often
about the same	about the same	about the same	about the same
less often	less often	less often	less often
much less often	much less often	much less often	much less often

7. How would you evaluate the transparency of the water in your community in comparison with our days?

30 years ago	**20 years ago**	**10 years ago**	**5 years ago**
much more transparent	much more transparent	much more transparent	much more transparent
more transparent	more transparent	more transparent	more transparent
about the same	about the same	about the same	about the same

less transparent	less transparent	less transparent	less transparent
not transparent at all	not transparent at all	not transparent at all	not transparent at all

8. How do you thing the quality of the water in your community will become?

In 5 years	**In 10 years**	**In 15 years**	**In 20 years**
much worse	much worse	much worse	much worse
worse	worse	worse	worse
the same	the same	the same	the same
better	better	better	better
much better	much better	much better	much better

Appendix 2

- much better: +2
- better: +1
- about the same: 0
- worse: -1
- much worse: -2

- much more: +2
- more: +1
- about the same: 0
- less: -1
- much less: -2

- much more often: +2
- more often: +1
- about the same: 0
- less often: -1
- much less often: -2

- much more transparent: +2
- more transparent: +1
- about the same: 0
- less transparent: -1
- not transparent at all: -2