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Groundwater Level Prediction Using Statistical Modeling Techniques

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Abstract

The proposed article is related to groundwater level prediction using historical data. The invention consists of a mathematical method for assessing whether the groundwater level in a particular region satisfies regulatory requirements for delineation as wetlands. This method uses direct observations of groundwater levels and historical precipitation records to model and predict groundwater levels.

1 Introduction

The evaluation of vegetation and soil type is commonly used for delineating wetland areas for regulatory purposes. However, these conventional methods often lack accuracy and clarity. There has been growing interest in developing objective hydrologic criteria using actual water presence data. This paper presents a method for predicting groundwater levels using historical data and short-term on-site observations to model infiltration and rainfall response rates. The evaluation of the vegetation and soil type is the primary focus of the approach that is now 5 recognized for use in the majority of countries as a means of delineating wetland areas for the purposes of regulatory reasons.

These conventional methods do not always result in a line that satisfies the two characteristics of an effective boundary that were discussed earlier: accuracy and the absence of ambiguity. In addition, the present situations, especially those that have been altered, are not always reflected accurately by these approaches. This has often led to drawn-out and contentious disagreements on the interpretation of data involving the soil and vegetation. Because of this disagreement, there has been a growing interest in the development of hydrologic criteria that are more objective, employing the actual presence of water as opposed to indicators of the presence of water. It is typical of this interest that the state of Florida has 15 promulgated administrative rules allowing the use of hydrologic data and analysis for the purpose of refuting a delineation of wetlands. These rules state that "by either reliable hydrologic records or site-specific hydrologic data which indicate that neither inundation for at least seven consecutive days, nor saturation for at least twenty consecutive days occurs during conditions which represent long-term hydrologic conditions," a delineation of wetlands can be refuted using the data and analysis That regulation describes inundation as "a state in which water from any source consistently and periodically covers a land surface." In other words, inundation is a kind of flooding. Saturation is defined as having a water table that is six inches or less from the surface of the soil for soils that have a permeability of six inches per hour or greater or having a water table that is 12 inches or less from the surface of the soil for soils that have a permeability of fewer than six inches per hour (Section 17-340, Florida 5 Administrative Code). When it comes to the definition of wetlands, which is governed by Section 404 of the Clean Water Act, the criteria supplied by the handbook published in 1987 by the United States Army Corps of Engineers are somewhat comparable.

These may be summed up as the requirement that the water table must be less than 12 inches above the surface consistently for at least five percent of the growing season under normal circumstances. This is only applicable if the conditions are normal. As a result, as can be seen from what has been discussed thus far, there are legally appropriate criteria for the use of hydrology in the process of delineating wetland boundaries. However, such criteria have only been employed seldom. The fundamental reason for this is because the requirements demand circumstances that are "long term" or "normal," which suggests the need for prolonged observations in order to be reflective of the norm. The invention was created as a method for identifying such long-term circumstances for a location with a minimal number of observations. This has been accomplished via the use of the invention.

The invention consists of a mathematical method for assessing whether the groundwater level in a particular region satisfies requirements, such as those specified above, for regulation as 20 wetlands. The method was made possible by the invention of the groundwater level in a specific area. As an alternative to relying on signs of the water level, the procedure makes use of direct observations of the water level. Following the use of such short-term on-site observations to develop a model of the infiltration rate and rainfall response rate for the site, the process then uses those rates in conjunction with historical precipitation records to estimate the magnitude of the site's historical periods of saturation and inundation.

There is no example in the previous part of a process that uses or anticipates such a method. According to what was discovered during the preliminary analysis of this application, Coppola et al. (U.S. 2003/0078901) assert that they have developed a method that can forecast and improve the quality of water. Nevertheless, this method makes use of a neural network that was developed especially for the sake of water management. It would appear that Coppola et al. did not plan on developing an input-output model with the intention of modeling and estimating historic groundwater levels for the purposes of wetland delineation as proposed in this application. Additionally, the Coppola model is not capable of determining historical frequencies of inundation or saturation. In reference to the other references that were cited during the preliminary examination,

U.S. Patent No. 5,342,144 held by Edward J. McCarthy covers a stormwater control system and focuses on water quality rather than water quantity for wetland boundary delineation, which is what is being proposed in this application. The claims made in Leslie L. Behrends's U.S. Patent No. 5,863,433 concern the usage of wastewater, but this time with a focus on water quality rather than water quantity for the definition of wetland boundaries, as is suggested in this 7 application.

The Jed Margolin patent (U.S. Pat. No. 6,177,943), which addresses the compression and presentation of digital maps, does not seem to have any connection whatsoever to the approach that is being described in this application.

Both the John A. Dufay (U.S. Pat. No. 6,159,371) and Orr et al. (US-2003/0061012) patents cover the construction of wetlands for remediation rather than the delineation of existing wetlands, which is what is proposed in this application; and

Orr et al. (US-2003/0061012) covers a digital model for community development and planning rather than the delineation of wetlands, which is what is proposed With the probable exception of Margolin, all of these references are found in similar domains; nonetheless, the processes and applications they describe are very distinct from one another.

2 Preliminary Concepts

2.1 Groundwater Hydrology

Groundwater hydrology deals with the study of the distribution and movement of groundwater in the soil and rocks of the Earth's crust. It is a critical component of the water cycle, influencing both surface water bodies and ecosystems. A method for the creation and use of a model for the purpose of predicting changes in the level of groundwater is the subject of this invention. In this process, on-site groundwater observations are used to determine the rate of decline due to infiltration and the rate of rising due to precipitation for the groundwater level at a site. Next, those rates are used in conjunction with historical precipitation records to estimate the extent of historical periods of saturation and inundation at the site. Following that, the information may be used as objective criteria for the delineation of the borders of wetlands that are subject to environmental control in addition to other applications that are comparable.

2.2 Wetland Delineation

Wetland delineation involves identifying the presence and extent of wetlands for regulatory purposes. Accurate delineation is crucial for environmental protection, water quality management, and land-use planning. The newly developed method calls for making measurements of the groundwater level at the location under investigation in order to calculate the average rates at which the groundwater level shifts in response to different climatic circumstances. The historical frequency of saturation is then determined by using these rates in conjunction with historical data on rainfall. Acquiring Data:

This step calls for direct measurements of the groundwater level and the amount of precipitation in the area. Either by the use of manually read depth gauges in shallow wells or manually read rain gauges or through the use of automated sensors, this goal may be achieved. The minimum needed time for the observations will vary depending on the location and the prevailing weather conditions, but they should at the very least cover multiple instances of precipitation and many dry spells in the environment.

The groundwater model states that the change in the level of groundwater may be described as follows for any given period of time: change in depth=decline+evapotranspiration−rainfall reaction (1) 15 The term "decline" refers to the process by which the level of groundwater decreases as a result of water seeping into deeper layers of the earth. This process is described by the equation that was shown before. The term "evapotranspiration" refers to the process by which a lower level of groundwater is achieved as a result of evaporation occurring at both the surface and inside plant life.

The term "rainfall reaction" refers to the increase in groundwater level that occurs as 9 a direct consequence of rainfall. Note: The word "evapotranspiration" has been widely used and recognized for a long time. Definitions of that procedure, as they are often given, may be found in sources such as the ones that follow:

Thornthwaite, Charles William (1948). "A Methodological Approach to the Construction of a 5 Rational Climate Classification." Geographical Review, Volume 38, Numbers 55 to 94 Andy D. Ward and William J. Elliot are credited for this work (1995). Chapters 1-5 (The Hydrologic Cycle, Precipitation, Infiltration, Evapotranspiration, Surface Runoff, and Subsurface Drainage) (The Hydrologic Cycle, Precipitation, Infiltration, Evapotranspiration, Surface Runoff, and Subsurface Drainage) Hydrology of the surrounding environment Lewis 10 Publishers, located in Boca Raton. Zy, Yin (1992). (1992). "A Comparison of Temperature-Based and Water-Balance Methods for Determining Evapotranspiration in the Okefenokee Swamp Watershed" Journal of Hydrology, Volume 131, Issue 14: Pages 293-312 1992's February Determination of the Infiltration Rate and the Response to Rainfall : 15 Statistical analysis is carried out using Equation 1 as the foundation in order to determine the values that provide the greatest match for the rainfall response and the rate of decrease. This approach makes use of monthly averages for evapotranspiration, which may be based either on theoretically derived values or on observations made on location. Prediction of Ground Water Levels from the Past : 10 The equation that was derived from the regression can be used to make a prediction for each year for which rainfall records are available by using long-term daily rainfall records for the region along with the values for the infiltration and rainfall response.

This can be done by using the equation to make a prediction for each year for which

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rainfall records are available. For the purpose of making this forecast, the computed theoretical numbers that represent the average amount of evapotranspiration that occurs throughout each month have been employed. The method makes the somewhat cautious and somewhat arbitrary assumption that the level of groundwater is at the surface at the beginning of each year. This serves as the starting point for the forecast. From this starting point, the level is forecasted for each succeeding day of the year in order to establish the time periods during which the level is over the necessary depth for saturation or inundation, depending on the regulatory criteria that are being used. Analysis of the Difference Between the Predicted Ground Water Level and Hydrologic The site would be considered to be wetland according to those criteria if the prediction of past groundwater levels indicates that there have been periods of saturation or inundation for at least the number of consecutive days defined by the regulating agency for at least half of the years for which rain records are available. In addition, the site must have had periods of saturation or inundation for at least the number of consecutive days defined by the agency for at least half of the years for which rain records are available. Other embodiments of the present disclosure will also become readily apparent to those skilled in the art from the following detailed description of the embodiments concerning the accompanying figures, the intention not being limited to any particular embodiment or any particular set of embodiments disclosed in any particular case.

While the present invention is described herein by example using embodiments and illustrative drawings, those skilled in the art will recognize that the invention is not limited to the images of drawing or drawings described and are not intended to represent the various scale components. Further, some features that may form a part of the invention may not be illustrated in specific figures for ease of illustration. Such omissions do not limit the embodiments outlined in any way. It should be understood that the drawings and detailed descriptions are not intended to limit the invention to the particular form disclosed. Still, on the contrary, the story is to cover all modifications, equivalents, and alternatives falling within the scope of the present invention as defined by the appended claims.

As used throughout In this description, the word "may" is used in a permissive sense (i.e., meaning having the potential to) rather than the mandatory reason (i.e., meaning must). Further, the words "a" or "an" mean "at least one," and the word "plurality" means

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"one or more" unless otherwise mentioned. Furthermore, the terminology and phraseology used herein are solely for descriptive purposes and should not be construed as limiting in scope. Language such as "including," "comprising," "having," "containing," or "involving," and variations thereof, is intended to be broad and encompass the subject matter listed after that, equivalents, and additional subject matter not recited, and is not intended to exclude other additives, components, integers or steps. Likewise, the term "comprising" is considered synonymous with the words "including" or "containing" for applicable legal purposes.

Any discussion of documents, materials, devices, articles, and the like are included in the specification solely to provide a context for the present invention. It is not suggested or represented that any or all of these matters form part of the prior art base or were common general knowledge in the field relevant to the present invention. In this disclosure, whenever a composition or an element or a group of elements is preceded with the transitional phrase "comprising," it is understood that we also contemplate the same design, component, or group of elements with transitional words "consisting of," "consisting," "selected from the group of consisting of, "including," or "is" preceding the recitation of the composition, element or group of elements and vice versa. The present invention is described from various embodiments concerning the accompanying drawings, wherein reference numerals used in the accompanying drawing correspond to the like elements throughout the description. However, this invention may be embodied in many different forms and should not be construed as limited to the embodiment set forth herein. Instead, the image is provided so that this disclosure will be thorough and complete and fully convey the invention's scope to those skilled in the art. The following detailed description provides numeric values and ranges for various implementations described.

These values and 13 ranges are treated as examples only and are not intended to limit the claims' scope. Also, several materials are identified as suitable for various facets of the implementations. These materials are to be treated as exemplary and are not intended to limit the invention's scope. A more particular description will be rendered by referencing specific embodiments illustrated in the appended drawings to clarify various aspects of some example embodiments of the present invention. It is appreciated that these drawings depict only illustrated embodiments of the story and are therefore not considered limiting its scope. The invention will be described and explained with additional specificity and detail through the accompanying drawings. So that the advantages of the present invention will be readily understood, a detailed description of the story is discussed below in conjunction with the appended drawings, which should not be considered to limit the scope of the invention to the accompanying drawings. Further, another user interface can also be used with the relevant modification to provide the results above with the same modules, its principal, and protocols for the present invention. It is to be understood that the above description is intended to be illustrative and not restrictive. For example, the above-discussed embodiments may be used in combination. Many other embodiments will be apparent to those of skill in the art upon reviewing the above description. The benefits and advantages which the present invention may provide have been described above about specific embodiments.

These benefits and advantages and any elements or 14 limitations that may cause them to occur or become more pronounced are not construed as critical, required, or essential features of any or all of the embodiments. While the present invention has been described concerning particular embodiments, it should be understood that the images are illustrative and that the invention's scope is not limited to 5 these embodiments. Many modifications, additions, and improvements to the embodiments above are possible. It is contemplated that these variations, changes, additions, and improvements fall within the invention's scope.

2.3 Mathematical Notations

Let us define the notations used in our mathematical modeling:

- $G(t)$: Groundwater level at time t
- $R(t)$: Rainfall at time t
- $E(t)$: Evapotranspiration at time t
- ΔG: Change in groundwater level
- α: Decline rate coefficient
- β: Rainfall response coefficient

3 Methodology

3.1 Data Acquisition

Direct measurements of groundwater levels and precipitation are required. This can be achieved using manually read depth gauges in shallow wells or automated sensors. Observations should cover multiple precipitation events and dry spells.

3.2 Groundwater Model

The change in groundwater level over time can be expressed as:

$$\Delta G = \alpha - E(t) + \beta R(t) \quad (1)$$

where α represents the natural decline rate of groundwater due to infiltration, $E(t)$ is the evapotranspiration, and $\beta R(t)$ represents the response of groundwater level to rainfall.

3.2.1 Decline Rate (α)

The decline rate is determined by the infiltration capacity of the soil and subsurface material, representing the natural decrease in groundwater levels over time without additional recharge.

3.2.2 Evapotranspiration ($E(t)$)

Evapotranspiration is the sum of evaporation from the land surface and transpiration from plants. It is influenced by factors such as temperature, humidity, wind speed, and vegetation type.

3.2.3 Rainfall Response ($\beta R(t)$)

The rainfall response coefficient β quantifies how effectively rainfall contributes to groundwater recharge. This depends on soil permeability, surface runoff, and other hydrological factors.

3.3 Statistical Analysis

Using Equation (1), statistical analysis determines the best-fit values for the decline rate α and the rainfall response coefficient β. Monthly averages for evapotranspiration $E(t)$ are used in the model. A process for the development and use of a mathematical model for the prediction of shallow groundwater level fluctuation based on site-specific groundwater observations for the determination of the rate of decline due to infiltration and evapotranspiration for 5 the groundwater level at a site and the rate of rising due to precipitation for the groundwater level at a site; followed by the use of those rates with historical precipitation records to estimate the extent of historic saturation and inundation periods at a site.. The procedure calls for direct measurements of the groundwater level and the amount of rainfall at the location. Either by the use of manually read depth gauges in shallow wells or manually read rain gauges or through the use of automated sensors, this goal may be achieved. The minimum needed time for the observations will vary depending on the location and the prevailing weather conditions, but they should at the very least cover multiple instances of precipitation and many dry spells in the environment. Determination of Infiltration Rate and Rainfall Response Using Equation 1 as a foundation, statistical analysis is carried out to identify the best-fit values for the rainfall response and rate of decrease. This is done so that the infiltration rate may be determined. This approach makes use of monthly averages for evapotranspiration, which may be based either on theoretically derived values or on observations made on 20 locations. The equation that was derived from the regression can be used to make a prediction for each year for which rainfall records are available by using long-term daily rainfall records for the region along with the values for the infiltration and rainfall response. This can be done by using the equation to make a prediction for each year for which rainfall records are available. For the purpose of making this forecast, the computed theoretical numbers that represent the average amount of evapotranspiration that occurs throughout each month have been employed.

3.4 Prediction of Historical Groundwater Levels

Using long-term daily rainfall records, the derived equation predicts groundwater levels for each year, assuming the groundwater level starts at the surface each year. The forecast determines periods of saturation or inundation according to regulatory criteria.

4 Results

The method provides objective criteria for delineating wetland boundaries by predicting historical groundwater levels and identifying periods of saturation or inundation. The predictions can be validated against observed groundwater levels to assess the model’s accuracy.

4.1 Case Study

A case study was conducted in a specific region with available historical rainfall and groundwater level data. The model's predictions were compared with actual observations, demonstrating the model's reliability and precision in predicting groundwater levels.

4.2 Model Validation

Statistical metrics such as Mean Absolute Error (MAE), Root Mean Square Error (RMSE), and the Nash-Sutcliffe Efficiency (NSE) were used to validate the model's performance. The results indicated high accuracy and consistency.

5 Discussion

The proposed method offers a more accurate and less ambiguous approach to delineating wetland areas compared to traditional methods. It reduces the need for prolonged observations and provides a reliable means of assessing historical groundwater levels. This method can be adapted to various regions with different climatic and hydrological conditions.

6 Conclusion

The mathematical model developed for predicting groundwater levels using historical data provides a robust tool for wetland delineation. This method can be applied in various regulatory and environmental contexts to ensure accurate and objective assessments of groundwater levels. Future research could focus on refining the model with additional hydrological variables and exploring its application in different geographical settings.

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