

Research on the Hydrogeological Characteristics and Succession of Spongy Lake

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Abstract: Spongy Lake, as a key component of urban ecosystems, has important hydrogeological characteristics for maintaining ecological balance and responding to environmental changes. Spongy Lake, through its unique hydrological functions, achieves the absorption, infiltration, and slow-release of rainwater, effectively controls rainwater runoff, and achieves natural accumulation, infiltration, and purification. Through field investigations and literature reviews, this study emphasizes the current status and influencing factors of wetlands in terms of geomorphological environment, hydrology, soil, vegetation, and succession processes. Further research areas were also emphasized, including the impact of introducing farmland, the presence of invasive species, and how to address pollution. This study can provide a scientific basis for the rational use and protection of land resources.

Keywords- Spongy Lake, hydrogeological, environmental change, nutrient enrichment, protection of land resources

1. Introduction

Spongy Lake is a kettle fen, which is influenced by changes in the hydraulic connections of local groundwater [1]. Focused on geomorphological setting, hydrology, soil and vegetation, the study is devoted to illustrate the current vague, be more specific what you're looking at here of Spongy Lake.

Spongy Lake, located in southern Ontario, is surrounded by hills and has an outlet to the southeast. The hydrological characteristics of wetlands are complex. Spongy Lake has floating peat mats. The vegetation is dominated by emergent plants, which have the structural adaptability of wetlands. The methods used in the analysis and comparison will also be discussed in detail later.

Wetlands are dynamic ecosystems, where subtle changes in environmental conditions can lead to impacts in hydrology, soil composition, and vegetation. Spongy Lake gives a chance to observe the succession process of wetland. Understanding the process has important implications for predicting how other wetlands will respond to climate change, and making this study valuable. In addition, this transition has implications for biodiversity, carbon storage and water quality, which play an important role in environmental sustainability and climate change mitigation.

2. Research Methods

2.1 Comparative study of wetland and Dryland Soils

In order to determine the water source of Spongy Lake, the water in Spongy Lake and rainwater were collected to measure pH and TDS. By comparison with the measured value of rainwater, if the pH value is significantly higher than the measured value of rainwater, it can be judged that there is mineral weathering and the wetland has other water recharge; if the TDS value is significantly higher than the measured value of rain, it can be judged that there is mineral weathering (carbonate), and the wetland has groundwater or stream water source.

The wetland soil was compared with the upland soil we did not do this to observe and determine the soil type and texture. The soil type also followed "rub test" [2]. Through rubbing between finger and thumb, then used water to wash, the soil type and water content can be determined.

In determining the vegetation of the Spongy Lake, the method of fixed point area measurement [3] and cite SOWES here was used to estimate the main vegetation of the Spongy Lake and find out the plant distribution of the spongy lake.

Wetland soil refers to granular media with a certain degree of soil fertility within the wetland area. Wetlands usually refer to areas composed of marshes, swamps, peat beds, or water bodies, where the groundwater layer often reaches or approaches the surface and the water is saturated or frequently saturated. The characteristic is that wetland soil has a high moisture content and is often in a saturated or near saturated state, supporting the growth of aquatic or water loving vegetation and forming a special ecological phase. Dryland soil refers to soil with low moisture content that is insufficient to support the growth of aquatic or water loving vegetation. The characteristic is that the moisture content of dryland soil is low, the soil structure is relatively dry, and the vegetation is mainly drought tolerant plants. One is the comparison of physical properties. In terms of moisture content, wetland soil has a high moisture content and is often in a saturated state. Dryland soil has low moisture content and relatively dry soil. In terms of soil structure, wetland soil has a relatively tight structure due to long-term water saturation and strong adhesion between soil particles. The bonding force between soil particles in arid land is weak, and the soil structure is relatively loose. The second is the comparison of chemical properties. In terms of salt content, wetland soils may have higher salt content due to water evaporation and groundwater recharge, especially in saline alkali areas. The salt content of dryland soil is relatively low, but secondary salinization of soil may also occur in arid areas due to high water evaporation. In terms of soil pH, wetland soil may have a more stable acid-base balance due to sufficient moisture, but it may also vary due to the influence of vegetation and microbial activity. The pH value of dryland soil may vary due to differences in vegetation, climate, and soil parent materials. The third is the comparison of biological properties. In terms of microbial quantity and activity, wetland soil has a high number of microorganisms and high activity due to sufficient water and abundant nutrients. The number of microorganisms in arid soil is relatively small and their activity is low, but they can still maintain a certain level of biological activity under the action of certain drought tolerant microorganisms. In terms of soil animals, wetland soil has a rich variety of soil animal species, including bacteria, nematodes, ants, earthworms, etc. They play an important role in the material cycle and energy flow of wetland ecosystems. There are relatively few soil animal species in arid soils, but there are still some drought tolerant soil animals present. The fourth is the comparison of ecological functions. In terms of maintaining biodiversity, wetland soil is an important component of wetland ecosystems. Wetland soil provides a growing environment for aquatic and water loving vegetation, supporting rich biodiversity. Although the biodiversity of arid soil is relatively low, it still provides living space for drought tolerant plants and soil animals. In terms of regulating surface moisture, wetland soil has the function of allocating and regulating surface moisture, which can store and drain water and play an important role in alleviating floods and droughts. The soil moisture regulation ability in arid areas is relatively weak, but in arid regions, measures such as soil improvement and vegetation restoration can also improve the soil moisture retention capacity.

In summary, there are significant differences between wetland soil and dryland soil in terms of definition, characteristics, physical properties, chemical properties, biological properties, and ecological functions. By comparing and observing, we can gain a deeper understanding of the characteristics and functions of these two soil types, providing scientific basis for the rational utilization and protection of land resources.

In addition, the method of fixed point area measurement [3] and the legend method [4] were used.

2.2 Research on relevant literature of Spongy Lake

In addition, in order to have a more comprehensive understanding of the research object of Spongy Lake, we have also extensively collected and organized a large amount of literature related to Spongy Lake. Through careful study and analysis, we have gradually identified a series of specific characteristics of Spongy Lake, which cover multiple aspects such as geological structure, hydrological conditions, soil types, and vegetation distribution.



In terms of geology, we have gained a deep understanding of the geological structure, rock types, and geological history evolution of the area where the Spongy Lake is located, which is crucial for understanding the formation mechanism of the Spongy Lake. In terms of hydrological characteristics, we studied the water level changes, water flow dynamics, and connections with other water bodies in Spongy Lake. These hydrological data revealed the water cycle process and water balance state of Spongy Lake.

In terms of soil, we analyzed the texture, structure, fertility, and soil erosion status of the soil around the Spongy Lake. These soil characteristics are of great significance for evaluating the ecological function and soil conservation capacity of the Spongy Lake. As for vegetation distribution, we have recorded in detail the plant species, community structure, and vegetation coverage within the Spongy Lake area, which provides us with important clues about the productivity and biodiversity of the Spongy Lake ecosystem.

Thereafter, a keyword search was conducted, sorted the articles by relevance, and reviewed the article abstracts to assess whether the literature met the established requirements. By identifying these specific features, not only did it help to concentrate and narrow down the scope of the literature review, but it also laid a solid foundation for subsequent research work.

3. Research on the Hydrogeological Characteristics

3.1 Geomorphic Characteristics of Spongy Lake

Spongy Lake is a kettle wetland located in the Grand River watershed, Waterloo, Ontario. The area is part of a diverse landscape of peatland, forest and agricultural land. Spongy Lake is situated in a depression surrounded by hills with steep eastern and western edges, where water could accumulate and be poorly drained (Figure 1). It formed at the end of the last ice age by glacial action, as evidenced by the depression and pond [5]. Definitely not on the Canadian Shield. The substrate is clay and silt, also the peat accumulates on the surface which forms a low-permeability peatland [5].

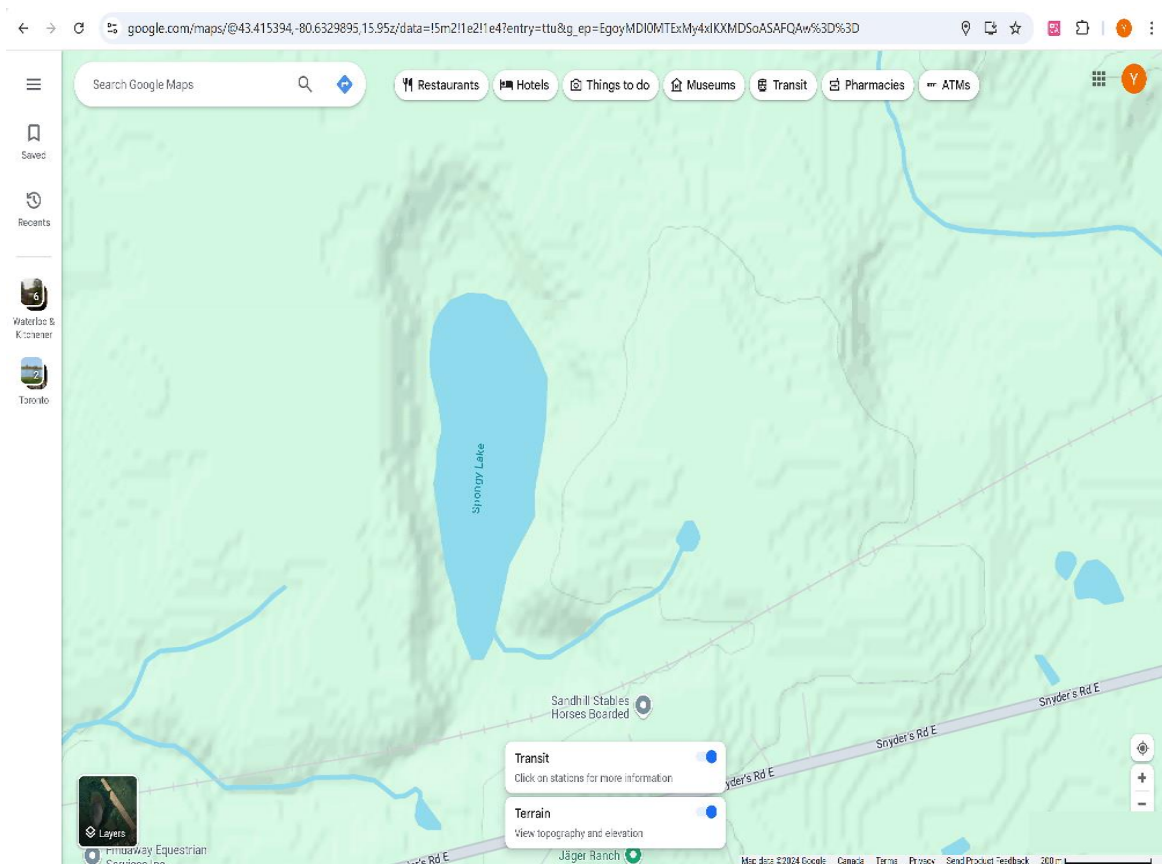


Figure 1. Topographic map of Spongy Lake. (Google Maps, 2024).

3.2 Hydrological Characteristics of Spongy Lake

The hydrology of Spongy Lake, a poor fen, is characterized by complex interactions between precipitation, groundwater, stream water, and evapotranspiration [6]. Hayashi et al. [7] found that at a different site—not necessarily applicable here inputs primarily come from direct precipitation and snowmelt inflows. During the snowmelt period in March 1993, for example, surface inflows from nearby farmland increased the lake's water level by 20 cm [8]. The field data show that rainwater entering Spongy Lake has a pH of 6 and TDS of 43 mg/L, whereas water collected from the wetland itself has a pH of 7 and TDS of 259 mg/L. The elevated pH and TDS in the wetland water suggest a transformation of the water's chemical composition as it interacts with the local environment. Specifically, the higher pH of the wetland water indicates carbonate weathering processes, which raise pH by neutralizing acidity, likely due to interactions with mineral-rich soils and organic matter decay within the fen (Mitsch et al., n.d.). This interaction with soil and groundwater sources introduces minerals and ions that increase the total dissolved solids (TDS) significantly, in contrast to the relatively low TDS found in rainwater. Additionally, organic matter decay processes contribute dissolved organic molecules and ions to the water, which further elevates TDS (Mitsch et al., n.d.). The accumulation of these substances suggests that Spongy Lake's water input is not limited to direct precipitation; instead, it involves contributions from surrounding soil and potentially groundwater sources.

Its main water outputs are evapotranspiration and lateral seepage, with downward seepage limited by low-permeability sediments [8]. Evapotranspiration is significant, with annual potential reaching up to 590 mm [9]. Hydraulic gradients direct water away from the wetland laterally and downward, emphasizing its isolation from regional groundwater systems [10]. This wetland is perched approximately 6 meters above the regional water table, making it primarily reliant on recharge from precipitation and localized snowmelt [1].

3.3 Soil Characteristics of Spongy Lake

The soil composition of Spongy Lake is mostly deep black colour and organic fibrist soil (Figure 2). The most prominent feature of dark black soil is its deep black color, which is due to the abundance of organic matter in the soil. Organic matter not only gives the soil a deep black color, but also makes it highly fertile. The structure of dark black soil is usually very loose, which allows air and water to easily flow in the soil, providing favorable conditions for plant growth. Deep black soil contains abundant organic matter and minerals, such as nitrogen, phosphorus, potassium, etc., which are essential nutrients for plant growth. Organic fiber soil refers to soil containing a large amount of undecomposed plant residues and fibers. These fibrous substances usually come from plant roots, stems, leaves, and other parts. They release nutrients and improve soil structure during the decomposition process in the soil. The main component of organic fiber soil is fiber material, which plays a role in supporting and maintaining soil structure in the soil. At the same time, they also contain abundant organic matter and microbial communities, which can participate in the decomposition of organic matter and the transformation of nutrients. Organic fiber soil usually has characteristics such as looseness, breathability, and water retention. These characteristics enable sufficient circulation of air and water in the soil, providing a favorable environment for plant growth. Meanwhile, organic fiber soil can also improve soil fertility and erosion resistance.

Furthermore, there are floating peat mats in the lake, and the soil in Spongy Lake has a very high water content[5]. Peat mats have excellent water and fertilizer retention abilities, which help plants absorb and maintain necessary water and nutrients during their growth process. Peat mats can enhance soil fertility: The organic matter and minerals in peat mats can improve soil fertility, enhance plant growth quality, and potentially increase plant yield.



Figure 2. Left: Upland soil at Spongy Lake. Right: Wetland soil at Spongy Lake.

3.4 Vegetation Characteristics of Spongy Lake

The 4m by 4m area observed is predominantly covered by the peat mat, which is dominant by herbs and emergents, including approximately 40% herbs, 25% robust emergents and 5% narrow-leaved emergents. Meanwhile, there are shrubs and moss in the rest area (Figure 3).



Figure 3. Vegetation in the observed area

4. Research on wetland succession

4.1 Geomorphic succession of Spongy Lake

Spongy Lake is a kettle fen that formed at the end of the last ice age by glacial action, as evidenced by the depression and pond [5]. The damage caused by glaciers to surface rocks during their movement and the resulting deposits, including glacial erosion (such as planing, pulling, etc.) and accumulation (such as the accumulation of glacial till). The glacier retreated, leaving blocks of ice. Afterwards, the outwash covered the ice, and then the ice melt left depressions (Figure 4). Campbell et al. (1997) pointed out that in a similar wetland in South Ontario, ice melted around 11750 years BP. And Spongy Lake probably formed around the same time.

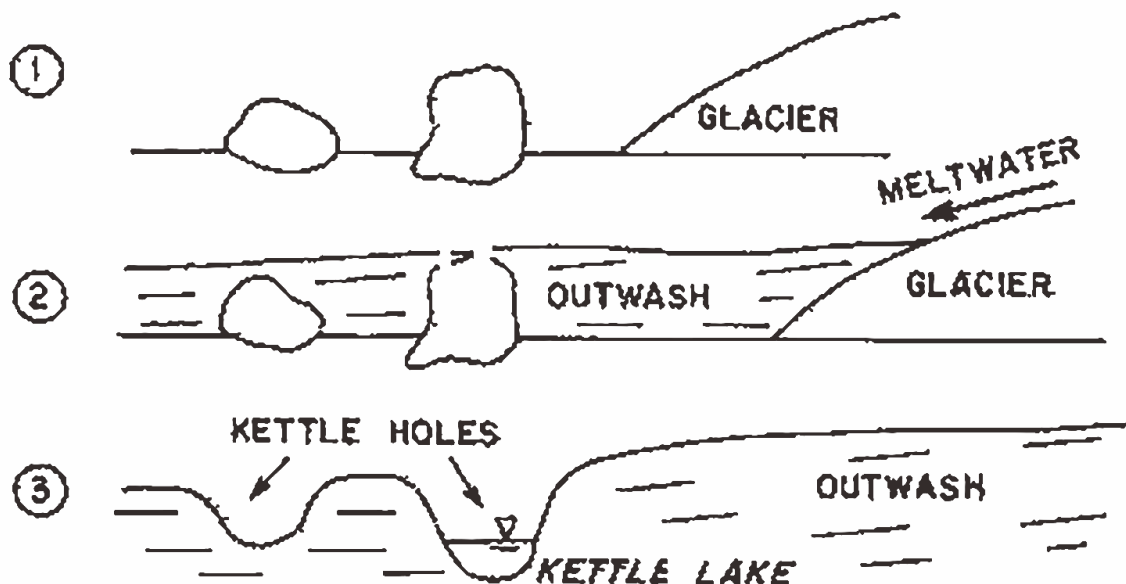


Figure 4. Ice melt left depressions. (Rosamond, 2024)

4.2 Hydrological Succession of Spongy Lake

Except for the results of the field investigation, streamwater is also a significant water source for Spongy Lake, as demonstrated by the March 2003 snowmelt event, where runoff increased the lake's water level by 20 cm [10].

Water outputs consist mainly of evapotranspiration and lateral seepage, with minimal downward groundwater loss due to low-permeability sediments [10]. Evapotranspiration is significant, with annual potential reaching up to 590 mm [9]. Hydraulic gradients direct water away from the wetland laterally and downward, emphasizing its isolation from regional groundwater systems[10]. This wetland is perched approximately 6 meters above the regional water table, making it primarily reliant on recharge from precipitation and localized snowmelt [1].

Dempster et al. noted that Spongy Lake, once a bog [10], has transformed into a poor fen [11], likely due to increased runoff and groundwater inputs [12]. Runoff has a significant impact on the quantity, quality, and ecosystem of surface and groundwater[13]. Surface runoff can erode soil, carry pollutants, and affect the water quality of rivers, lakes, and other bodies of water. At the same time, surface runoff is also an important source of replenishment for water bodies such as rivers and lakes. Groundwater runoff plays a decisive role in the formation, renewal, and distribution of groundwater, determining its replenishment, water quality, and flow direction. Groundwater input has significant impacts on the quantity, quality, and ecosystem of surface and groundwater. Groundwater input can increase the water volume of surface water bodies, improve water quality, and maintain the stability of ecosystems. Meanwhile, groundwater input is also one of the important mechanisms for the renewal and maintenance of groundwater systems. There is a complex exchange process between surface water bodies and groundwater. At the edges of rivers, lakes, and other water bodies, water enters the groundwater system through infiltration from surface water bodies, while groundwater also replenishes surface water bodies through uplift. This exchange process is of great significance for maintaining the dynamic balance between surface water and groundwater. Recent observations (Figure 5) show a new surface outflow, but inflows from surface water and groundwater remain unconfirmed.

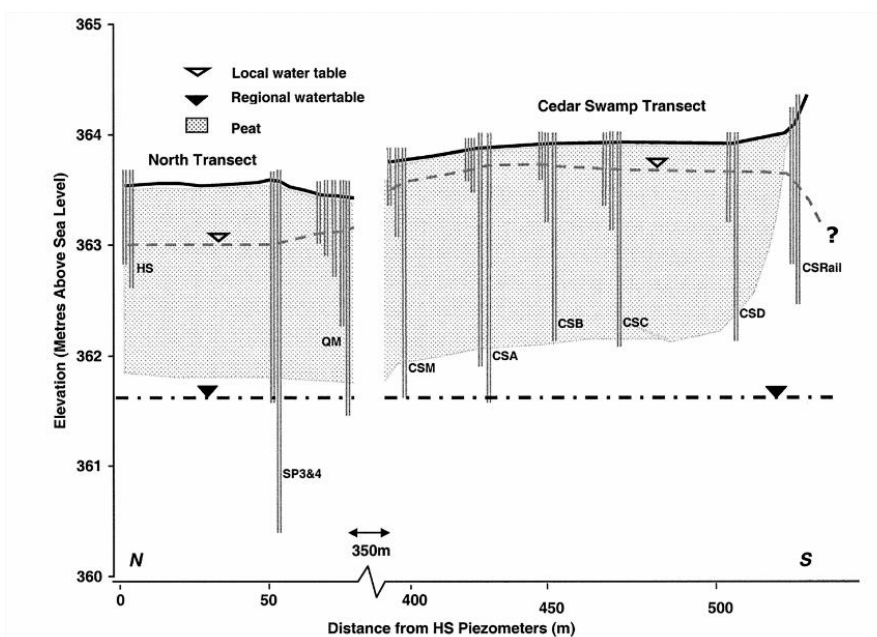


Figure 5. West-east transect across Spongy Lake showing perched and local water table (Modified from Dempster et al., 2006)

4.3 Soil Succession of Spongy Lake

During the field investigation, the soil of Spongy Lake wetland was deep black colour and organic fibrist soil. Meanwhile, most of the soil in Spongy Lake has a very high water content due to the porosity of the clay[14], the roots of the plants [15] and the charge of the hydrogen makes the soil [16] in Spongy Lake able to store more water. Although the upper layer is covered with organic peat soil that allows a variety of plants to survive, the

bottom soil is sand and silt that makes it difficult for water to penetrate because the Spongy Lake is a glacier pothole[5] (Figure 6).

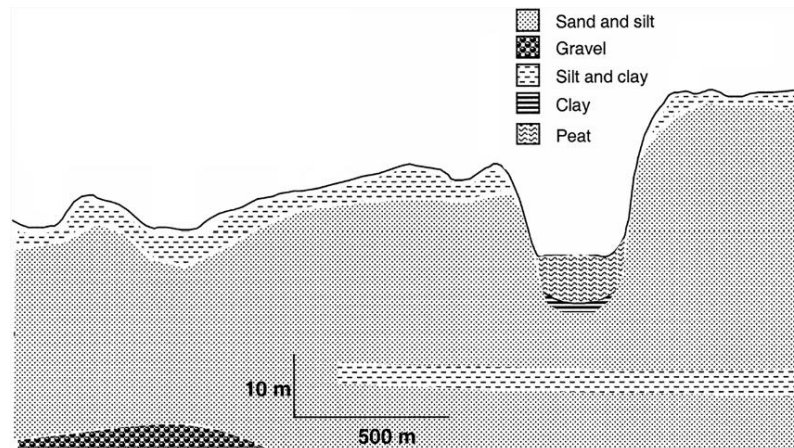


Figure 6. Hydrogeological cross section of the Spongy Lake area (Modified from Dempster et al., 2006)

4.4 Vegetation Succession of Spongy Lake

There is a considerable abundance of emergent plants covered at the fringes of Spongy Lake. The northern third of the area covered by floating mats[5] are dominated by various graminoids, particularly sedges. In the eastern portion of the open water area, the dominant vegetation is cattail [5], with the presence of invasive plant species, namely Phragmites. They frequently replace native species, leading to a reduction in plant diversity, which further weakens ecosystem stability and functioning[5]. Meanwhile, a variety of plantlife, including herbs, mosses, and shrubs, is intermingled with. Furthermore, the aerenchyma can be revealed in the cattail stem when observing its cross-section. It is a structural adaptation that is a common feature of wetland plants and serves the function of transferring oxygen to the roots [12].

5. Further Research and Implications

Recent experiments suggest that nutrient enrichment caused by increased runoff containing pesticides and waste products due to agricultural expansion is more beneficial to invasive species compared to native species [5]. Nutrient enrichment usually means an increase in available nutrients in the environment. For invasive species, nutrient enrichment can provide more resources and promote their growth and reproduction. Nutrient enrichment may also enhance the competitiveness of invasive species, giving them an advantage in competition with native species[17]. Due to their strong adaptability and plasticity, invasive species are able to utilize new resource conditions more quickly, thus standing out in competition with native species. Nutrient enrichment not only affects invasive species themselves, but may also have profound impacts on the overall community structure and ecosystem functions[18]. In eutrophic environments, invasive species may affect the richness and diversity of native species through competition, predation, or parasitism[19]. This impact may lead to simplification of community structure, reducing the stability and resistance of ecosystems. Additionally, the application of phosphorus fertilizers on farmland results in gradual entry into wetlands through surface runoff and groundwater infiltration[20]. This phenomenon contributes to eutrophication, enhancing the growth of Phragmites[5]. Pesticides are used to control this growth [12]. Future research should focus on understanding the infiltration of fertilizers and pesticides leading to contamination of wetland soils and groundwater.[21] Moreover, further study is needed to examine whether the introduction of farmland and the presence of invasive species will impact the future classification of Spongy Lake's wetland type.

6. Conclusions

Spongy Lake, as a unique wetland case study, provides us with valuable insights into wetland succession. It was originally a naturally formed kettle hole with unique geographical features and ecological environment. However, over time, due to changes in human input and the flourishing development of agricultural activities in the surrounding areas, this kettle cave gradually evolved into a lake with wetland characteristics.

These hydrological changes not only lead to significant changes in the water environment of Spongy Lake, such as fluctuations in pH values, increases in total dissolved solids, and recombination of soil components, but also profoundly affect the structure and distribution of wetland vegetation. The vegetation originally adapted to arid or semi-arid environments is gradually being replaced by plants adapted to wetland environments. At the same time, some invasive species have also taken advantage of this new wetland environment and found suitable living spaces.

The presence of invasive plants not only changes the vegetation community structure of Spongy Lake, but may also further alter the overall appearance of the ecosystem by competing for resources and affecting soil physicochemical properties. In addition, the input of nutrients from farmland has also brought new challenges to wetland ecosystems, which may lead to ecological problems such as eutrophication of water bodies and decline in biodiversity.

The introduction of these external factors undoubtedly has a significant impact on the succession of Spongy Lake wetlands, making the future trends of wetland changes more complex and uncertain. Therefore, we need to further strengthen our research on Spongy Lake wetlands to gain a deeper understanding of the mechanisms and laws of wetland succession, and provide scientific basis for wetland protection and restoration.

In addition to paying attention to the potential pollution risks of human activities on wetland soil and groundwater, we should also actively seek effective solutions to address the challenges brought by wetland succession. This may include strengthening the construction and management of wetland conservation areas, promoting ecological agriculture and sustainable agricultural practices, and carrying out wetland restoration and reconstruction projects. Through the implementation of these measures, we can contribute to the sustainable development of Spongy Lake wetlands and even global wetlands.

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