Reliability-Based Approach to Hyporheic Zone Depth Delineation for Groundwater Remediation Strategy

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I. ABSTRACT

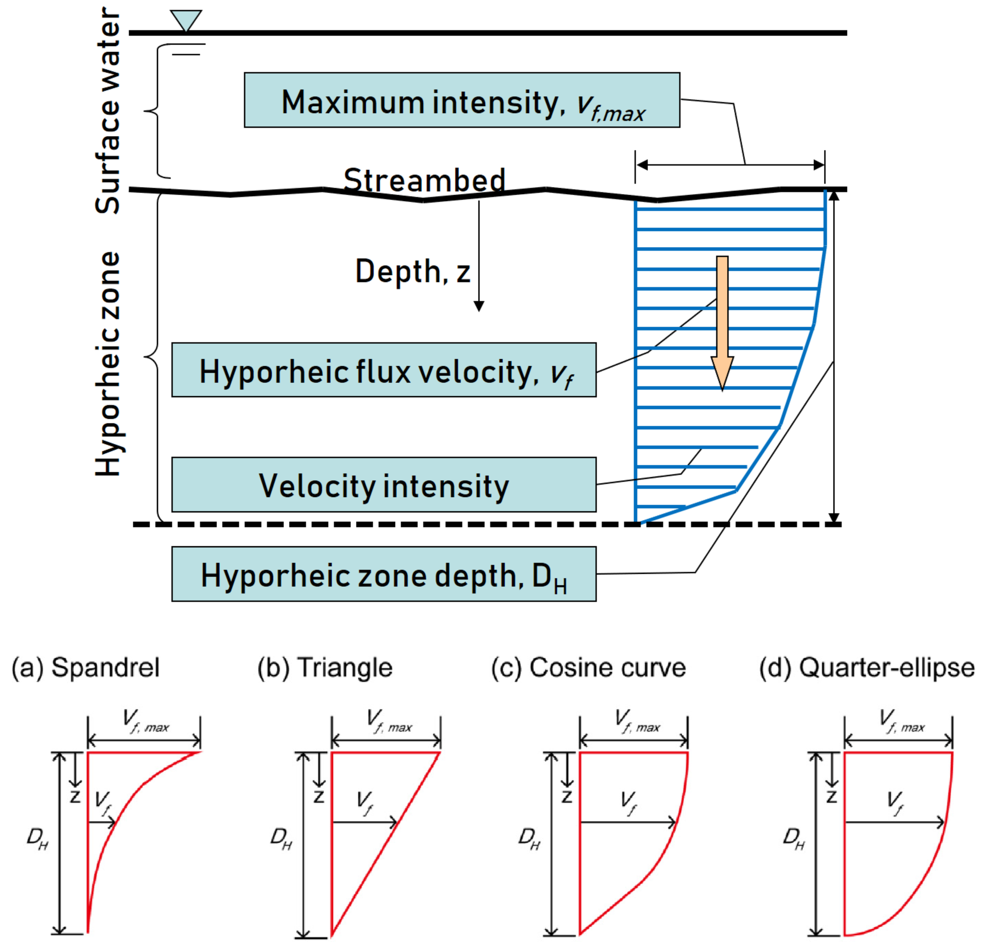
Natural phenomena like hyporheic zone depths show intrinsic statistical behavior due to large variability of related parameters. In the previous researches, authors proposed a deterministic method to delineate hyporheic zone depth using a simple field temperature measurement, and studied a probabilistic method to present a proper statistical distribution model for hyporheic zone depth. As a next step forward, this research proposes remediation strategies on contaminated groundwater system in relation to hyporheic zone depth management. Primarily, demand of hyporheic zone depth to achieve a required recovery ratio is predetermined. The field hyporheic zone depth is, then, changed according to each strategies. The two probabilistic variables, demand and field values, are modified such that the difference are reduced.

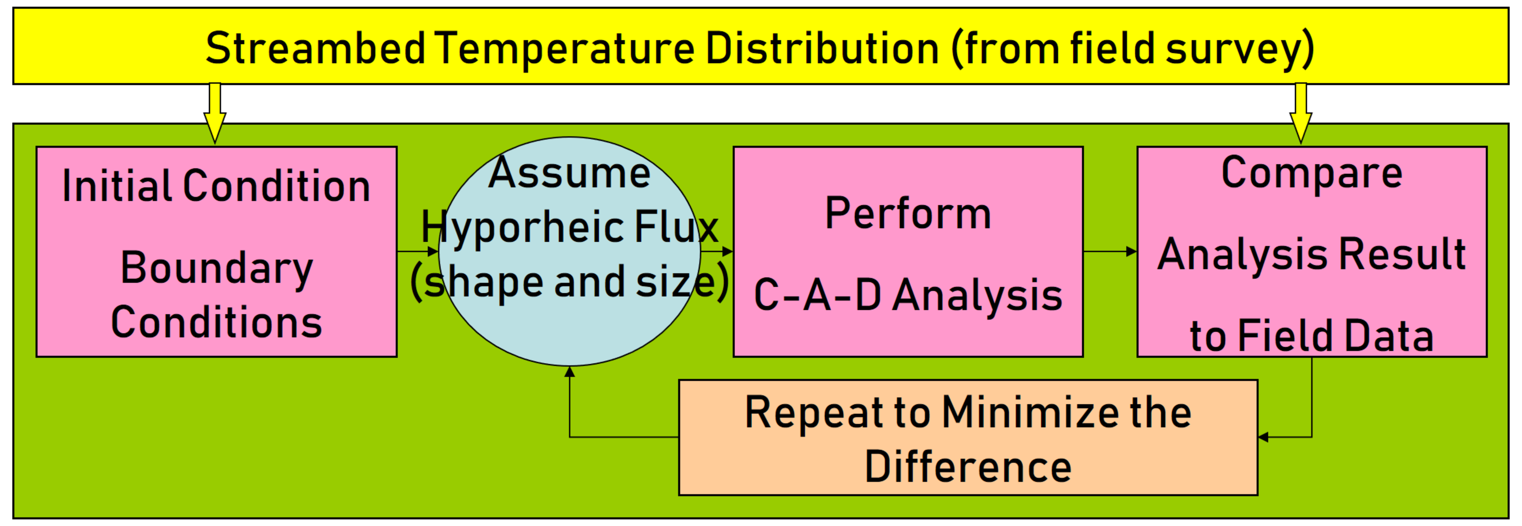
The index applied to evaluate each strategy in this paper was adopted from the concept of reliability index. This approach is frequently used in many fields of science and engineering, including a safety design of structures. The key point of safety design involves sufficiency of safety margins between a strength criterion and the requirements, and this is what the reliability index evaluates. The paper is structured to introduce reliability-based approach in terms of general concept and hyporheic zone depth management first, and proceeds to a development of index. The paper concludes with performance evaluation of strategies. This paper is of value because a combination of the previous research on the probabilistic property extraction of hyporheic zone depth and the presented approach of performance evaluation has potential to offer another useful tool to the remediation of contaminated groundwater.

II. DELINEATION OF HYPORHEIC ZONE DEPTH

A. Estimating HZD

Figure 1. Hyporheic flux consists of two parameters: hyporheic flux shape and size. A set of hyporheic zone depths and the magnitude in vertical direction forms the size of hyporheic flux. the assumed shape of the hyporheic flux includes the spandrel, triangle, cosine, and a quarter of an ellipse





$$\rho c \frac{\partial T}{\partial t} = \lambda_e \frac{\partial^2 T}{\partial z^2} - n \rho_f c_f v_f \frac{\partial T}{\partial z}$$

Figure 2. The temperature distribution of the streambed is influenced by the hyporheic flux, and the temperature distribution of the streambed can be calculated by CAD analyses. The heat transfer in the streambed is described by the above "conduction–advection–dispersion" differential equation. The hyporheic flux that minimize the difference between the calculated and the measured temperatures is determined.

B. Probabilistic Delineation of HZD

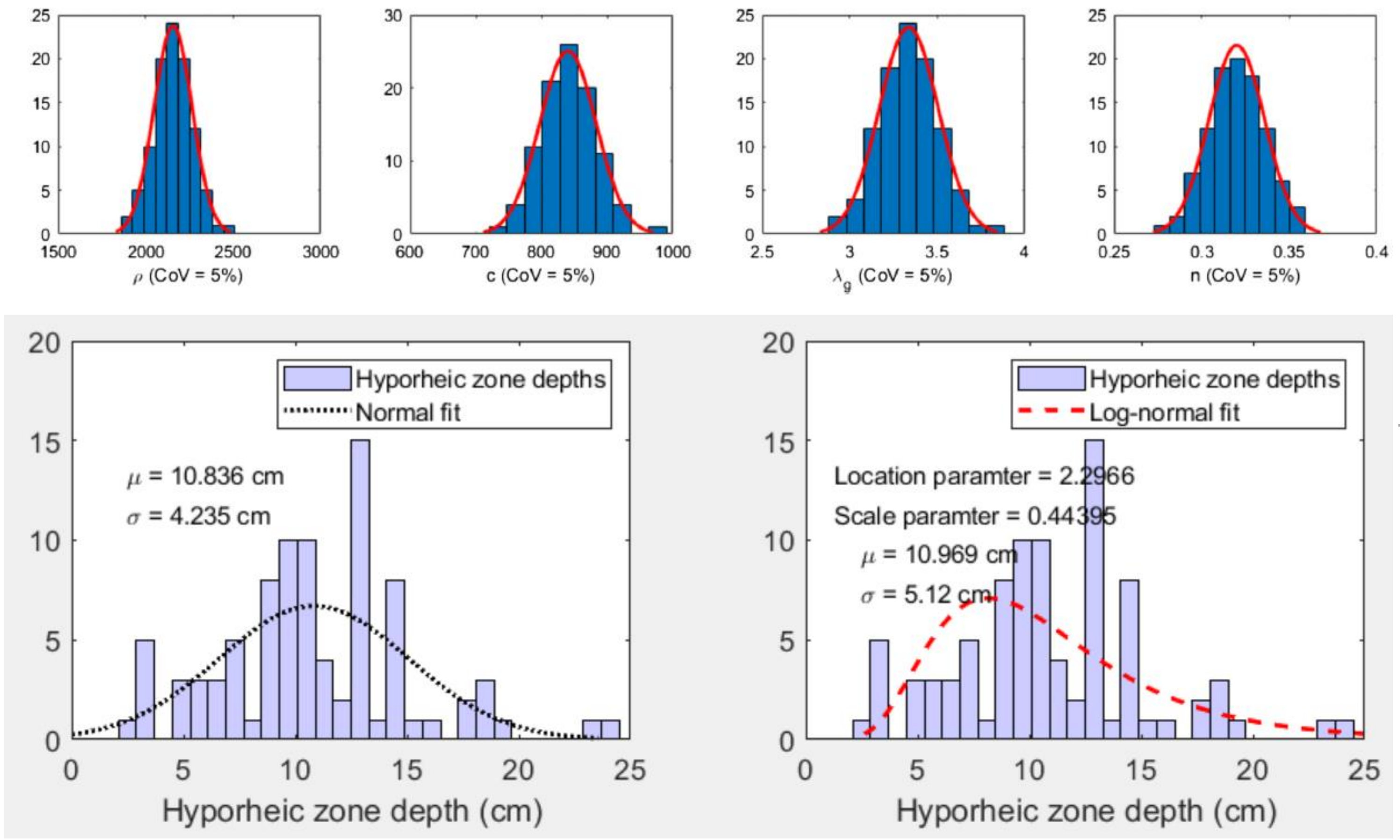


Figure 3. The real-world parameters vary widely around their means. For the probabilistic delineation of HZ, the principal parameters in the governing equation are considered random values and sampled using Monte-Carlo simulation. Repeated 100 CAD analyses gives a histogram with fitting with different probability density functions(normal fitting gives p-value of 0.5916 with Kolmogorov-Smirnov test)

III. METHODS for Reliability-Based Approach

A. Introducing Reliability Index β representing the Success of HZD management

$\Phi(\cdot)$: the cumulative distribution function for the standard normal distribution

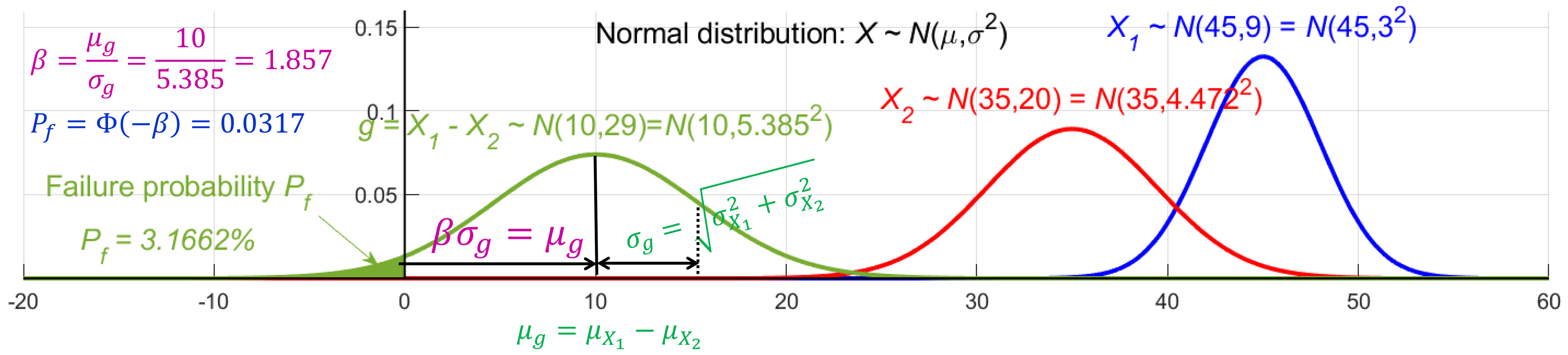


Figure 4. HZD management can be treated as a function g = HZD_{Field} – HZD_{Target}. The two variables are probability variables(blue and red lines), thus g is also probability variable(green line). Whether HZD management is successful or not can be measured via the distance between y-axis and μ_g. The distance is normalized by introducing reliability index β to reflect different standard deviations σ_g.

B. Illustrative Example for the previous field case

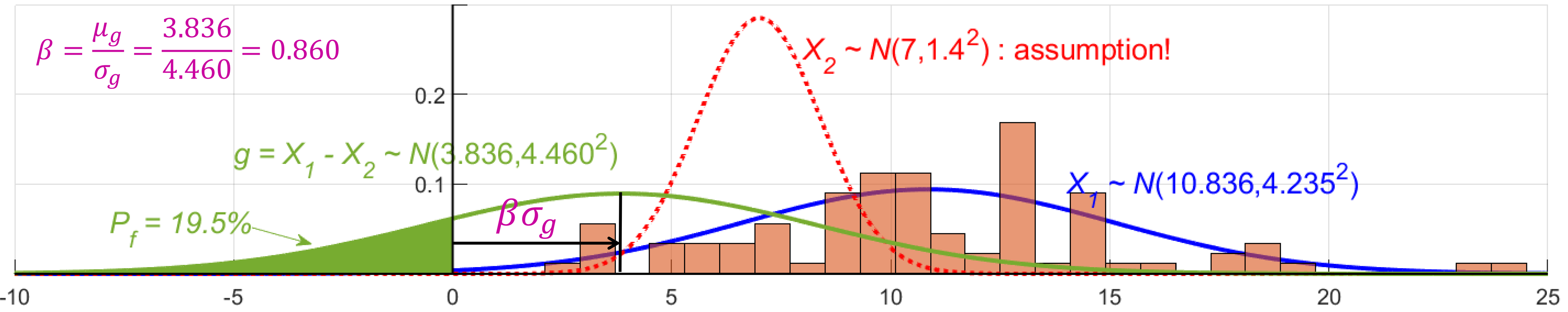


Figure 5. Reliability index for the previous case is 0.860 from the green line, if we assume the distribution of HZD_{Target} as $N(7,1.4^2)$. The target distribution, even its mean value of course, is not known for now, which is left for the future research.

IV. CONCLUSION

A method to evaluate the HZD management in terms of a representing index is presented. HZDs for field and target values are treated as probability variables, and their difference also follows a probability distribution where the success/fail of HZD management is reviewed. The target HZD is not known for now, which needs further research for a general agreement.

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