Rithet's Bog Water Quality and Hydrology Study

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1. ACKNOWLEDGEMENTS

This project was started in October of 1998 based on graduate work done by Karen Golinski. It would not have happened without the help of Ms. Golinski or the Rithet's Bog Conservation Society and we would like to thank both of them for their help and support, allowing us be a part of the preservation of Rithet's Bog.

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2. ABSTRACT

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A one-year baseline hydrological study and water quality analysis on Rithet's Bog in Saanich, B.C. was performed for a Sustainable Research Project. This project is part of the Camosun College Environmental Technology program curriculum. Rithet's Bog is a coniferous treed type basin bog in which *Sphagnum* moss should be the dominant substrate in the undisturbed situation. The purpose of the baseline study was to collect data concerning water quality and water table levels in order to make management recommendations that ensure the preservation and regeneration of bog plant communities. The study consisted of two mensuration experiments: a stratified block design and an offset transect design using dipwells to determine the conditions of the disturbed land and comparing oxygen, percent saturation, specific conductivity and temperature. The results of the experiments showed a water table that dropped well below the surface of the bog forest and high pH levels inhibiting the growth of *Sphagnum* moss species in all areas examined. Conductivity levels for much of the year were found to be five times higher than expected in a bog. A statistical analysis was performed on three identified regions: Bog Forest, Agricultural land and Surface Flows. The analysis identified a statistical difference in pH levels for the three regions with the bog forest having the lowest pH and, therefore, the greatest potential for *Sphagnum* regeneration. It was also shown that the bog forest had a significantly lower conductivity than the other two regions, which is a result of the surrounding agricultural land acting as a filter or buffer zone for the centre of the bog forest. The results of the transect through Rithet's Bog failed to identify any areas that met all requirements for the regeneration of *Sphagnum spp*. mosses. The analysis did; however, identify the two areas of interest surrounding dipwells 5 and 6. Management recommendations including preserving the existing buffer zone, removal of invasive vegetation, blockage of drainage ditches and damming the inflow channel were made as a means of increasing the potential habitat for *Sphagnum spp*. mosses and other remnant bog vegetation.

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3. INTRODUCTION

This report contains background information, procedures, results and recommended management options regarding the groundwater quality of Rithet's Bog. The baseline study was done by request for the Rithet's Bog Conservation Society in hope that it may help in the preservation of the existing remnant bog community

3.1 History

Of the seven large bogs formerly found on the Saanich Peninsula, Rithet's is the last (Golinski 1997). Unfortunately, it has been experiencing a rapid succession of species from *Sphagnum* dominated to a tree dominated plant community as a result of agricultural use, excavation of ditches and seasonal drainage. These damaging activities began in approximately 1880 and by 1922 the effects could be seen as vegetational changes in the central part of the bog.

The now reclaimed fields along Chatterton Way and Dalewood Lane were thought to have once been a lagg region containing a fen or shrub swamp vegetation (Golinski 2000). In the early 1900's the natural vegetation was cleared from this buffer zone for farming purposes. This continued until 1994 when agricultural and drainage activities were stopped and the hydrological and plant communities again began to change in response to the wetter conditions.

In more recent years, the natural drainage patterns of the basin have been altered by urbanization. Consequently, storm water volume has increased drastically due to the flow over impermeable surfaces that were once subject to percolation. Residential lawn irrigation and fertilization have also significantly affected seasonal moisture and nutrient regimes.

3.2 Background

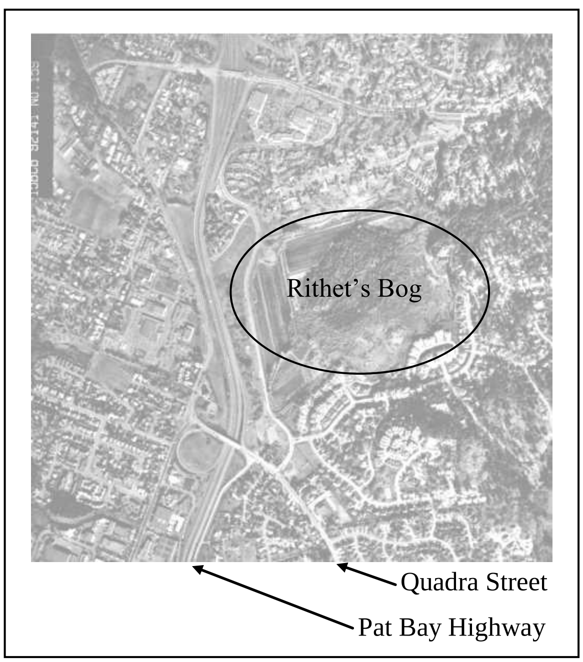


Figure 1: Location of Rithet's Bog

Rithet's Bog is a 42-hectare nature sanctuary located in Saanich just east of the Patricia Bay Highway and north of Quadra Street (Figure 1). The Corporation of the District of Saanich (CDS) controls the park management, which under Municipal Park zoning P5 requires that all management decisions be primarily concerned with conservation values. However, since the catchment area had already been highly altered by agriculture and urban development, the question arises as to what exactly is being conserved.

As a locally rare habitat type, naturalists and scientists have long recognized the ecological, archival, and educational value of Rithet's Bog. Karen Golinski, an Interdisciplinary Studies student at the University of Victoria, has done extensive research on several bogs in coastal environments and has been studying Rithet's for five years. Ms. Golinski, the Rithet's Bog Conservation Society (RBCS), and the CDS are all interested in the quality of water affecting the bog. There are several inflow sites along the bog perimeter and one major outflow, which drains into the Colquitz

Creek. Colquitz Creek is recognized as an important stream for salmon habitat and is currently being studied under the Urban Salmon Habitat Project, a joint Federal and Provincial project.

There are several concerns regarding the conditions of Rithet's Bog with one of the most influential being an increase in pH of the ground water. The cause for this is still undetermined; however, a potential source may be runoff water from the surrounding area. This water has recently been diverted around the bog via ditches so any non-point pollution from the surrounding urban areas should be contained within them.

Water table is another major governing factor over bog ecosystem survival. It is necessary to determine the extent to which the water table is dropping and why it is doing so. Labrador tea (*Ledum groenlandicum*), often the last bog-dependent species to remain in drained bogs, is common to Rithet's.

Finally, newly developed fen communities are now found on the southern edges of the bog. A bog is a normal natural successional stage following a fen so this regression posses more questions.

3.3 Objectives

The objectives of this study were to collect baseline data concerning the quality of water entering, leaving, and standing in the Rithet's Bog forest. These data are a starting point to which all future data can be compared to establish what kinds of changes are occurring in the bog and the rate at which these changes are proceeding.

Data and recommendations from this study will be given to the Rithet's Bog Conservation Society. It may be used at their discretion to help resolve a management plan for the bog. Perhaps it will also clear up some of the questions about the depth and location of the ditches and whether they are necessary or not.

Perhaps the most significant aspect of this study is the possibility of preserving an important ecosystem that has become very rare to the Southern Vancouver Island/Saanich Peninsula area.

3.4 Hypotheses

- If the pH in the Rithet's Bog ground water is above 4.5, then it will not be conducive to the regeneration of *Sphagnum* spp. Mosses native to the area.
- If the ground water levels in the bog are significantly below normal, then it will not be conducive to the regeneration of *Sphagnum* spp. mosses.
- If the temperature, specific conductivity, and dissolved oxygen are not within normal bog levels, then *Sphagnum* spp. mosses will not regenerate.

3.5 Literature Review

The literature published pertaining to bogs and fens in recent years is mainly in the form of scientific journal papers with many of these based on studies of bogs in Europe and eastern Canada. Many of the papers focus on aspects of hydrology as this has been generally agreed upon to be the main determining factor in bog functioning.

Ingram (1977) defined the diplotelmic bog by describing the differences in permeability and seepage in the two peat layers of a bog in the paper, "Soil Layers in Mires: Function and Terminology". The Gorham, Eisenreich, Ford & Santelmann (1985) article "The Chemistry of Bog Waters" describes the reasons for fluctuations in pH levels and provides a break down of the sources for nutrient input into bogs. The more recent literature focuses on hydrological management options for bogs and fens. Both Schouwenaars' (1995) paper, "The Selection of Internal and External Water Management Options for Bog Restoration" and LaRose's (1997) "Rewetting of a Cutover Peatland: Hydrologic Assessment" point out the importance of the water table in the re-establishment of *Sphagnum* dominated vegetation. Some of the management options discussed include blocking dams, constructing bunds, enlarging the area occupied by open water and the creation of hydrological buffer zones.

Bog vegetation has also been the topic of many scientific papers. In particular, Takagi et al. (1999) published the "Effect of the Invasion of Vascular Plants on Heat and Water Balance in the Sarobetsu Mire, Northern Japan." This paper states that the invasion of vascular plants into bogs increases water consumption as evidenced by a comparison of evapotranspiration in a *Sphagnum* bog versus a vascular plant dominated peatland. The peatland has a relatively higher rate of evapotranspiration. The 1995 paper by van Breemen, "How *Sphagnum* Bogs Down Other Plants", identifies *Sphagnum* moss as an 'ecosystem engineer' in creating an acidic, nutrient-poor, cold and anoxic environment for other plants. This paper, along with Wheeler's (1993) "Botanical Diversity in British Mires" conclude that bogs are in fact climax communities. They state that the progression of the bog plant community to forested areas is a result of human disturbance (i.e. the drainage of the bogs) as opposed to a natural succession.

Past literature on Rithet's Bog is taken mostly from Karen Golinski's publications. The first was "Environmental Overview of Rithet's Bog" (1995) which gave the background information and setting for the following reports. The second was "Rithet's Bog Conservation Strategy," outlining future management options to support the bog's survival (1997). The most recent publication was "An Overview Assessment of Hydrology and Water Chemistry at Rithet's Bog, Saanich, B.C." (2000). This report has compared water table fluctuations in Rithet's Bog to other bogs in order to determine any soil-water chemistry variations within the bog and has made management recommendations based upon this analysis. Golinski concludes that urbanization is the main force exacerbating past agricultural damage. The major problems impeding the restoration of bog vegetation are low water levels in the summer and poor water quality. The recommendation is to conserve the remaining fragments of original plant communities. Rithet's Bog is mentioned in Banner *et al.* (1988) "Wetlands of Pacific Canada" which describes Pacific Coast bogs and classifies Rithet's Bog as a coniferous treed type basin bog.

Information on peatlands can also be found on the Internet, which includes wetland definitions. The Internet is also a good resource for photographs of bog plants.

4. HABITAT OVERVIEW

4.1 Wetland Habitat

Wetlands have a significant ecological, economical, educational and aesthetic value that promote national and international issues concerning wildlife and fisheries. The open waters and vegetation of wetlands of the Pacific region serve as a major flyway for migratory birds as well as habitats for local waterfowl (Banner *et al.* 1988). In addition, wetland estuaries and water channels also support spawning and juvenile salmon as well as other varieties of fish populations. Rithet's Bog, in particular, provides habitat for many species of mammals, including muskrats, and at times deer. It is also known as a popular birding spot among the locals with a Great Horned Owl, Blue Heron and many others (Golinski 1995). There has been a report of a subspecies of silk moth endemic to British Columbia and rare to Vancouver Island found in the bog (Golinski 1995) in addition to many invertebrates including an undescribed species of cladoceran (*Macrothrix sp*.) which is probably a new species (Sendall 2000).

Other animals relying on wetland habitats are insects, amphibians, and reptiles. It is well known that insect species thrive in damp, muggy areas and as they provide the stable food base, other animals are encouraged to take up residence. Amphibians also take advantage of the moisture provided by wetlands throughout their entire life cycle. It helps in preventing the desiccation of the animal and its eggs. At Rithet's Bog, the rocky outcrops also provide a place for snakes and lizards to energize and sun themselves.

Wetlands have also been known to safeguard communities located downstream by reducing the impacts of flood waters. They retain the initial barrage of water for a slower release throughout the year. The absorptive capacity is related to the type and depth of organic material which acts to reduce the amount of free flowing water and improve water quality through filtration of nutrients, sediments and pollution.

Although Rithet's Bog is a highly disturbed bog site, there is still value to the area. Having a natural park so close to the city provides many recreational opportunities and due to its proximity to schools, including Camosun College and the University of Victoria, an excellent outdoor classroom.

4.2 Classification of Wetlands

Canada is divided into general wetland regions derived from north-south temperature, and east-west precipitation gradients (Banner *et al.* 1988). These regions are based on broad climatic zones and subzones. The zone to which Rithet's Bog belongs is the Pacific Coast Wetland Region. Its subzone is the Pacific Temperate Wetland. It is characterized by mild winters, warm summers and high amounts of precipitation.

A specific wetland classification is based on ecological parameters, which influence the growth and development of these lands (Banner *et al.* 1988). These include biotic factors such as vegetation and abiotic factors including hydrology and water quality.

There are three levels of organization in the Canadian Classification System; Classes, Forms and Types (Banner *et al.* 1988). The Canadian system describes 5 classes that encompass bogs, fens, swamps, marshes and shallow open water. These classes are distinguished from one another by factors such as acidity, open water availability and nutrient regimes. Of the five classes described, only two pertain to Rithet's Bog: bog and fen.

Wetland form is the next level of classification. Forms are defined by features such as, morphology, presence of patterns, position in the landscape and tidal effects, if any (Banner *et al.* 1988). These forms reflect differences caused by environmental factors such as origin of the water, peat development and permafrost. There are seventy different wetland forms in this classification system and, from these, Rithet's can be characterized as a basin. A basin bog is situated in a geomorphologic depression that has essentially closed drainage.

The final division of the Canadian Classification System of wetlands is type. Type is based on the general physiognomy of the vegetation cover and includes coniferous or hardwood trees, tall or low shrubs, rushes or mosses. There are sixteen wetland types within the five-wetland classes (Banner *et al.* 1988). However, there are only two types of basin bog: coniferous treed type, which pertains to Rithet's or moss type.

Using the Canadian Classification System of wetland, Rithet's Bog is described as a coniferous treed type basin bog (Banner *et al.* 1988).

4.2.1 Bog

A bog is an ombrotrophic peatland with a water table at or near the surface, poor ground water nutrient content and a low pH. More recent literature describes bogs as climax ecosystems and in the rare case that a bog remains undisturbed, the ecosystem reaches equilibrium and will not proceed to a forested stage unless disturbed (Wheeler 1993, van Breemen 1995).

The presence of a high water table creates the perfect conditions for *Sphagnum* moss to invade an area. *Sphagnum spp.* tends to lower pH, soil temperatures and dissolved oxygen within the soil thereby supporting peat accumulation (Banner *et al.* 1988). The dominant substrate of Rithet's Bog is decomposed *Sphagnum* mosses and sedge peat with the prevalent vegetation consisting of shore pine (*Pinus contorta* var *contorta*) and western hemlock (*Tsuga heterophylla*). The shrub layer is composed of salal (*Gautheria shallon*) and Labrador tea (*Ledum groenlandicum*). Finally, the herb layer includes *Sphagnum spp*. and *Vacciniums oxycoccuss*. This type of vegetation is a recognized result of drainage and disturbance (Banner *et al.* 1988).

The surface of a bog is typically flat with a domed centre where the most peat accumulation is located. The depth, in the centre, is generally 8.5-9.9 m (Banner *et al.* 1988). Because it is raised above the mineral ground water level, the centre of the bog receives its nutrients and water by atmospheric deposition only. Any nutrients held in this deposition are quickly incorporated into the biomass so there is no opportunity for dissolution in the ground water. The result is nutrient poor ground water.

Basin bogs occur in sites with small depressions that infill with organic deposits creating a substrate for primary peat accumulation and subsequent bog development. Basin bogs can form from natural hydrosere succession, from decreased water tables caused from downcutting of effluent streams and from poorly drained flat or sloped terrain (Banner *et al.* 1988). Rithet's first began as a lake with sedge-dominated vegetation and gradually evolved to a *Sphagnum* dominated bog (Golinski 1995). Accumulated peat is extremely dense and saturated with water, making lateral groundwater movement difficult. At Rithet's Bog the inflow water is diverted around the domed peat mass, through ditches. Artificially drained basins, such as Rithet's Bog, consist of a *Sphagnum* phase that has been succeeded by shrub and tree vegetation. Fibrous, humic, litter dominant sediment has been produced from this shrub and tree vegetation which is disruptive to normal bog function (Banner *et al.* 1988).

4.2.2 Fen

Fens are minerotrophic peatlands with a water table usually at or just above the surface and a pH of 5.5 or greater (Vitt 1994). Fen vegetation receives most of its water and nutrients from ground water that has come in contact with mineral soils. The minerals dissolve in the ground water making it nutrient rich. The dominant substrate materials of a fen are decomposed sedges and brown moss peat with the vegetation consisting of sedges, grasses, reeds, brown mosses, shrubs and possibly a thin tree layer (Banner *et al.* 1988).

Fens can be divided into three types based on their processes of formation. These are:

1. topogenic, which are influenced by stagnant ground water (Rithet's);
2. sologenic, influence by surface water; and
3. limnogenic, influenced by associated lakes or ponds.

Fens can be divided again by vegetational composition into poor fens (pH 4.0 - 5.5) which are dominated by mesotrophic *Sphagnum* and rich fens, which are less acid (pH > 5.5) and dominated by brown mosses (Vitt 1994**).** The higher pH and brown moss species found at Rithet's are indicators of a rich fen.

5. PHYSICAL CHARACTERISTICS

The evolution of wetlands is very complex, but by studying the stratigraphy of their deposits and the morphology of the landscape, evidence can be found to establish how they gradually developed.

5.1 Geomorphology

Glaciation and fluctuating sea levels caused the major geomorphic changes affecting wetland development in the Southern Vancouver Island Region. The late-Wisconsin glaciation was the most recent glacial event to affect Canada and occurred 17 000-18 000 years ago. The glaciers scraped and scoured the landscape as they advanced, cutting many deep depressions. As they retreated over the continents, large mineral lakes were left in these depressions and by about 6 000 bp (before present), most glaciers had disappeared altogether (Banner *et al.* 1988).

In addition to glacial influences, the marine environment also affected coastal areas. These areas had been submerged by the glacial weight and were considerably depressed relative to sea level. As melting occurred, the great weight was lifted. The land rebounded gradually exposing basins and depressions filled with lacustrine sediments (Banner *et al.* 1988). The organic marine sediments supported the wetland vegetation that proceeded to invade these areas. Rithet's Bog has formed in one of these marine clay laden basins.

The mineralogical composition and physical characteristics of bedrock and soil materials are other factors influencing wetland development. Mineralogical composition of bedrock and soil materials affects the quality of the water that comes in contact with it through dissolution. Areas where the soil or bedrock is abundant in nutrients will have nutrient-rich surface waters whereas areas containing deficient parent material will have nutrient-poor waters. The soil parent material allows plants better suited to these conditions to survive and flourish (Banner *et al.* 1988).

5.1.1 Soil Composition

The main types of soils found in wetlands are described in the Canadian Soil Classification System (Banner *et al.* 1988). This system is a hierarchical structure consisting of orders that are further subdivided into "great groups". The great groups associated with wetlands are Organic, Fibrisols, Cryosols and Gleysols. Wetland soil must be 40 cm thick of moderately (mesic) to a well (humic) decomposed matter or 60 cm thick of poorly (fibric) decomposed matter. The Fibrisol great group has soils predominantly consisting of a mesic middle tier of 40% or more rubbed fibre by volume. Organic Cryosols have an organic layer over 40 cm thick with a permafrost table within 1 m of the surface. Dull colours or distinct mottles of high colour strength within 50 cm of the surface characterize Gleysolic soils. Gleyed layers are usually found near the surface, which are created by reducing waterlogged conditions. Depending on the severity of the waterlogging, the soil may show a grey, blue or green colour rather than mottles, which are produced by periodic oxidizing conditions.

5.1.2 Soil Texture

The texture of the parent materials determines the porosity of the soil, which controls how much water is able to percolate through it (Banner *et al.* 1988). Dense, hard bedrock or fine-textured material such as silt and marine clay allows minimal water penetration and, as a result, the precipitation remains on the surface. These types of parent materials also resist erosion and the development of drainage systems. The undrained surfaces in turn promote the development of wetlands.

5.2 Stratigraphy

Thriving peatland vegetation is well adapted to the conditions of constant saturation. Accumulation occurs when climate or other physical conditions result in a rate of growth of plants such as mosses, reeds, or sedges that exceeds the rate of decomposition (Reed 1998). Waterlogged soils compound this effect by promoting a slower rate of decomposition. Eventually, the saturated plant remains compress to form peat for which the continuous soaking is essential for preservation.

Layers with different functions occur in organic soils such as peat and in mineral soils. The structure of a bog is diplotelmic, or two layered, where the differentiation is based on the hydrological peculiarities of organic soils (Ingram 1977). The two layers of a bog are the upper acrotelm and the underlying catotelm (Figure 2).

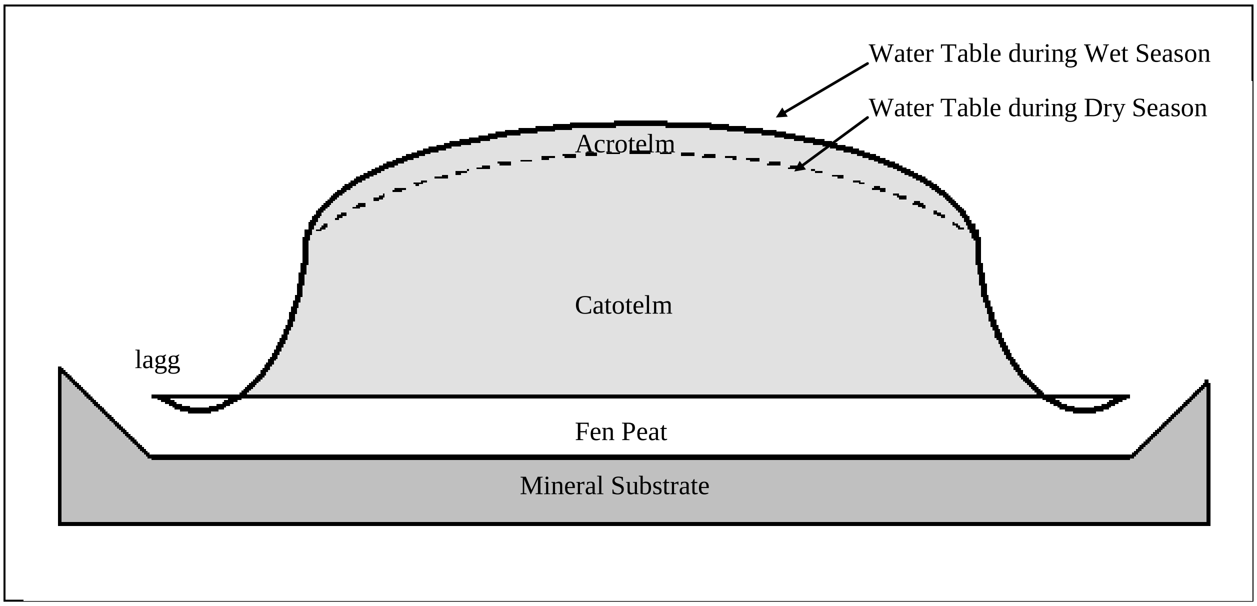


Figure 2: Stratigraphy of a Raised Bog

The acrotelm contains an oscillating water table and shows a variable water content (van Breeman 1995). It has a live matrix of growing plant material, including *Sphagnum* moss. As it is subject to periodic air entry the acrotelm is rich in aerobic bacteria and other microorganisms which aid in peat formation. This layer also has a large diversity of growing plant material. Most of the water movement in a bog is laterally through the highly permeable acrotelm.

The catotelm has a high water content invariable with time and is not subject to air entry, therefore; the catotelm is devoid of peat-forming aerobic bacteria and is poor in microbes (Ingram 1977). This is the thickest peat layer and remains permanently saturated. The catotelm is less permeable than the acrotelm. In fens, the tall plants are rooted in the catotelm, whereas the short plants are rooted in the acrotelm.

5.3 Hydrology

Hydrology is the study of the properties of the earth’s water, especially of its movement over land (The Canadian Oxford Dictionary 1998). It is the most important aspect of wetland development in that it affects the general type of wetland, nutrient make-up and renewal of groundwater supply, as well as species diversity and social value. Wetlands play an important role in the hydrology of watersheds. They act in buffering against shoreline erosion, water purification and flood peak moderation along with providing a rich source of biodiversity.

The two major factors that influence wetland hydrology are climate and the morphology of the land. Climate is the prevailing weather of an area with characteristic precipitation and temperature patterns (Banner *et al.* 1988). The West Coast of Canada is a temperate rainforest with mild summers and winters for its latitude. A major rainshadow effect is produced over the Victoria region by the Olympic Mountains located across the Juan de Fuca Strait; however, the vegetation is relatively lush from the evenly distributed precipitation received throughout the year.

The benefits of the precipitation are supplemented by the common coastal occurrence, fog. Fog condenses on leaves providing moisture and reduces insolation decreasing the potential for evapotranspiration. This reduced insolation lowers soil and air temperatures thereby slowing decomposition (Banner *et al.* 1988).

The second factor to influence wetland development is morphology of the ground surface. The land morphology influences the distribution of surplus water and external water sources which in turn influences the wetland location. For example, bedrock and surface contours cause water to naturally drain into and stagnate in depressions, flat plains and catchment basins (Banner *et al.* 1988).

5.4 Water Quality

The two most important variables influencing water quality in wetlands are pH and water table. For healthy bog conditions, pH should be between the levels of 3.5 and 4.5. It is unlikely that the pH will fall below this level but if it happens to rise above it, the bog vegetation will disappear and other species better adapted to more alkaline conditions will flourish (Banner *et al.* 1988).

Bogs also require a high water table to support indigenous vegetation. The critical level here is 40 cm below the surface. If the water falls below this level for prolonged periods of time, it is not likely that the healthy bog community will survive. Many of the representative plants have no roots or vascular tissue to tap into and make use of a deep water table and rely exclusively on diffusion as a means of gaining nutrients and water.

Three other parameters affecting water quality to a lesser extent than pH and water table include, specific conductivity, temperature and dissolved oxygen. Specific conductivity measures the total cation concentration of the water in μS/cm. For an undisturbed bog, conductivity should be less than 100 μS/cm indicating a low dissolved ion concentration in the water. *Sphagnum* moss effectively takes up the cations and releases hydrogen ions, in turn, keeping the pH acidic. The moss also provides natural insulating qualities that act to reduce the temperature of underlying layers to lower than the ambient. Dissolved oxygen is the volume of oxygen water can hold and should also be at reduced levels. Low dissolved oxygen indicates minimal aerobic activity in the soil, which reduces the rate of decomposition. Percent saturation of oxygen is a standardized measure of the total amount of oxygen water can hold (Banner *et al.* 1988).

6. VEGETATION

6.1 *Sphagnum* Moss

Sphagnum moss is the major climax vegetation in a healthy bog. Once it takes hold in a wetland area, it changes the environment to suit itself and extirpate all other intolerant species. Its disappearance is an indicator that natural conditions have been altered in some way to the detriment of the bog community.

6.1.1 *Sphagnum*, Hydrology and Water Quality

The hydrology and water quality of a bog determines the vegetational structure of the wetland. At the same time, bog vegetation affects the water regimes. The two factors are inextricably linked. *Sphagnum* moss species present in bogs are largely responsible for how it functions. *Sphagnum* is uniquely adapted to its environment acting as an "engineer" in producing favorable conditions for its own optimal growth while restricting other non adaptive plant species. However, before *Sphagnum* becomes established in an area, the right hydrological conditions must exist. *Sphagnum* moss lacks root structure and, therefore, can only occur where water flows are negligible.

Hydrology plays an important role in defining the bog plant community. The quantity, quality and periodicity of water drive the ecological development of peatlands (Golinski 2000). As noted earlier, the upper layer in a bog is more permeable than the lower layer allowing water to percolate downward reducing the surface flow to nil. Bogs are dominated by oligotrophic species of *Sphagnum* that live in highly acidic environments.

Fens are less permeable than bogs in the upper soil layers and at times may have surface flows. In fens, a slow water-flow will cause small sedges to dominate and a rapid flow with a variable water table will cause taller plants to dominate. Fens can be divided into poor fens (pH 4.0-5.5) which are dominated by mesotrophic *Sphagnum*, and rich fens, which are less acid pH 5.5) and are dominated by brown mosses (Vitt 1994).

Hydrology in bogs differs from that of fens and, as a result, the vegetation differs. In order for other vegetation to survive it must be equipped to function in an acidic engineered environment.

Figure 3: *Sphagnum* moss

As an artificially drained, coniferous treed type basin bog, Rithet's has a unique plant species structure that reflects the hydrology, water quality and history of a disturbed bog. Rithet's fen vegetation; however, reflects relatively high water table levels throughout the year, as well as higher pH and higher calcium concentrations than bogs: normal conditions for a fen (Golinski 2000).

6.1.2 *Sphagnum* Moss: Structure and Function

Sphagnum moss often dominates the vegetation of bogs in temperate and cold climates (Figure 3). The structure of

Sphagnum moss relates to how it functions in a bog environment. It lacks rhizoids and internal water-conducting tissue so capillary uptake is the major water conducting process. Eighty percent of the plant's volume is made up of porous, absorbent hyaline cells (van Breemen 1995). *Sphagnum* is highly susceptible to desiccation and when these cells are emptied during drought, the moss has a whitish appearance. This produces a high albedo reflecting much of the sun's incident radiation. A cooling effect comes over the bog habitat as the heat is reflected away rather than absorbed.

The combination of accumulating moss and a lack of drainage increases the concentration of the acidic byproducts. *Sphagnum* species require a low pH and low calcium concentration environment which, in a raised bog, is achieved by the downward flow of rainwater and the isolation of the plant from minerotrophic groundwater. *Sphagnum* has a high cation exchange capacity due to its sugar composition in which the CH_2OH side chain has been replaced by a carboxylic acid group (van Breemen 1995). The carboxylic acid group has a strong ionic charge that effectively attracts cations. Since *Sphagnum* intercepts nutrients so efficiently, it follows that mineralization of nitrogen and phosphorous is significantly higher in *Sphagnum*-dominated bogs than in brown moss dominated fens (van Breemen 1995). *Sphagnum* moss brings about water stagnation in initially well-drained mineral topsoils. In a situation where drainage has occurred, the ensuing aeration and decomposition of the peat can increase permeability making it an unsuitable substrate for *Sphagnum* mosses.

6.1.3 *Sphagnum* Moss: An "Environment Engineer"

Sphagnum moss builds an acidic, nutrient-poor, cold and anoxic habitat that few other plants can tolerate. The invasion of *Sphagnum* species occurs at first patchily by the less acidophilic members and then by the more acidophilic, carpet-forming species. Finally, the strongly acidophilic, hummock-forming species will dominate over time (Gorham et al 1985). Bog water becomes acidic in the presence of *Sphagnum* because of its efficient cation exchange ability and the acidity of its decomposition products. The moss exchanges hydrogen cations for other nutrient cations and the hydrogen released contributes to the acidity of the water. The pH, or acidity of water is a measure of the hydrogen ion concentration where a high concentration results in a low pH, or high acidity. The moss can intercept nutrients from the atmosphere, leachates and the litter of overstory plants, thereby reducing the nutrient supply to vascular plants. The species is also efficient at outcompeting other species for light. It uses dead tissue (like trees, but peat instead of wood) to attack its competitors at the root. In this way, *Sphagnum* shortens the growing season for other plants because it is heat-insulating and lengthens it for itself because the euphotic zone of the moss carpet is relatively warm. The acidic, nutrient-poor, cold environment and slowly permeable peat act to depress vascular plants. The reduced vegetation increases light availability and wetness via decreased evapotranspiration to *Sphagnum*: a positive feedback loop. The result is that adverse conditions are effectively "engineered" for other plants (van Breemen 1995).

6.2 Other Bog Vegetation Present

Bog vegetation is restricted to plant species adapted to nutrient-poor, acidic conditions. Woody vascular plants are mainly shallow-rooting trees and dwarf shrubs; however, the drainage of a gives these plants a competitive advantage. The high nutrient supply and drainage of Rithet's Bog is the reason there are so many vascular plants. The vascular plants act as evapotranspiration "pumps", removing the groundwater from the bog. The vegetation type is directly related to the rate at which water table drops as predominantly deciduous plant communities (found in Rithet's buffer zone) have large leaf surface areas that house a larger number of stomata. Stomata are the major mechanism for evapotranspiration. Vegetation such as shrubs and grasses have root systems that facilitate water extraction from deeper peat layers. This extraction causes the water table to drop to a lower level during a dry period than it would if it were dominated by *Sphagnum*. The moss eventually gets shaded out as the canopy cover of woody vegetation increases.

The morphology of an undisturbed bog is that of alternating hummocks and hollows. Stunted, xeromorphic trees and shrubs grow on the better-drained hummocks and the hollows remain treeless. The trees and shrubs on the hummocks provide structural support to species of *Sphagnum*. The wetter areas (or hollows) are dominated by the *Sphagnum* species best adapted to wet conditions in addition to other bryophytes.

In Rithet's Bog, *Sphagnum henryense* and *S. pacificum* may be threatened by the colonization of Hardhack (*Spiraea douglasii*) in the west-side of the pine forest (Golinski 2000). The colonization of coniferous trees is typical of a disturbed bog that has become drier and more nutrient-rich. A mature stand of shore pine (*Pinus contorta* var. *contorta*) and some western hemlock (*Tsuga heterophylla*) trees exist in the centre of Rithet's Bog (Figure 4). The trees increase water loss through evapotranspiration and rainfall interception. Coniferous trees also shade out bog vegetation and can smother other vegetation with leaf litter. As the water table is re-established in the forest, the coniferous trees fall and input nutrients into the bog. This changes the soil–nutrient composition and can negatively affect remnant bog communities that depend on a nutrient-poor environment. Labrador tea (*Ledum groenlandicum*) growth is dense in Rithet's Bog. It is often the last bog-dependent species to survive drainage.

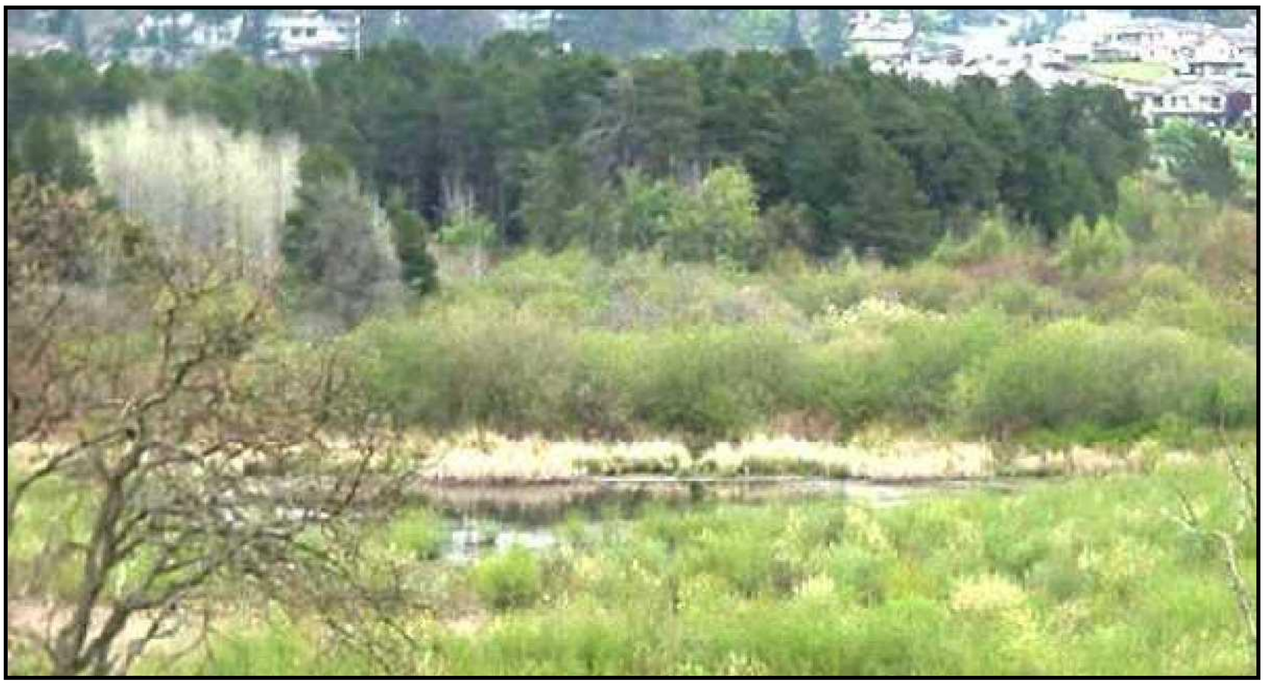


Figure 4: Bog Forest (in background) at Rithet's

The cessation of drainage and resulting wetter conditions in the centre of the bog has lead to three main effects:

- the decline of shore pines in the central bog forest;
- the colonization of the remnant bog community by hardhack, and
- the establishment of willows and other species adapted to wet conditions in the abandoned fields (Golinski 2000).

As noted earlier, vegetation in the fen reflects relatively high water table levels throughout the year as well as high pH values and calcium concentrations. The presence of brown moss (family *Amblystegiaceae*) colonization in the Rithet's Bog fen generally indicates a rich fen environment. The link between hydrology and vegetation is important in the development and maintenance of the bog environment as a whole. *Sphagnum* moss is present in most bogs and with its unique abilities, it is a determining factor in the stabilization of this relationship. The vegetation in Rithet's Bog can be seen as a mirror reflecting the complex water quality and water quantity characteristics that occur in a disturbed bog.

7. METHODS

Sampling began in early January 1999 and was conducted on a biweekly basis until the end of December 1999. These specific methods were used to enable a comparison of conditions between regions in the park and across the bog forest. A profile of pH, water table, conductivity, percent saturation oxygen, dissolved oxygen could be determined across the year and perhaps compared to subsequent years.

7.1 Sampling Design

The study consisted of two mensuration experiments: a stratified block design (Figure 5) and an off-set transect design (Figure 6) across the bog forest. Rithet's Bog naturally stratified out into agricultural land, bog forest, and surface flows providing the framework for the first design. The agricultural land was divided again by drainage ditches into three blocks where each block received a dipwell. These were numbered 1, 2 and 3. A transect line crossed the bog forest with dipwells numbered 4, 5 and 6 off-set from it. The dipwell is the experimental unit or smallest unit of the experiment that can receive the measurement treatments. The purpose of these dipwells was to determine the conditions of the disturbed land and to compare it to the bog forest and surface flows. Finally, the surface flows again showed a block formation with outflow, inflow, north ditch and south ditch.

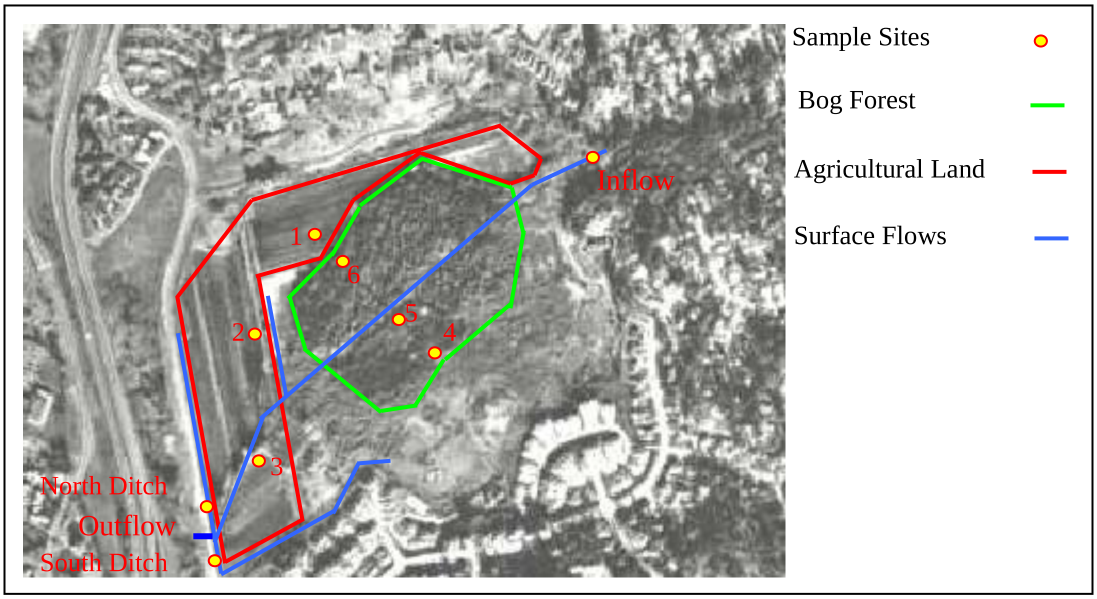


Figure 5: Block Design

In the second experiment the bog forest dipwells 4, 5 and 6, were placed randomly along a transect line that included dipwell 1 and the fen dipwell. The transect was used to get a profile of conditions across the bog forest. By including dipwell 1 in the transect it might be possible to ascertain whether or not the ditches were draining the bog or fulfilling their purpose of diverting polluted urban storm water around the fragile ecosystem. A comparison could also be made between the bog forest (dipwell 4) and the buffer zone (fen dipwell) that remained inundated for much of the year.

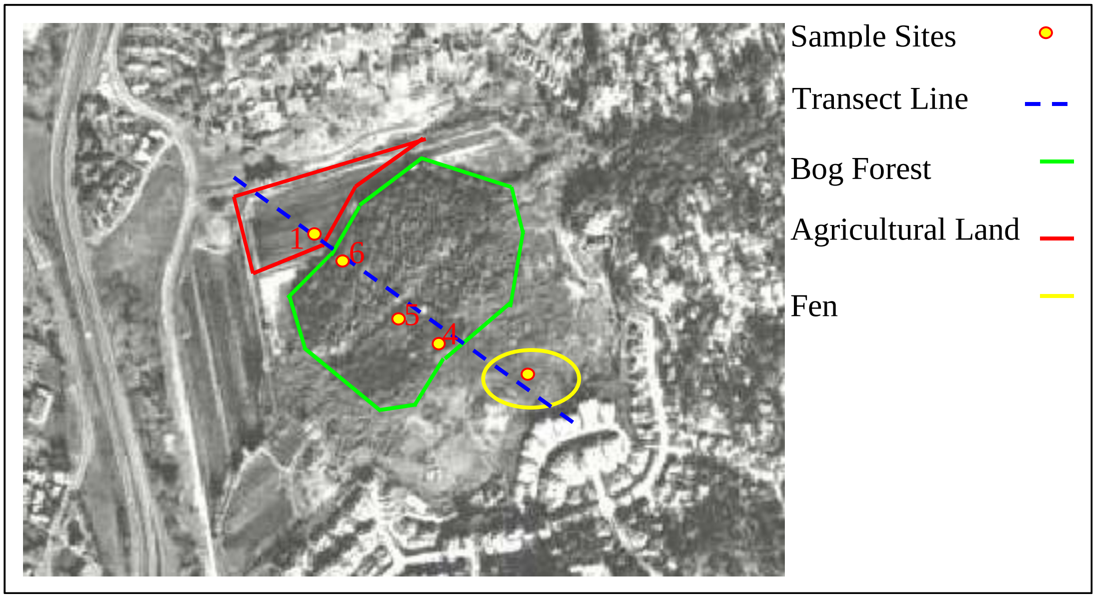


Figure 6: Transect Design

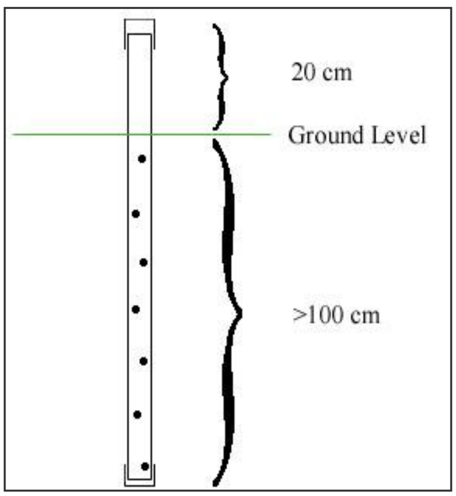


Figure 7: Schematic Diagram of Dipwell

The method of extraction involved placing a 2.5 cm diameter, 120 cm long PVC tube in the ground with 20 cm remaining above ground (Figure 7). The 100 cm length of tube below ground had small holes to allow ground water to seep in for easy removal using a hand pump. The water in the dipwells was not homogeneous along their length; the water at the bottom had different characteristics from the water at the top. The study required an average. Therefore, two subsamples were taken from each well and an average was used.

7.2 Procedures

The following sections describe the steps followed at each sampling site and the parameters that were measured there.

7.2.1 Dipwells

At each dipwell measurements of water table, pH, dissolved oxygen, percent saturation, specific conductivity and temperature were taken. However, in cases where dipwells were greater than 20 cm inundated, no measurements were taken as this would lead to surface water mixing.

Water table was measured first, as all other measurements required the water to be extracted from the wells. It was determined by blowing air lightly through a rubber hose while lowering it into the dipwell until bubbles could be heard. The tube was then marked at the top of the dipwell, and the length inside the dipwell was measured. Corrections were made at the time of data entry to take into account the 20 cm of dipwell that remained above the surface.

Prior to any other measurement being taken, water had to be extracted from each well using a small hand pump. A small amount of well water was used to rinse the two 500 mL Nalgene bottles before they were filled for sampling.

Hanna pH Meter   YSI Model 85

Figure 8: Hanna pH meter and YSI Model 85

The pH and dissolved oxygen parameters were measured first as both were affected by exposure to the atmosphere. For the sampling sessions in the first half of the year, pH was measured using the Barnant Field pH Meter # 501-3134 and for the second half the Hanna Model 9023 (Figure 8) was used. Hanna required only one calibration and was good for 3 hours after, whereas the Barnant was much more finicky requiring calibrations at each site. Dissolved oxygen, specific conductivity, temperature and percent saturation were measured using the YSI Model 85 (Figure 8).

On November 12, 1999 two samples were collected from each dipwell and kept in 250 mL bottles to be used to determine the buffering capacity at a later date.

7.2.2 Surface Flows

The inflow stream and outflow culvert were surveyed to get a rough estimate of the amount of water entering and leaving Rithet's Bog. The pH, dissolved oxygen, percent saturation, conductivity, and temperature conditions were measured, however, because the probes could be placed directly into the flow, only one measurement was taken. This procedure was also followed for the north and south ditches which emptied directly into the outflow culvert. The outflow and ditches had a fairly stagnant flow so the probes could be placed directly into the water. A waterfall aerated the inflow forcing the measurements to be taken from a pool upstream of the fall. This was also the first site measured when boggin' so temperature was also measured with a thermometer to ensure the proper calibration of the YSI.

7.2.3 Inflow Discharge

A stream's discharge is the volume of water that passes by a point per unit of time, usually measured in m^3/s. Measurements of the stream profile used to calculate discharge were taken under the bridge at the Fir Tree Glen entrance to the park and down stream of the waterfall. This section of the stream started below the pool created by the waterfall and ended at the dense shrubbery down stream. It was about seven meters long and maintained a fairly regular flow through the year with the exception of a dry spell in mid summer.

The profile was determined by measuring the channel width at half-meter intervals along the seven-meter length (Figure 9). Channel depth measurements were then taken at 25 cm intervals in a transect across the stream to the height of the channel banks. The transect measurement was performed every meter along the seven meter length. The stream was assumed to have a rectangular bed so a cross sectional area could be determined.

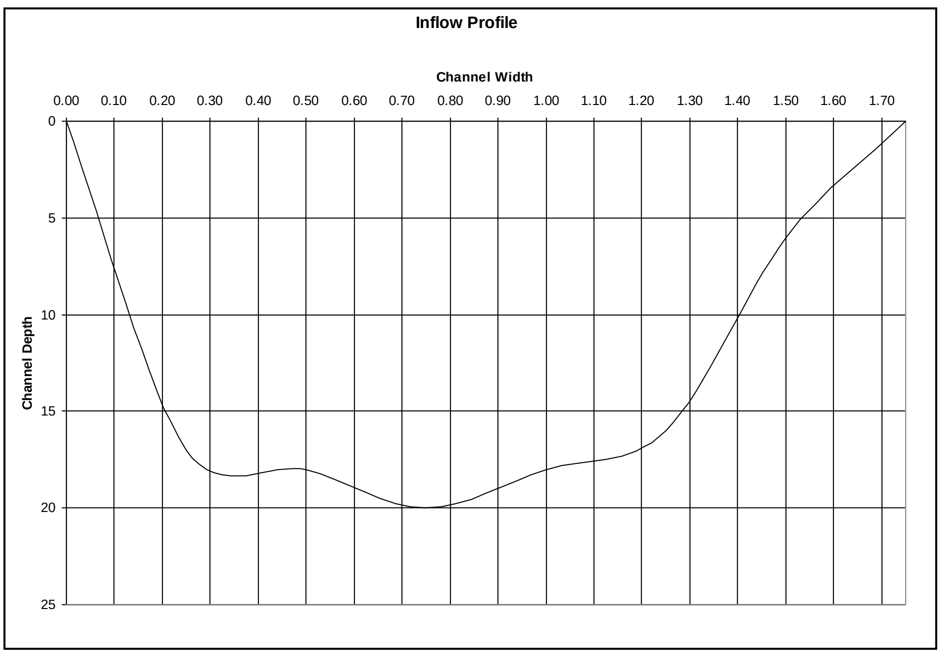


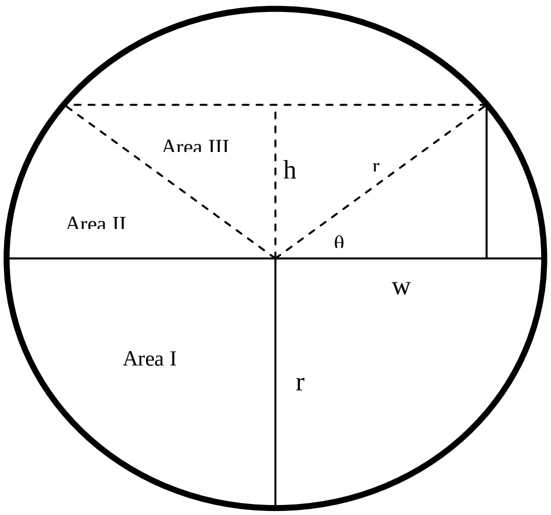
Figure 9: Profile of Inflow

The stream velocity was found by placing a Ping-Pong ball in the stream's thalweg and timing how long it took to float down the seven-meter length. The floating object method was used, as the inflow was too shallow to use the conventional digital flow meter. Five replicates were done on each test day throughout the year with the exception of the extreme low flow days during mid summer. Results for the Inflow and Outflow calculations can be found in Appendix F.

Stream depth was the final measurement required for determining discharge. This was the depth at the thalwag and measured during each sampling event.

7.2.4 Outflow Discharge

The outflow was a culvert that passed under the Pat Bay Highway and into a tributary of the Colquitz River. As an anthropogenic waterway, it had easily measured and calculated dimensions (Figure 10). The water height was measured at each sampling event, as was velocity. In this case the digital flow meter could be used except during the extreme dry time of year. Two replicates were done using the digital flow meter.



$$\theta = \arcsin\left(\frac{h}{r}\right)$$

$$Surface \cdot Area = \pi r^2$$

$$Diameter = (d) = 122cm$$

$$Radius = (r) = 61cm$$

$$Height = (h) = [Depth \cdot measurement(m) - 0.61]$$

$$r^2 = w^2 + h^2$$

$$w = \sqrt{r^2 - h^2}$$

$$\sin\theta = \left(\frac{h}{r}\right)$$

Surface Area of the Culvert Calculation

$$\text{Area I} = \frac{1}{2}\pi r^2$$

$$\text{Area II} = 2\left(\frac{\theta}{2\pi} \bullet \pi r^2\right) = \frac{\theta}{\pi} \bullet \pi r^2 = r^2 \bullet \arcsin\left(\frac{h}{r}\right)$$

$$\text{Area III} = 2\left(\frac{1}{2} w \bullet h\right) = w \bullet h = h\sqrt{r^2 - w^2}$$

Total Area = Area I ± (Area II + Area III)

$$\text{Total Area} = \frac{1}{2}\pi r^2 \pm \left(r^2 \arcsin\left(\frac{h}{r}\right) + h\sqrt{r^2 - h^2}\right)*$$

*If depth measurement is > 0.61,then Area I + (Area II + Area III);
If depth measurement is < 0.61,then Area I - (Area II + Area III).

Figure 10: Calculation of Surface Area of Outflow.

Profile measurements were not necessary for the ditches as they emptied into the outflow.

7.2.5 Other Sources of Water

Some of the differences between volume flowing in and volume flowing out of Rithet's Bog may be accountable to atmospheric precipitation and the number of unmarked private storm pipes draining into the ditches along the park's perimeter. A certain volume of water would also have been help in the basin in storage and later lost as evapotranspiration or seepage.

8. QUALITY ASSURANCE / QUALITY CONTROL

Quality assurances and quality controls are the procedures and protocols that were followed at each sampling event. They also include actions taken to determine or reduce error due to the sampling mechanism. The purpose of assurances and controls is to ensure that all samples are treated consistently throughout time and takes into account discrepancies due to treatment of the water samples through the extraction mechanism. Some of the measures taken were mentioned previously in the Methods section but are reviewed in greater detail here.

Dissolved oxygen was the first parameter measured at all sampling sites. The probe was immediately put into the sample and the reading was taken at the standard count of ten seconds. Dissolved oxygen changes once above ground so this control was used to keep the data consistent. Measurements were also taken on percent saturation and pH soon after extraction for the same reasons. Using dark tinted sample containers further reduced the possibility for photooxidation.

The controls and assurances taken for the surface water included taking measurements of the inflow above the waterfall so dissolved oxygen was not affected as well as doing five replicates of the velocity using the floating object method and two replicates using the velocity meter.

Quality control measures taken at the dipwells included rinsing collection bottles and probes at each site with well water prior to testing to remove contaminants from previous sites. Of the 120 cm long dipwell, 100 cm was below ground with small holes in it. The 20 cm remaining above ground did not have any holes in it and was checked periodically to ensure the rim remained 20 cm above ground. Test sites that had water covering the top of the dipwell did not need to be sampled as the surface and groundwater mixing would skew results. Dipwells were occasionally pulled out of the ground and cleared as they would fill with sediment.

Connecting a short tube to the end of the pump reduced the addition of oxygen into the water due to the extraction method. This allowed the collection bottle to be filled from the bottom with a reduced amount of splashing. The pumping process may have introduced oxygen to the sample and thereby affected the dissolved oxygen reading. An estimate of the error introduced through extraction was determined through a procedure done in the lab. Actions were taken in which a running mean was used to ascertain the oxygen error. An explanation of the procedure and results can be found in Appendix B.

9. Results

In the following section, the results are given for each dipwell and surface flow. A graphical trend over the year is given for each variable starting with pH, then conductivity, dissolved oxygen, percent saturation of oxygen, water table and finally, temperature. Sampling began at sampling period 1 (sp1) on January 17, 1999 and was conducted every two weeks until sampling period 24 (sp24) on December 12, 1999.

9.1 pH of Groundwater

The pH measurements for the agricultural land were fairly stable throughout the year (Figure 11). Collectively, the agricultural dipwell pH measurements ranged from a low of 5.34 at dipwell 1 on April 14 (sp7) to a high of 6.84 in December (sp 23) at dipwell 3 (Table 1). The agricultural dipwells also demonstrated a pH averaging 6.02, noticeably higher than that of the forest dipwells, pH 4.57 (Table 2).

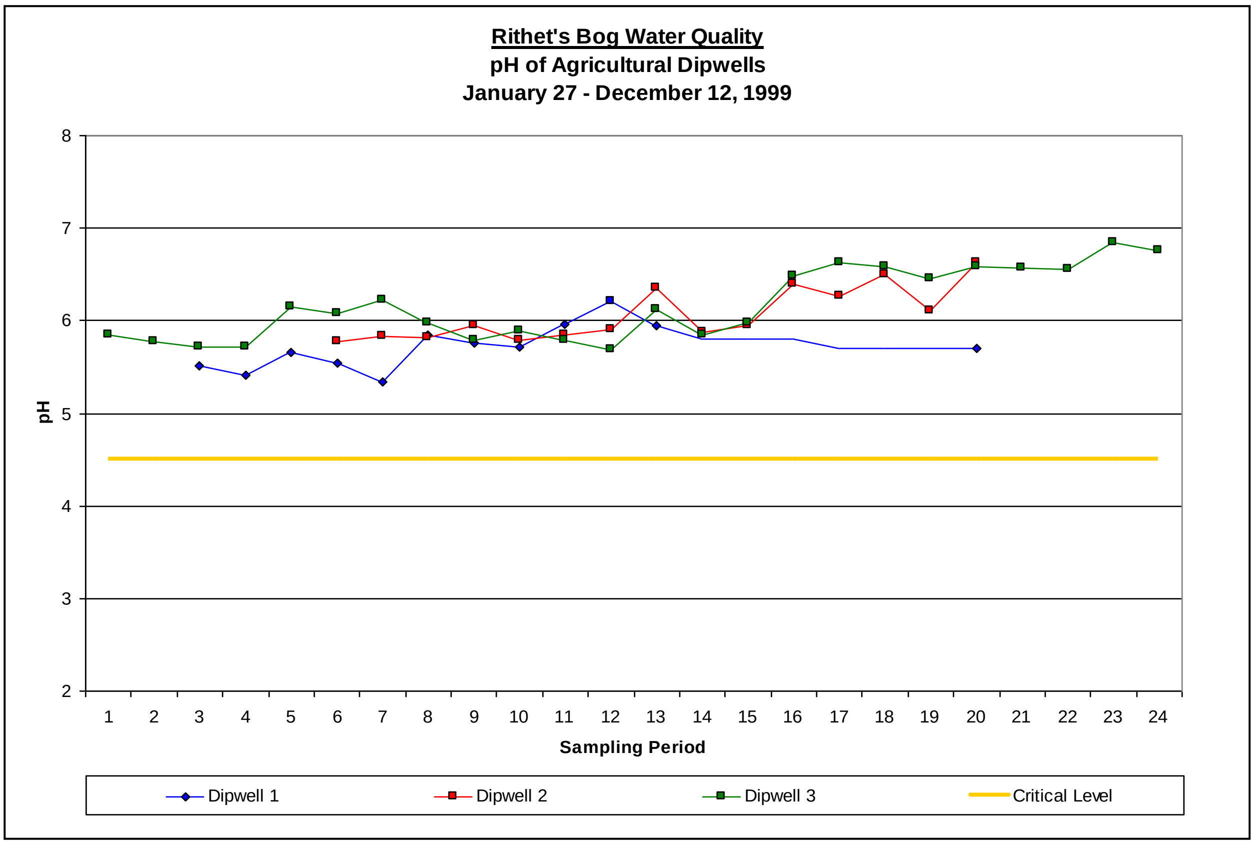


Figure 11: pH of Agricultural Dipwells.

The agricultural dipwells experienced surface water inundation that inhibited a significant portion of the measurements from being taken. From those that could be collected at dipwell 1, a low pH of 5.34, a high of 6.61 and an average for the year of 5.77 were ascertained. The first measurement from dipwell 2 was not taken until March 31 (sp6) due to flooding and the last was October 16 (sp20). The surface water remained at acceptable sampling levels for only 28 weeks. The measurements collected were, similar to dipwell 1, very stable with a range of only 0.85 and averaged 6.10 for the year. Dipwell 3 also demonstrated a stable constant upward trend through the year averaging 6.19 but rising from 5.68 on January 27 (sp1) to 6.8 on December 12 (sp24). There was no point during the year when any of the agricultural land dipwells had a pH below the critical level of 4.5.

The forest dipwells showed a much greater fluctuation in pH throughout the year than did the agricultural land dipwells (Figure 12). They ranged from a low of 3.01 to a high of 6.93. Dipwell 4 stayed below the critical level of 4.5 during the winter months. However, near the end of May (sp9), the pH rose above this level and remained there until the last sampling period of October (sp21). The pH at dipwell 5 was consistently above the critical level for most of the year. It took a sharp drop to 3.08, recorded on October 31 (sp21) but returned to a high mark of 6.36 on the next sampling date. The pH of this dipwell averaged 5.17 for the year, which is significantly above the identified critical level. Dipwell 6 had a full year average for pH of 3.87 and most closely met the requirements of *Sphagnum* moss. For most of the year, pH remained below the critical level; however, it did rise above 4.5 for a six-week period from July 21 (sp16) to October 7 (sp19).

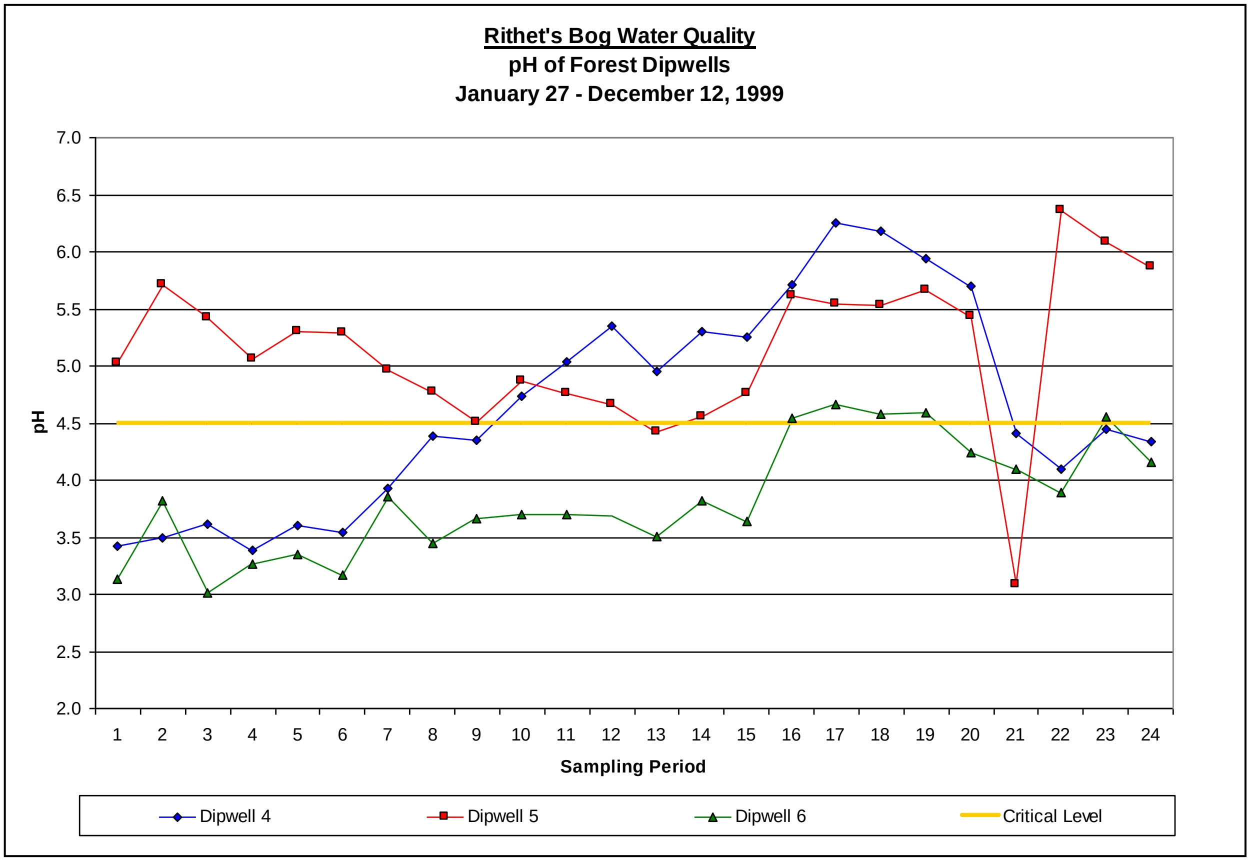


Figure 12: pH of Forest Dipwells.

The pH of the surface water, which averaged a fairly neutral 6.87, was expected as it was accumulated rainwater unaffected by ground variables such as *Sphagnum* (Figure 13). pH of surface flows also showed minimal fluctuation throughout the year when compared to the forest remaining in the neutral range around pH 7.0. The trend remained reasonably stable in this range as the year progressed. The surface flows recorded a low pH of 5.83 for the outflow on the 3rd of February (sp2) and a high of 7.93 for the inflow on September 16 (sp18).
Data collection for the Fen started on July 10 (sp13) when the water level finally dropped below the surface. Recording started at pH 5.8 and dropped slightly to 5.6 before rising at a fairly steady rate to a high of 6.45 during sp18 and then dropping to the final sample of 6.3.

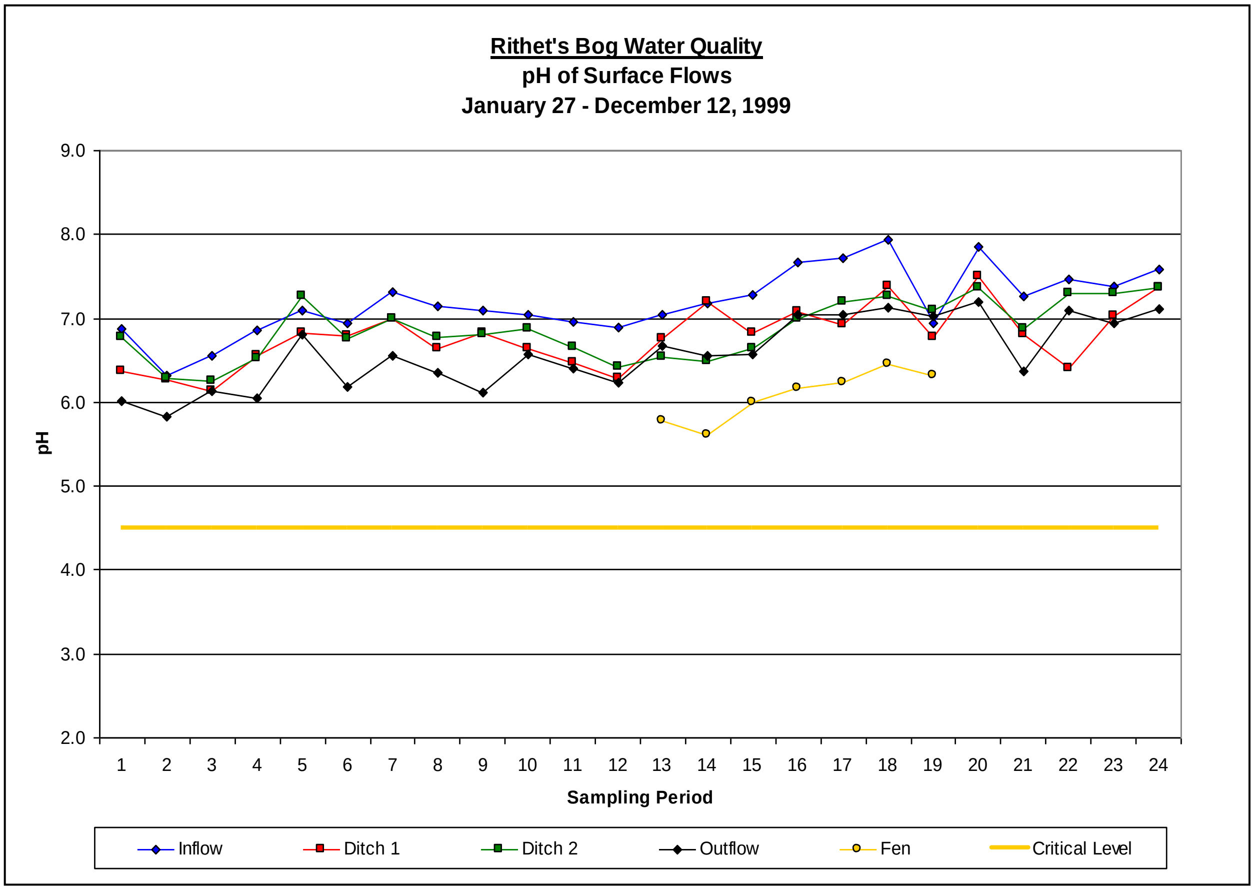


Figure 13: pH of Surface Flows.

Table 1: Summary of pH Measurements.

	Inflow	1	2	3	4	5	6	Ditch 1	Ditch 2	Outflow	Fen
Minimum	6.32	5.34	5.77	5.68	3.39	3.08	3.01	6.13	6.26	5.83	5.61
Maximum	7.93	6.61	6.62	6.84	6.93	6.36	4.66	7.50	7.36	7.20	6.45
Range	1.61	1.28	0.85	1.16	3.55	3.28	1.65	1.37	1.11	1.37	0.84
Average	7.21	5.77	6.10	6.19	4.66	5.17	3.87	6.80	6.88	6.61	6.08

The pH measurements for bog forest, agricultural land and surface flow were combined to get an average for each region as shown in Figure 14 and Table 2. This figure demonstrates a substantial difference in ground water pH between the three regions. As expected, the bog forest has the lowest, most acidic, average pH and the surface flows remain relatively neutral. The outliers at sp 11 have been attributed to a calibration problem with the Hanna pH meter as it was brand new and this was the first time it had been used in the field. The error also showed consistency throughout the sampling day.

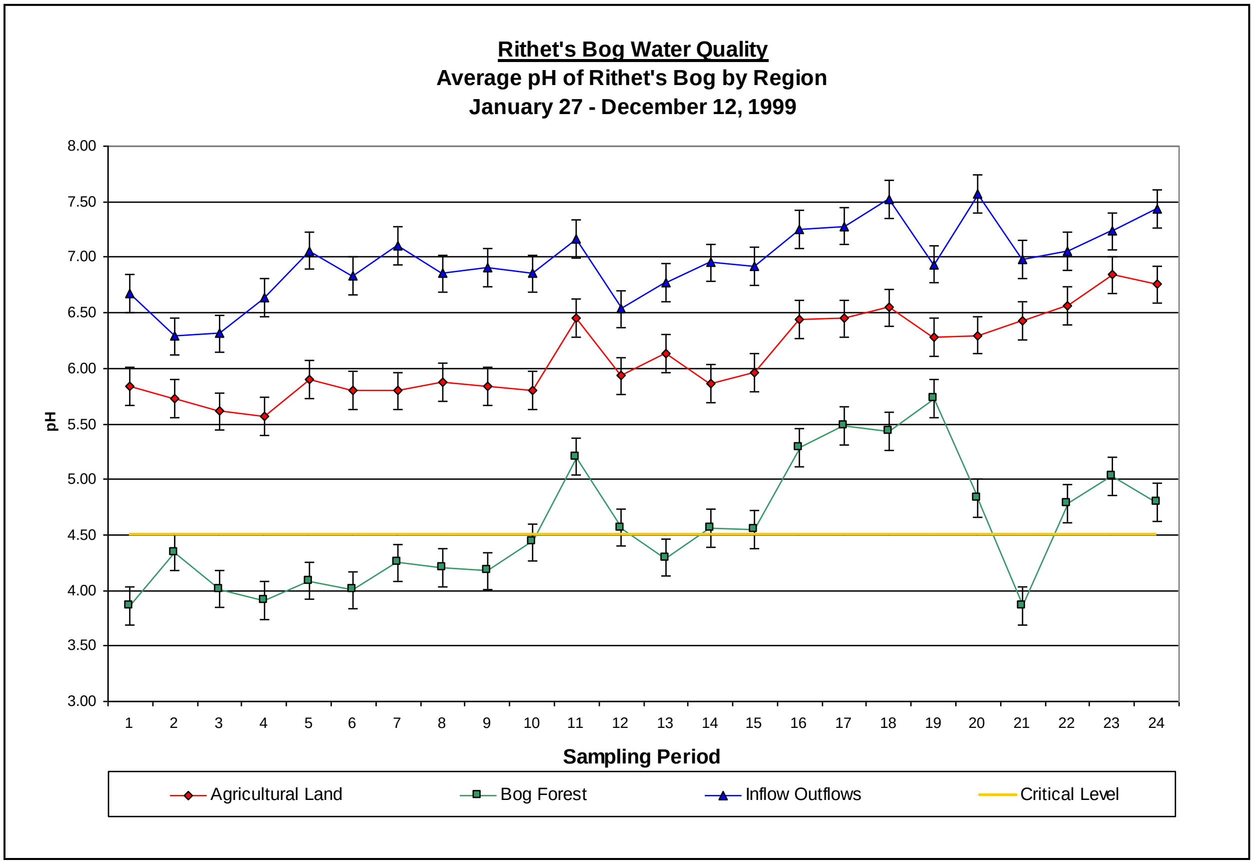


Figure 14: Average pH by Region

Table 2: Summary of pH by Region

	Agricultural Land	Bog Forest	Surface Water
Minimum	5.34	3.01	5.83
Maximum	6.84	6.93	7.93
Range	1.51	3.92	2.10
Average	6.02	4.57	6.87

9.2 Specific Conductivity of Ground Water

For the majority of the year, the average specific conductivity of the ground water found in the forest remained a great deal lower than the agricultural land and surface waters (Figure 15). Levels also appeared to be much steadier in the forest, showing a constant trend. The agricultural dipwells and surface flows; however, show many fluctuations throughout the year.

As the rains increased in the fall from sp18 to sp24 the groundwater levels and readings became increasingly variable especially for surface flows.

Conductivity readings for the fen were relatively stable compared to other wells from a low of 353.05 µS/cm on June 26 (sp12) to a high of 497.4 µS/cm on September 16 (sp18).

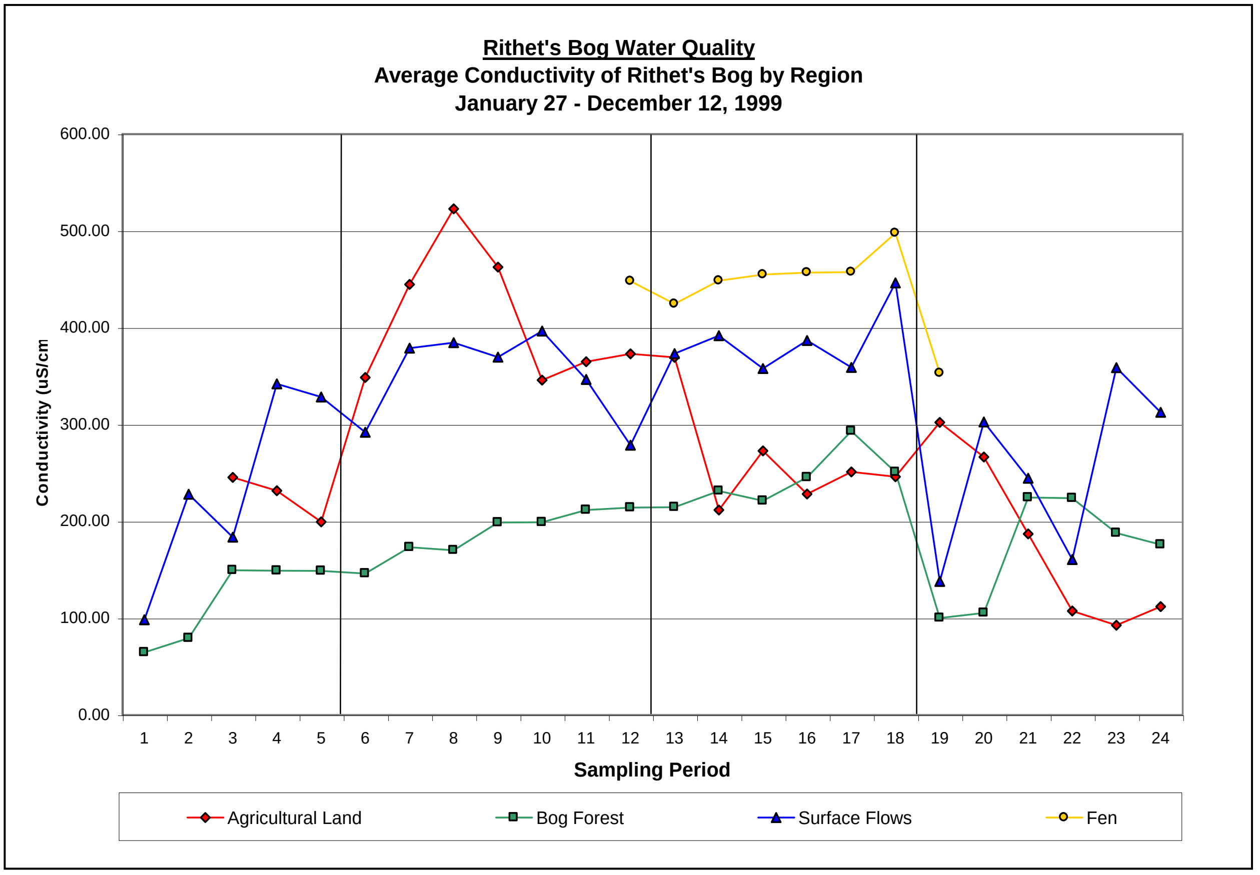


Figure 15: Average Conductivity by Region.

Table 3: Summary of Specific Conductivity Measurements. (μS/cm)

	Inflow	1	2	3	4	5	6	Ditch 1	Ditch 2	Outflow	Fen
Minimum	90.50	174.70	279.25	277.50	83.05	139.90	101.05	85.80	172.70	133.70	353.05
Maximum	302.00	641.50	556.50	509.80	518.00	269.60	235.85	460.30	718.00	503.00	497.40
Range	211.50	466.80	277.25	232.30	434.95	129.70	134.80	374.50	545.30	369.30	144.35
Average	243.37	388.45	362.35	375.71	263.31	186.70	138.17	319.73	398.81	307.37	442.51

Table 4: Summary of Conductivity by Region. (μS/cm)

	Agricultural	Bog Forest	Surface
Minimum	174.70	83.05	85.80
Maximum	641.50	518.00	718.00
Range	466.80	434.95	632.20
Average	367.25	193.61	318.85

9.3 Dissolved Oxygen

The dissolved oxygen measurements for the forest dipwells averaged around 5.44mg/L for the year (Table 6). Of all the areas sampled this area stayed the most stable. Figure 16 shows no difference between the bog forest and the agricultural land which averaged 4.79 mg/L. Agricultural areas also showed variation with readings ranging from 1.05 mg/L to 9.17 mg/L. The surface flows showed a large seasonal fluctuation in dissolved oxygen from 13.81 mg/L in the winter to 1.23 mg/L in the late summer.

For the fen, this parameter had relatively few fluctuations compared to the other wells averaging 3.73 mg/L (Table 5). The range was 2.85 mg/L with a high of 5.14 mg/L and a low of 2.30 mg/L.

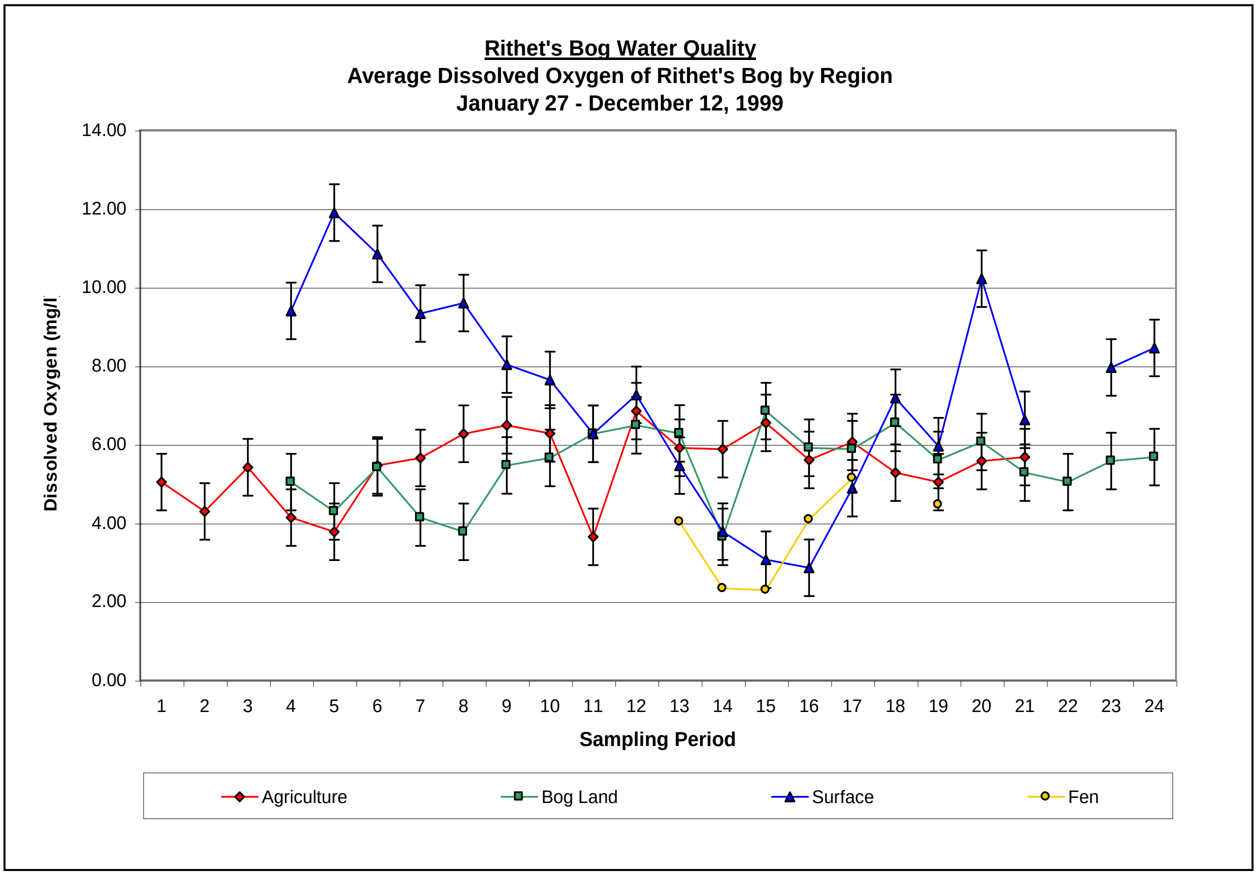


Figure 16: Average Dissolved Oxygen by Region

Table 5: Summary of Dissolved Oxygen measurements. (mg/L)

	Inflow	1	2	3	4	5	6	Ditch 1	Ditch 2	Outflow	Fen
Minimum	2.81	2.22	1.57	1.05	4.40	1.12	3.60	1.32	1.23	1.86	2.30
Maximum	12.09	8.53	9.17	5.77	8.02	6.01	7.69	10.45	13.81	12.64	5.14
Range	9.28	6.31	7.60	4.72	3.62	4.89	4.09	9.13	12.58	10.78	2.85
Average	8.52	5.39	5.42	3.55	6.43	4.23	5.68	6.59	6.63	5.70	3.73

Table 6: Summary of Dissolved Oxygen by Region. (mg/L)

	Agricultural Land	Bog Forest	Surface Water
Minimum	1.05	1.12	1.23
Maximum	9.17	8.02	13.81
Range	8.12	6.90	12.58
Average	4.79	5.44	6.86

9.4 Percent Saturation of Oxygen

The annual trends for percent saturation of oxygen were similar to those for dissolved oxygen in that the bog forest and agricultural land showed minimal changes while the surface flows showed a large fluctuation (Figure 17). Since percent saturation is a standardized measure of dissolved oxygen it was expected that the two graphs would show comparable results.

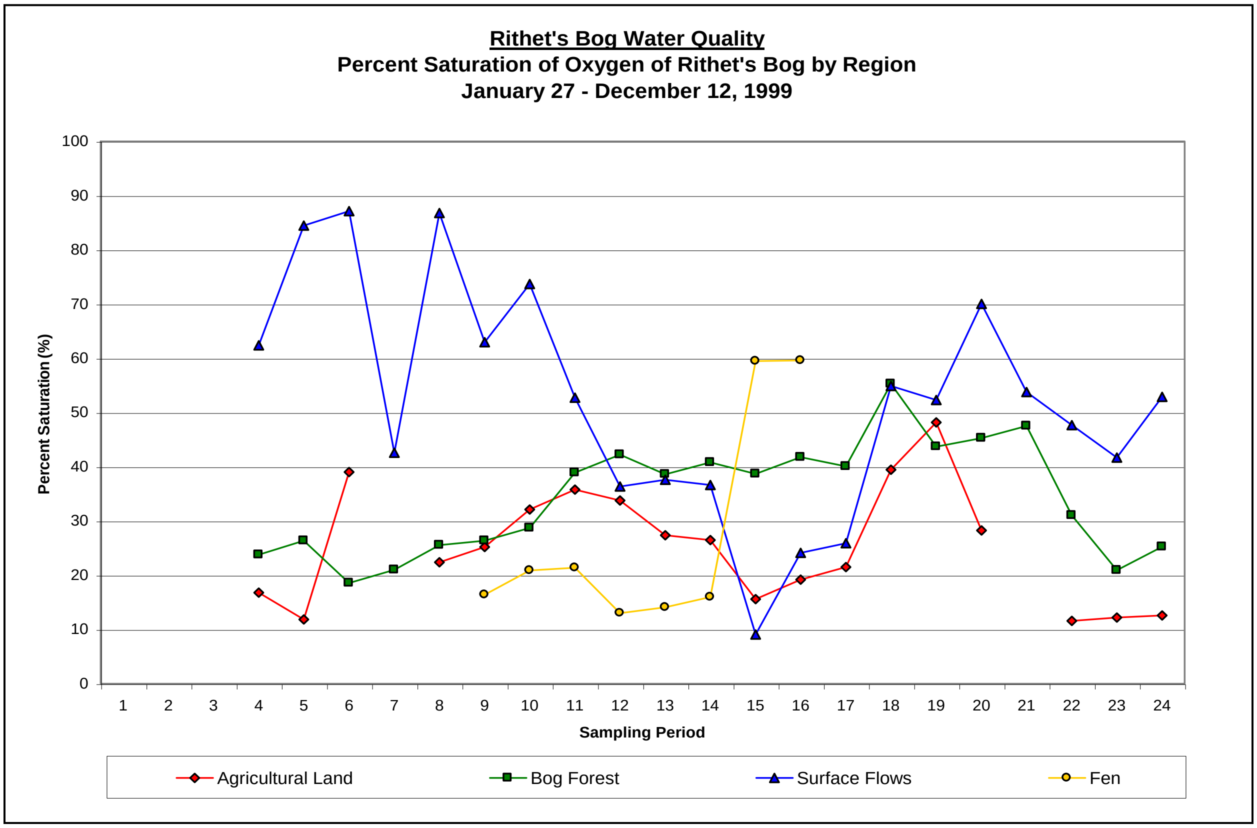


Figure 17: Average Percent Saturation of Oxygen by Region.

bog forest water produced a low variability with a minimum reading of 8.10% at dipwell 5 and a maximum of 69.20% at dipwell 4 (Table 7). Dipwell 4 averaged 46.24% while dipwell 5 and 6 were 20.09% and 36.25% respectively. Agricultural dipwells displayed slightly more variability ranging from a low of 3.60% at dipwell 3 to a high of 85.50% at dipwell 2.

Minimum values for this region were all below 10.0% saturation and averaged just above 25.0% as a whole (Table 8). Surface water varied the most with a range of 103.80%. The lowest reading was 5.60% at ditch 1 and was recorded on July 7 (sp15); the highest value was 109.40% at ditch 2 recorded during sampling on March 31 (sp3). The water in the fen ranged from 13.00% on July 7 (sp15) to 59.60% on October 7 (sp19), a span of 46.60%.

Table 7: Summary of Percent Saturation of Oxygen Measurements. (% mg/L)

	Inflow	1	2	3	4	5	6	Ditch 1	Ditch 2	Outflow	Fen
Minimum	7.80	9.40	5.03	3.60	21.70	8.10	15.80	5.60	9.20	12.10	13.00
Maximum	102.40	79.50	85.50	35.00	69.20	37.20	65.20	106.40	109.40	71.10	59.60
Range	94.60	70.10	80.47	31.40	47.50	29.10	49.40	100.80	100.20	59.00	46.60
Average	69.19	41.76	35.73	13.08	46.24	20.09	36.25	49.84	51.04	39.62	27.61

Table 8: Summary of Percent Saturation of Oxygen by Region. (% mg/L)

	Agricultural Land	Bog Land	Surface
Minimum	3.60	8.10	5.60
Maximum	85.50	69.20	109.40
Range	81.9	61.10	103.80
Average	25.23	34.31	52.19

9.5 Water Table

Water levels at all sample sites showed extreme variation between winter highs and summer lows. Each dipwell in the agricultural land was inundated with water at some point during the year (Figure 18). Dipwell 1 and 2 remained inundated for extended periods of the year; dipwell 1 for 14 weeks and dipwell 2 for 20 weeks. The highest water mark of 20.0 cm above ground level was reached by dipwell 3 on February 3 (sp2) (Table 9). Dipwells 2 and 3 has ranges 49.3 cm and 61.6 cm and maintained a relatively high water table only approaching 40.0 cm below the surface around September 16 (sp18). Dipwell 1; however, fell below the 100.0 cm mark for 10 weeks, from sp14 to 19, producing the largest fluctuation ranging the full 120 cm from 20.0 cm above ground to 100.0 cm below the surface.

The forest dipwells also fluctuated between surface inundation and ground dehydration although not as extreme as the agricultural land (Figure 19). Dipwells 5 and 6 both had standing water around them on February 3 (sp2) reaching 15.00 cm and 13.00 cm respectively, above the surface. Dipwell 4 also had its high mark of 2.2 cm below the surface on this sampling day and approached a low of 85.0 cm below the surface during sp19. The water table then rose to 19.4 cm below the surface just two-weeks later.

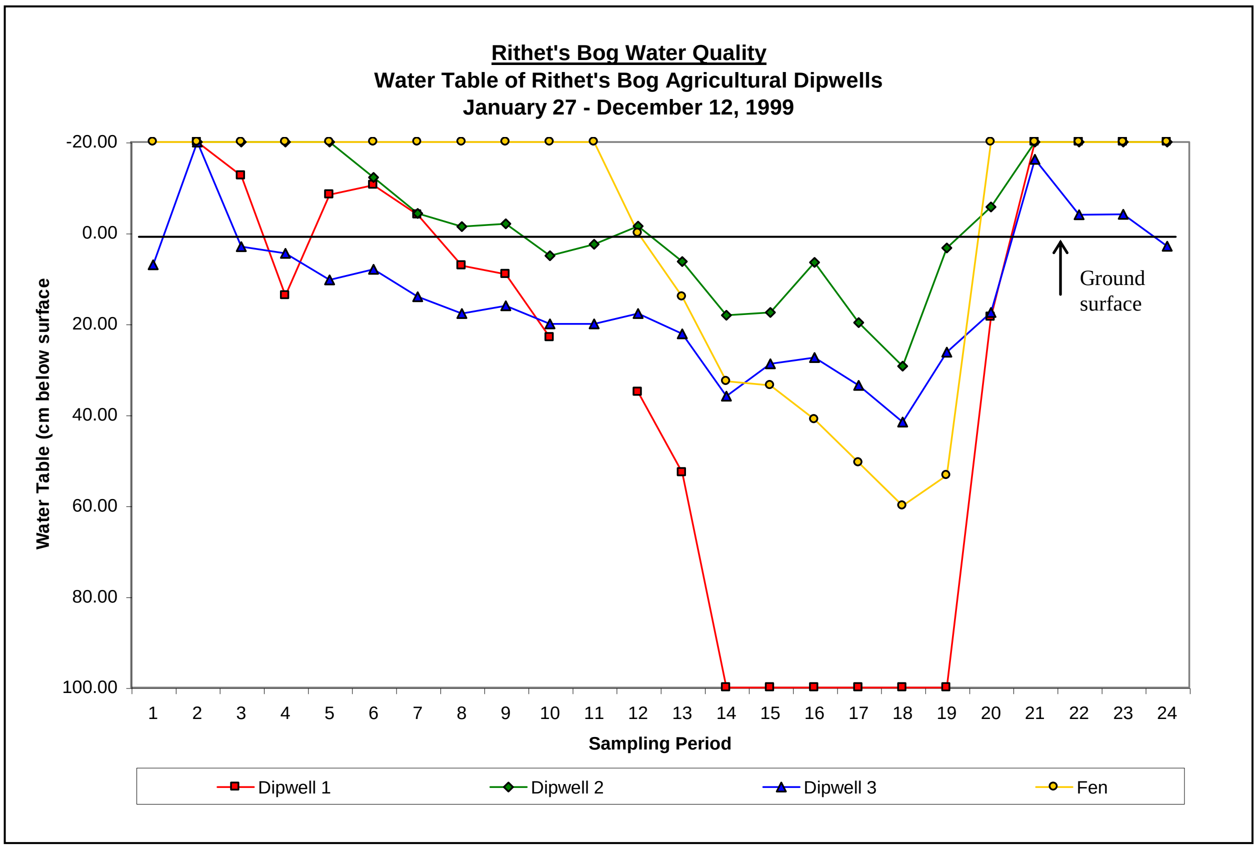


Figure 18: Water Table for Agricultural Land and Fen

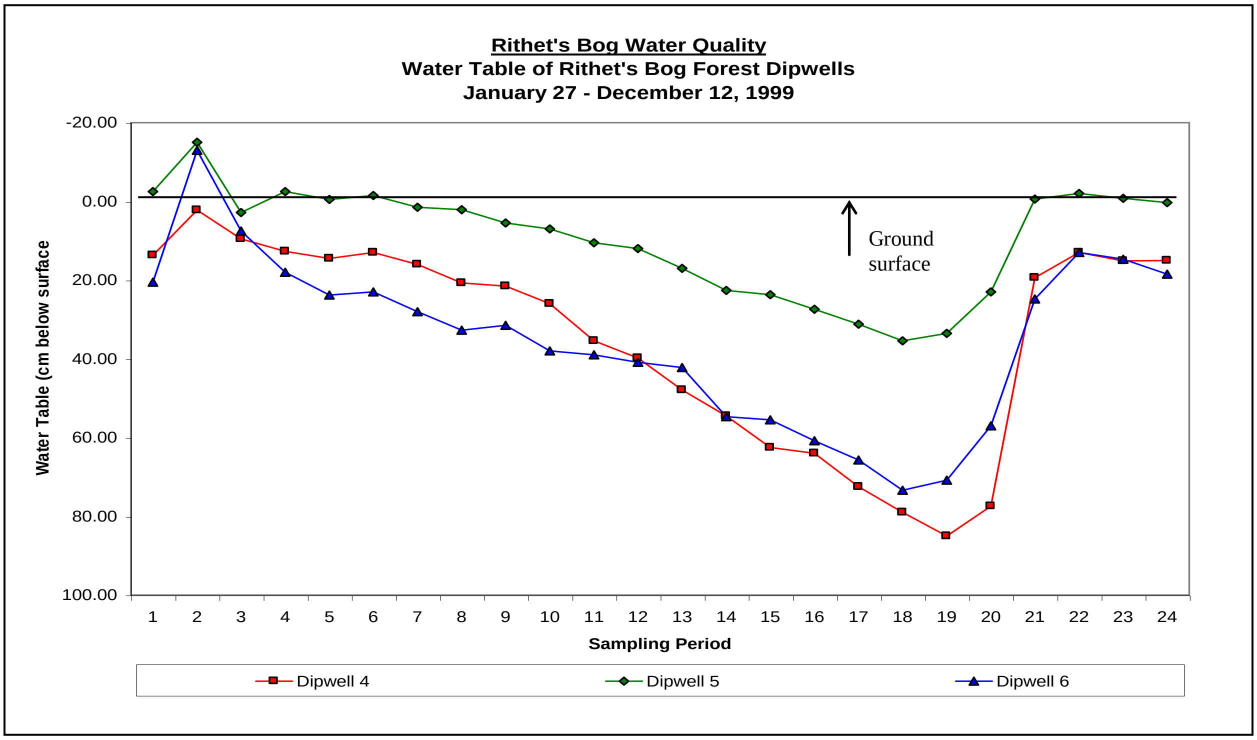


Figure 19: Water Table of Forest Dipwells

Dipwell 6 follows the trend observed at dipwell 4 very closely, dropping to 73.4 cm on September 16 (sp18) and rising to 24.8 cm during sp21. The water table at dipwell 5 fluctuates much less than at 4 and 6 with a range of only 50.4 cm. This is very different from 4 and 6, which had ranges of 82.8 cm and 86.4 cm respectively.

The fen remained inundated for the majority of the year (Figure 18). For a brief 14-week period from June 26 (sp) to October 7 (sp), the water table dropped to the surface or below that allowed for ground water sampling to be conducted. The fen was the last dipwell for which sampling was started. The water table went from 53.3 cm below the surface on October 7 (sp19) to inundated on October 16 (sp20), just nine days later, and remained above the surface for the rest of the year.

The water level of the inflow and outflow also changed throughout the year; however, the outflow was much more extreme (Figure 20). The inflow had a more constant water level trend through the year than the outflow shown by its straighter line and a range of only 9.5 cm (Table 9). The outflow showed very high water levels of 68 cm at sp 21 and reached a minimum of 6.5 cm at sp 14.

Table 9: Summary of Water Table Measurements.

	Inflow	**1**	**2**	**3**	**4**	**5**	**6**	**Outflow**	**Fen**
Minimum	3.00	-20.00	-20.00	-20.00	2.20	-15.00	-13.00	6.50	-20.00
Maximum	12.50	52.70	29.30	41.60	85.00	35.40	73.40	68.00	60.00
Range	9.50	72.70	49.30	61.60	82.80	50.40	86.40	61.50	80.00
Average	7.78	1.49	-3.43	13.75	34.60	9.59	35.04	22.61	-1.46

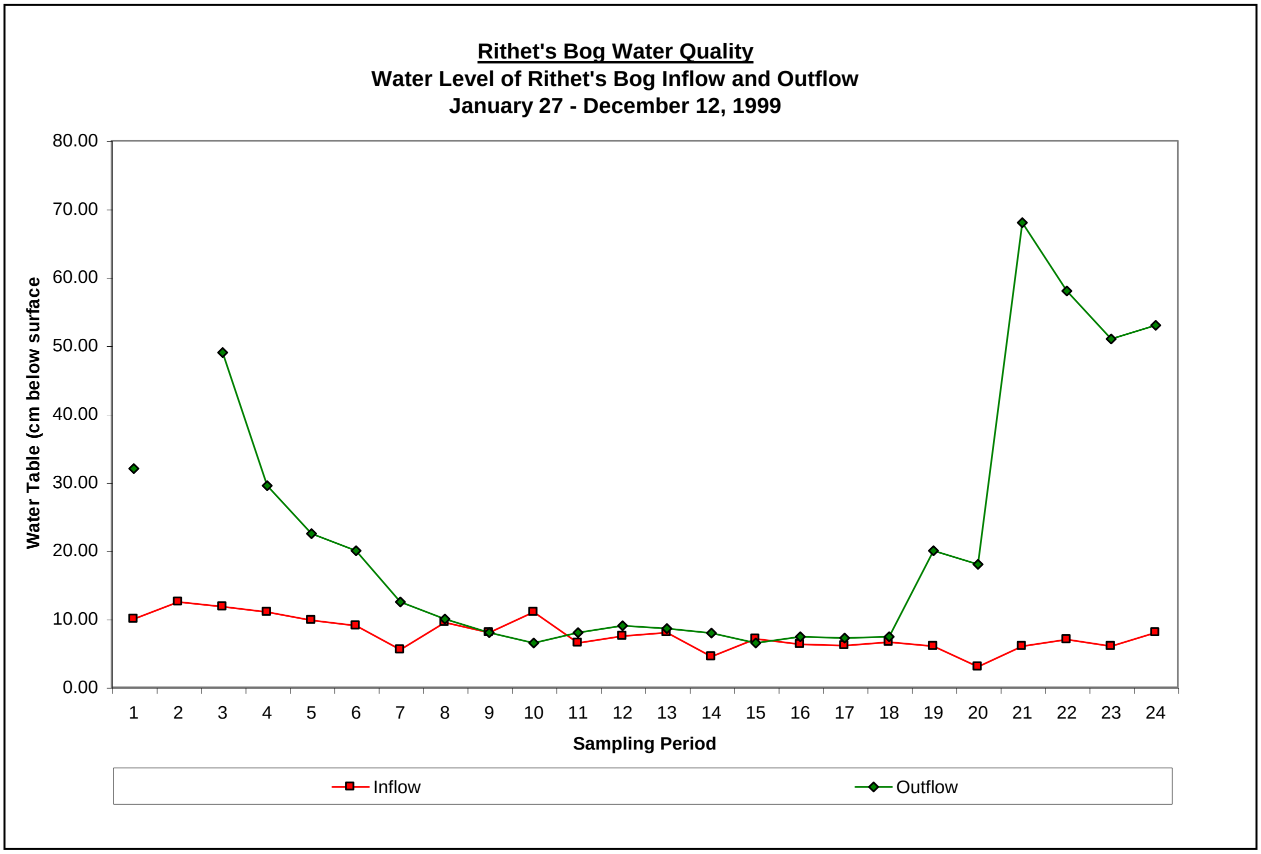


Figure 20: Water Table of Inflow and Outflow

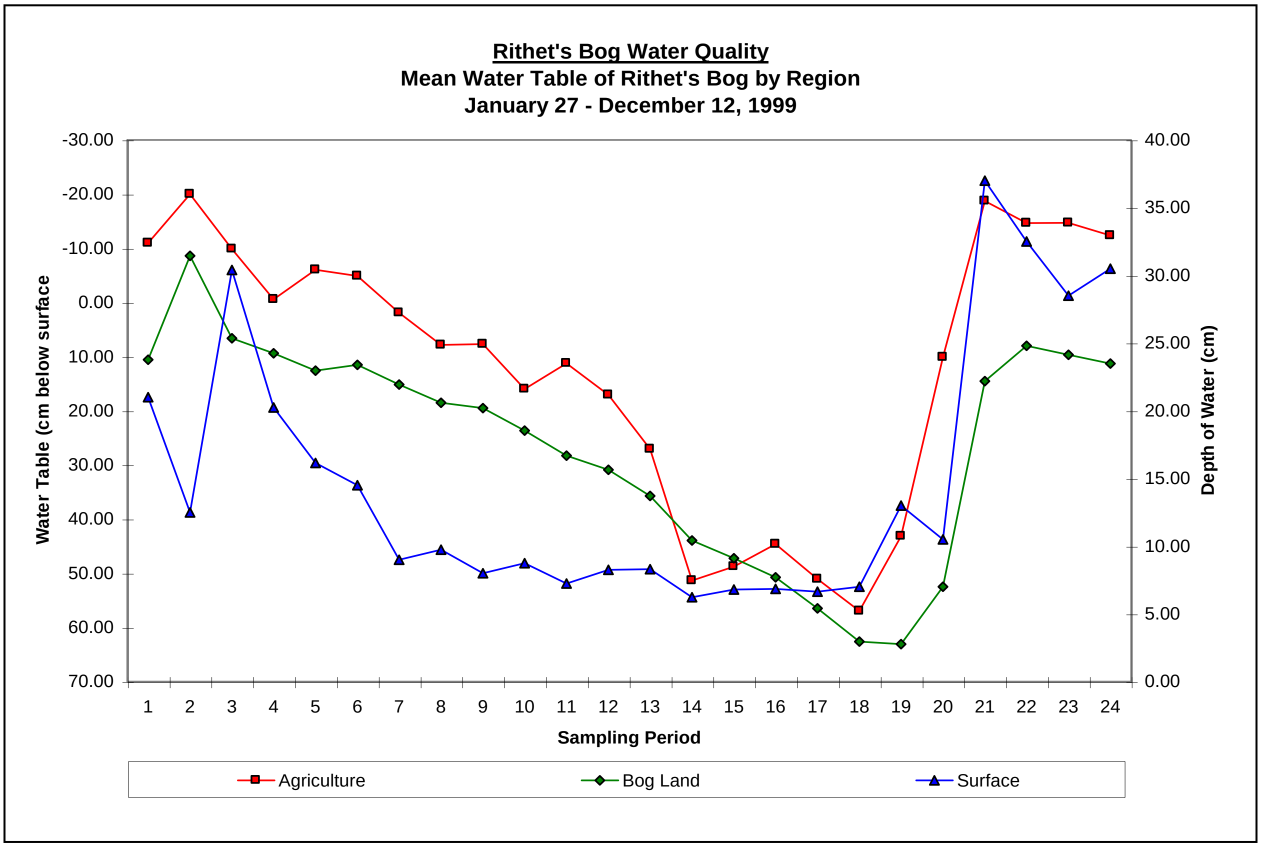


Figure 21: Water Table of Rithet's Bog by Region

Figure 21 shows that all regions in the bog displayed similar water table fluctuation trends throughout the year. Water table measurements in forest and agricultural dipwells were highest on February 3 (sp2) with all but dipwell 4 being inundated. Water tables dropped steadily until September 16th (sp18). At this point the water table became stable or experienced a slight increase before rising drastically with fall rains

Table 10: Summary of Water Table by Region

	Agriculture	Bog Forest
Minimum	-20.00	-15.00
Maximum	100.00	85.00
Range	120.00	100.00
Average	11.75	26.41

9.6 Temperature

Figure 22 shows the average ground water temperature of each region of Rithet's Bog. The average temperatures of the bog forest ground water were slightly lower than the agricultural and surface water temperatures. As normal weather conditions prevailed through the summer, the groundwater temperature in the forest dipwells rose more slowly than the water in the agricultural dipwells and surface flows. Conversely, as the climate cooled in the fall, forest ground water decreased in temperature at a slower rate than the ground water of the other two regions. In the fen, water temperature ranged 2.15°C over the period it was accessible to sampling (Table 11). The average ground water temperature for the fen was 15.97°C.

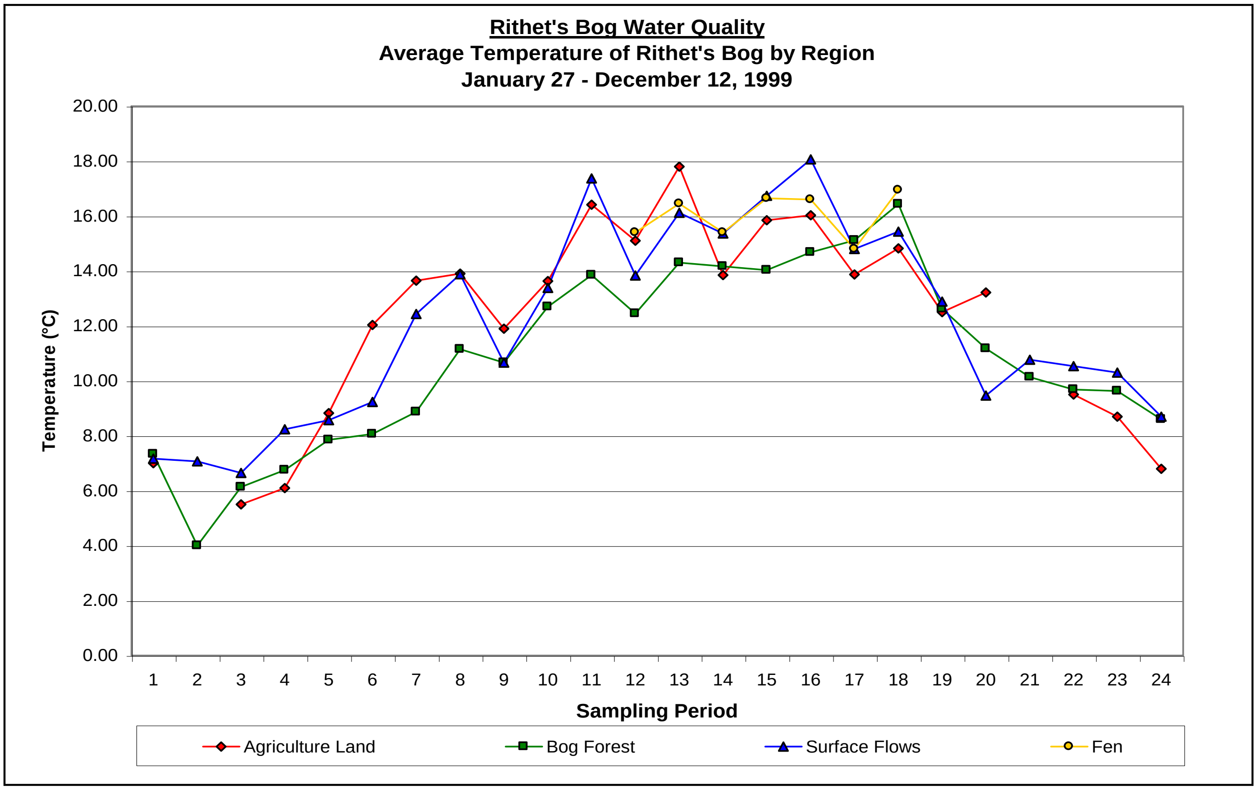


Figure 22: Average Temperature by Region

Table 11: Summary of Temperature Measurements. (°C)

	Inflow	**1**	**2**	**3**	**4**	**5**	**6**	**Ditch 1**	**Ditch 2**	**Outflow**	**Fen**
Minimum	7.55	5.05	12.60	5.45	6.30	5.40	6.70	6.70	5.50	5.00	14.80
Maximum	17.10	19.50	19.30	15.15	20.40	14.15	14.75	18.80	19.10	16.90	16.95
Range	9.55	14.45	6.70	9.70	14.10	8.75	8.05	12.10	13.60	11.90	2.15
Average	11.42	13.14	15.40	10.95	12.39	9.94	10.71	12.50	12.04	10.90	15.97

10. Discussion

The discussion is separated into two parts. The first makes comparisons between the regions found in the randomized block design using statistics. The second is an interaction analysis that explains trends along the transect line through the bog forest.

10.1 Experiment 1: Randomized Block Design

A statistical analysis was performed on the blocks described in the methods section to compare their water quality variables. The student edition of the Minitab Statistical Analysis computer program was used to perform three comparison tests: a Balanced Two-Way Analysis of Variance (ANOVA), Tukey's Multiple Comparisons and a Two Population t-Test.

Table 12: ANOVA Division of Factors

		Factor A		
		Level a	Level b	Level c
Factor B	Level a	variable	variable	variable
	Level b	variable	variable	variable
	Level c	variable	variable	variable

Two-Way ANOVA is a method of analyzing the effects of two factors on some variable. The two factors in this study are Region and Season and the variables are pH, conductivity, % saturation of oxygen, and temperature. Each factor was subdivided further into levels shown in Tables 12 and 13.

Table 13: ANOVA Division of Factors for pH

		Region		
		Forest	Agricultural	Surface
Season	Wet	pH	pH	pH
	Intermediate	pH	pH	pH
	Dry	pH	pH	pH

A Balanced Two-Way ANOVA requires that all sample sizes be equal (same number of sites) so the forest and agricultural land received three dipwells each. Since the two ditches flowed into the outflow, the combination of their attributes should have equaled the outflow. Therefore the three surface flow measurements used in the ANOVA were inflow, north ditch and south ditch.

The three hypotheses tested by the Balanced Two-Way ANOVA were:

- H_O Region: The means of the variable for each region are equal.
- H_O Season: The means of the variable for each season are equal.
- H_O: Region and Season do not interact to produce an effect on the variable.

If these null hypotheses are rejected, the following alternate hypotheses may be tested:

- H_A for Region: The means of the variables for each region are not equal.
- H_A for Season: The means of the variables for each season are not equal.
- H_A: Region and Season interact to produce an effect on the variable.

Minitab produces outputs that are compared with critical values to reject or fail to reject the null hypotheses. The program outputs for Two-Way ANOVA for each variable are given in Appendix C. The significant numbers produced by Minitab are the F-statistic and the p-statistic.

If the F-statistic is greater than the critical value given in the F-table (statistical constants table), the null hypothesis is rejected.

If the p-statistic is less than the critical value, the null hypothesis is rejected. At a 95% confidence level, the critical p-value would be 0.05 (critical p-value = 1.00 - 0.95).

10.1.1 pH

Table 14: Minitab outputs for the Balanced ANOVA for pH.

Factor	Critical F-Value	F	P
Region	3.55	54.820	0.000
Season	3.55	1.640	0.222
Region*Season	2.93	0.270	0.892

Critical p-value: 0.05

As shown in Table 14, Season and Region*Season both fail to reject the null hypothesis. The F-statistics for both are lower than the critical value and the p-statistics for both are greater than 0.05.

H_O Season: The means of the pH for each season are equal.

H_O: Region and Season do not interact to produce an effect on pH.

In the case of Region, the F-statistic is greater than its critical value and the p-statistic is less than its critical value. Therefore, reject the null hypothesis for Region:

H_A for Region: The means of the variables for each region are not equal.

For ANOVA tests such as this that reject the null hypothesis, a Tukey's Multiple Comparison test is recommended. Minitab produces a pictorial description of the relationship between the regions. It shows which ones are different as well as which is the lowest and which is the highest. The minitab ouputs for each variable are given in Appendix C.

Minitab outputs for Tukey's Multiple Comparison test for pH are shown in Figure 23.

```
                              INDIVIDUAL 95% CI'S FOR MEAN
                              -------+---------+---------+---------
Bog Forest                    (--*---)
Agricultural Land                          (--*---)
Surface Flow                                        (--*--)
                              -------+---------+---------+---------
                                    5.0       6.0       7.0
```

Figure 23: Tukey's Multiple Comparison for pH

This picture shows the differences between bog forest, agricultural land and surface flows. The bog forest is the most acidic with a mean pH of 4.57. It is encouraging to see that the bog forest is the most acidic as it is the least disturbed area and has the greatest potential for regeneration. However, a mean pH of 4.57 also shows that at some stage during the year the pH rose above the critical level for *Sphagnum* regeneration of 4.5. Although the bog forest has the greatest potential for regeneration, it still does not maintain acceptable pH levels throughout the year.

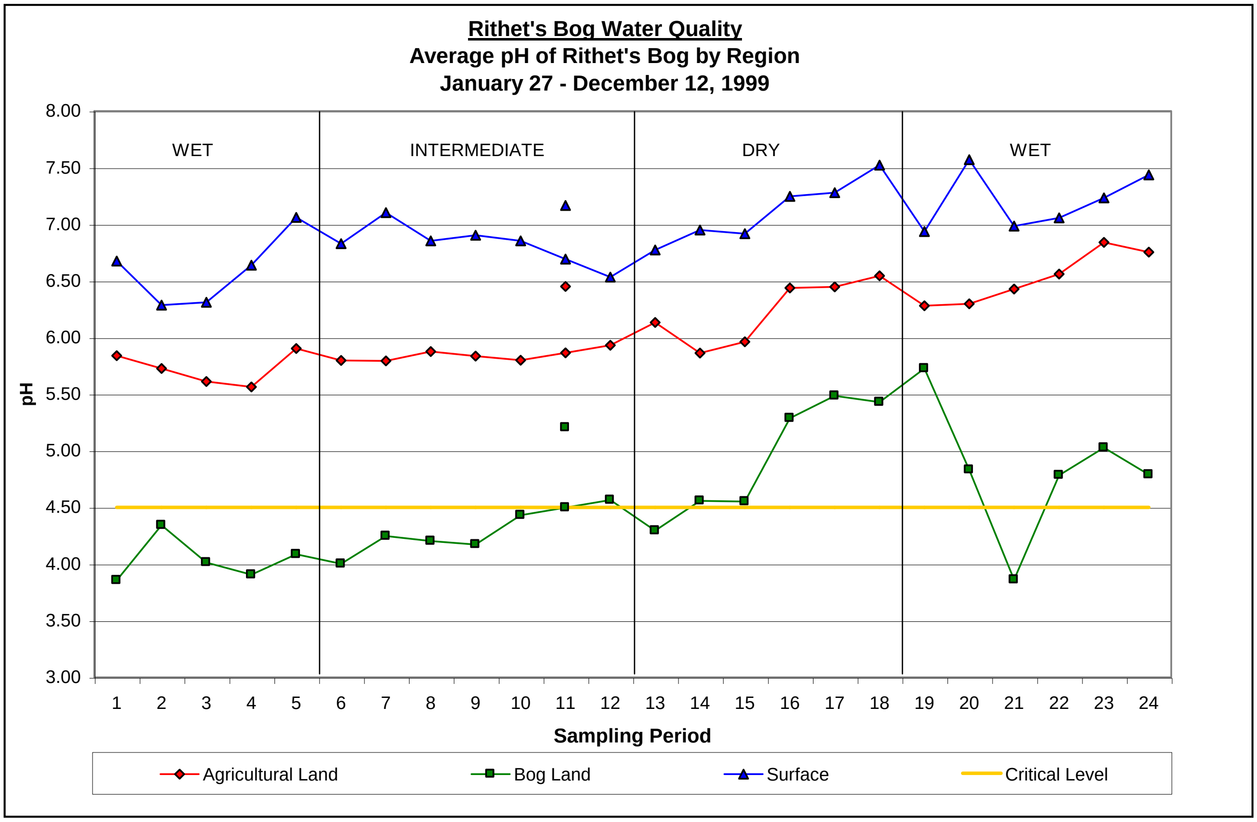


Figure 24: Average pH of Rithet's Bog by region

The above graph (Figure 24) supports the statistical findings as it shows the separation of the pHs for each region. The bog forest remains at a lower pH than the surface flows and the agricultural land for the duration of the year. The bog forest also remains below the critical level of 4.5 for most of the year. However, it rises above this value during the dry season producing conditions that are not conducive to *Sphagnum* growth. A low pH provides a hostile environment for aerobic bacteria so decomposition does not occur and the peat layers build up. The difference between the bog forest and the other areas may be due to the fact that the forest is the least disturbed region in the park. The presence of *Sphagnum* moss, though limited, reduces the pH in the bog forest due to its efficient cation exchange ability.

10.1.2 Conductivity

Table 15: Minitab Outputs for Balanced ANOVA for Conductivity

Source	Critical F-Value	F	P
Region	3.55	13.110	0.000
Season	3.55	0.250	0.782
Region *Season	2.93	1.290	0.311

Critical p-value: 0.05

Again, the results show that the null hypotheses for season and region*season are not rejected whereas that for region is rejected. Therefore:

H_A Region: The means of the conductivity for each region are not equal.

And a Tukey's multiple comparison was performed.

Minitab outputs for Tukey's Multiple Comparison test for Conductivity

```
                        INDIVIDUAL 95% CI'S FOR MEAN
                        -------+---------+---------+---------
Bog Forest               (-----*-----)
Agricultural Land                              (------*-----)
Surface Flow                         (-----*------)
                        -------+---------+---------+---------
                              200       300       400
```

Figure 25: Tukey's Multiple Comparison for Conductivity

The Tukey's Multiple Comparison picture shows that there is a significant difference between the bog forest and the other two regions. However, there is no significant difference between the agricultural land and the surface flows as shown by their overlapping confidence intervals.

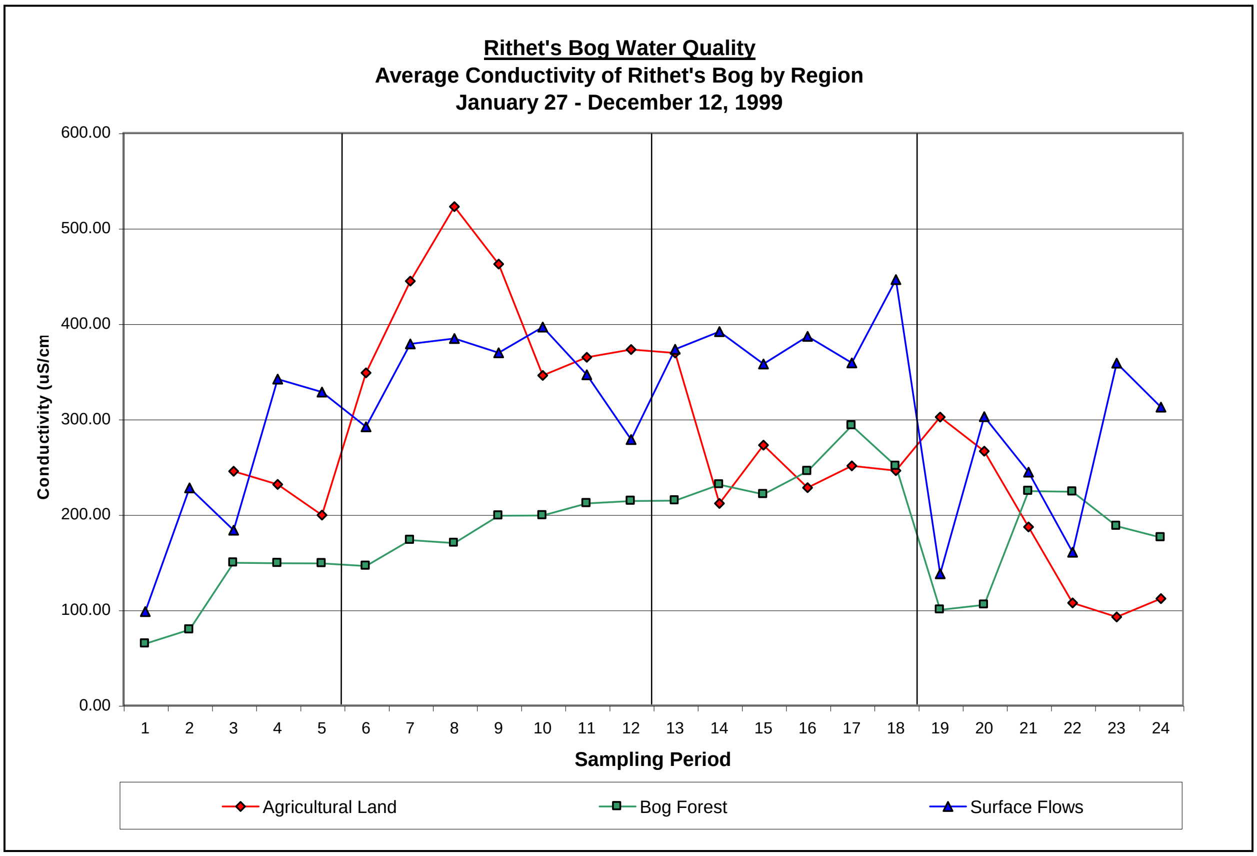


Figure 25: Average Conductivity of Rithet's Bog by Region

Figure 25 also supports the statistical findings. The bog forest has the lowest mean conductivity of all the regions. However, at 200 µS/cm it is high enough to indicate disturbance. Undisturbed ombrotrophic bogs acquire their nutrients from the atmosphere. *Sphagnum* and other mosses are efficient at intercepting nutrients from the atmosphere, leachate and the litter from overstory and incorporating it into their biomass. This leaves minimal amounts in the ground water. A bog should have a conductivity lower than 100 µS/cm (National Wetlands Working Group 1988). Runoff could be the most influential factor contributing to relatively high conductivity. During the rainy season there is an influx of rainwater that has picked up dissolved ions from flowing over impermeable surfaces in the surrounding developed areas. These ions become filtered out in the agricultural land so a lower concentration reaches the bog forest. The high conductivity shown in Rithet's Bog forest most likely a result of the decomposition processes that would normally be hindered in a low pH environment. *Sphagnum* moss functions to take up these nutrients and replace them with hydrogen ions that build up and produce an acidic pH. The surface flows are diluted by precipitation during the winter and sprinkler water during the summer, which results in a lower conductivity. All three regions are far from the acceptable level for conductivity of less than 100 μS/cm (Banner *et al.* 1988).

10.1.3. Percent Saturation of Oxygen

The results in table 16 show that Season and Region*Season both fail to reject the null hypothesis while Region rejects it again.

H_A Region: The means of the percent saturation oxygen for each region are not equal.

Table 16: Minitab outputs for Balanced ANOVA for Percent Saturation

Source	Critical F-Value	F	P
Region	3.55	8.310	0.003
Season	3.55	0.830	0.451
Region*Season	2.93	2.570	0.073

Critical p-value = 0.05

And a Tukey's multiple comparison was performed.

Minitab outputs for Tukey's Multiple Comparison test for Percent Saturation of Oxygen

```
                          INDIVIDUAL 95% CI'S FOR MEAN
                          ---------+---------+---------+-------
Bog Forest                     (------*-------)
Agricultural Land          (------*-------)
Surface Flow                                 (------*-------)
                          ---------+---------+---------+-------
                          30        45        60
```

Figure 26: Tukey's Multiple Comparison for % Saturation

The Tukey's Multiple Comparison picture shows that the difference here is between the surface flows and the other two regions. There is no significant difference between the bog forest and the agricultural land as shown by the overlapping confidence intervals.

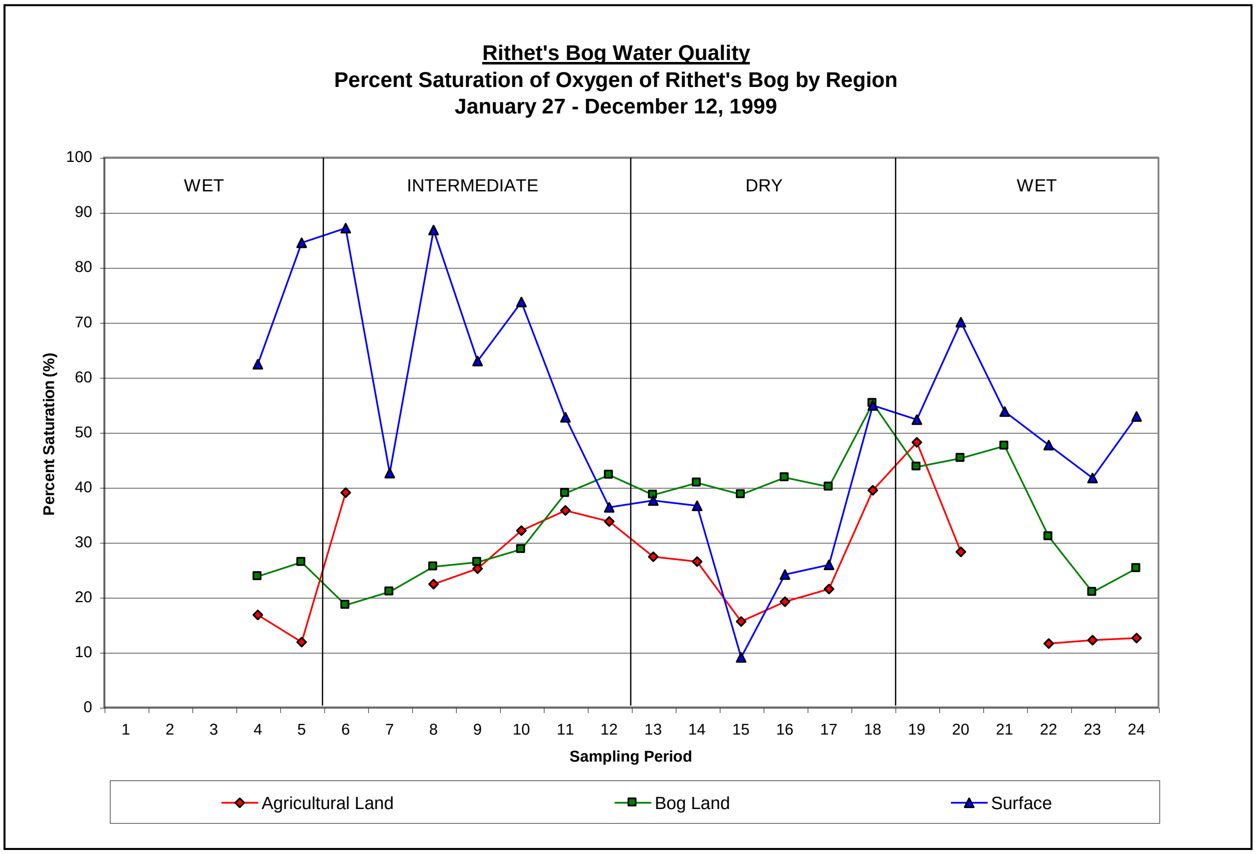


Figure 27: Average Percent Saturation of Oxygen of Rithet's Bog by Region.

The above graph (Figure 27) shows the Percent Saturation of Oxygen of ground water in Rithet's Bog by region. In an undisturbed bog the amount of oxygen present in the ground water should be very low. An anoxic environment is created in the ground water as the *Sphagnum* lowers the pH so no aerobic organisms can survive. The Percent Saturation of oxygen in the bog forest, shown in green, is high enough to indicate disturbance. The probable reason for the high oxygen content is the higher pH resulting from the lack of *Sphagnum* moss. In Rithet's Bog the higher pH has allowed aerobic microorganisms to move in thus increasing decomposition and oxygen levels. The increased rate of decomposition also recycles nutrients into the soil having a negative effect on conductivity.

The next two parameters looked at were water table and temperature. These two variables were analyzed differently from the previous ones as it is fairly obvious that season has an effect on them. During the winter months, water table was higher and temperature was colder than it was during the summer months. Since this is general knowledge there is not point in doing an analysis of seasonal effects on the bog.

10.1.4 Water Table

For the regional analysis, ground water table could not be compared with surface flow depths as they would be comparing incompatible factors. Surface Flows were removed from the analysis leaving only bog forest and agricultural land. A Balanced ANOVA is not sensitive enough to compare less than two factors, so a Two Population t-Test was performed instead. This test is specific to two populations: Bog Forest and Agricultural Land. The t-Test shows whether or not there is a difference between the two populations and produces results that are used to reject or fail to reject the null hypothesis.

The null hypothesis for water table is:

H_O: There is no difference in water table between agricultural land and bog forest

A summary of the results of the t-Test are shown below. The p-statistic is greater than the critical value of 6.314 obtained from the statistical t-table. The null hypothesis is not rejected so there is no significant difference between the water tables of the bog forest and the agricultural land. This is confirmed by the overlap of the confidence interval from the Tukey's Multiple Comparison test.

```
TTEST MU Forest = MU Agri (VS NE): T= 2.00  P=0.062  DF=  16
```

```
INDIVIDUAL 95% CI'S FOR MEAN
                                                   -+---------+---------+---------+-----
Bog Forest                                                     (---------*--------)
Agricultural Land                                  (---------*--------)
                                                   -+---------+---------+---------+-----
                                                    0        15        30        45
```

Figure 28: Tukey's Multiple Comparison of Water Tables

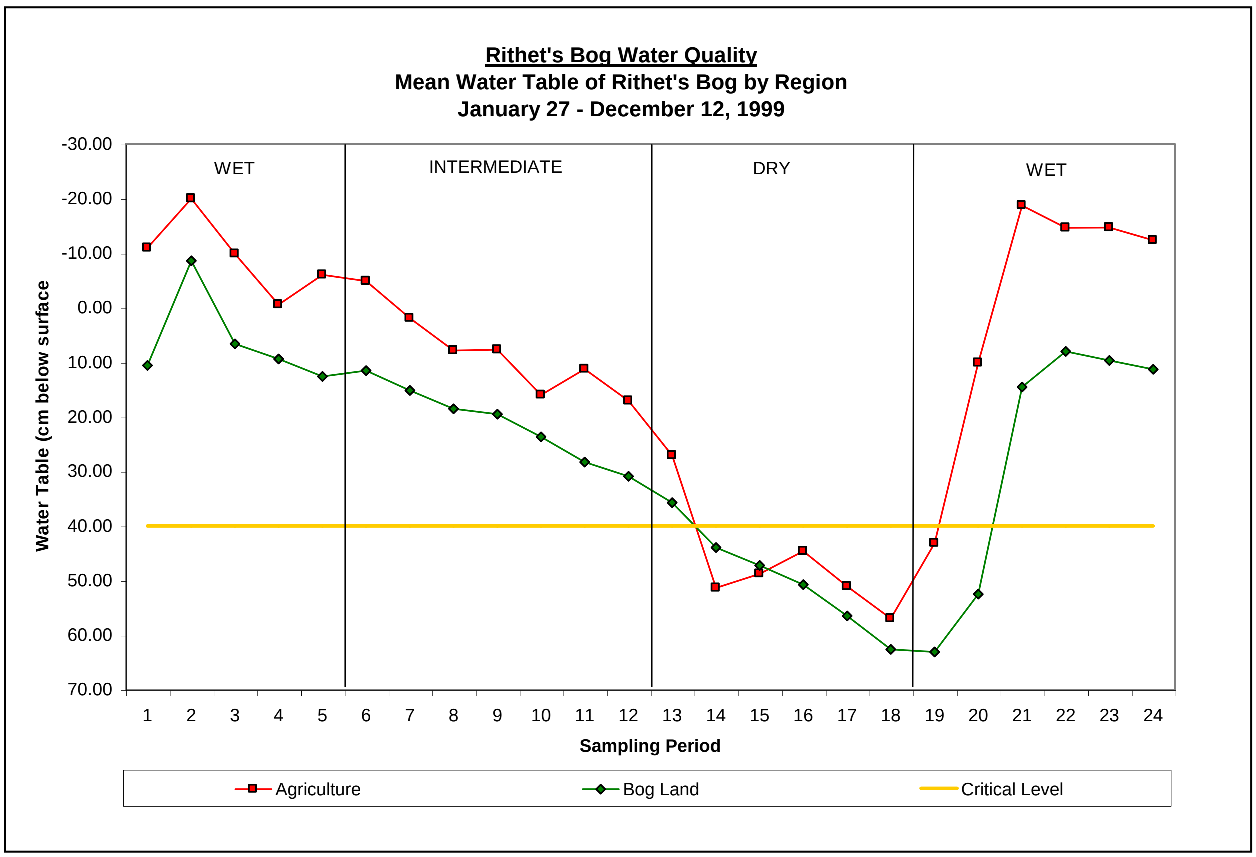


Figure 29: Average Water Table of Rithet's Bog by Region.

The graph supports the t-Test, showing that there is no significant difference between the bog forest and agricultural land. Both lines closely follow the same dehydration and rehydration trend. The graph also supports the assumptions that season affects the water table as shown by the large fluctuation from inundated in the winter to almost completely dry in the summer. There is concern regarding the water table fluctuation in the bog forest as water that is more than 40 cm below the surface is not conducive to *Sphagnum* regeneration. The above graph shows a slow drop in water table over the spring and a rapid rise again in the fall to the surface where it remains for the winter. For a bog to thrive the water level must remain at or near the surface throughout the year. The extreme variation in the summer may be due to the evapotranspiration of deep rooted vascular plants that can tap the water table at a greater depth. During the winter months; however, there is enough precipitation and inflow to compensate for the evapotranspiration. There is also a serious lack of *Sphagnum* that severely retards the water holding capacity of the upper ground layers. In an undisturbed raised bog, atmospheric precipitation is supposed to be the only factor contributing moisture to the water table and vascular plants should be in the vegetational minority.

10.1.5 Temperature

Sphagnum mosses also affect temperatures in a bog. In an undisturbed bog the temperature under the moss should be lower than the ambient temperature, which is true of Rithet's Bog. In the summer the *Sphagnum* of an undisturbed bog losses pigment and looks lighter, reflecting the sun's heat back into the atmosphere and thereby acting as an excellent insulator to the layer underlying the moss. However, in Rithet's Bog the slightly lower temperature in the forest is more likely due to the insulating effects of the tree canopy cover (Figure 30).

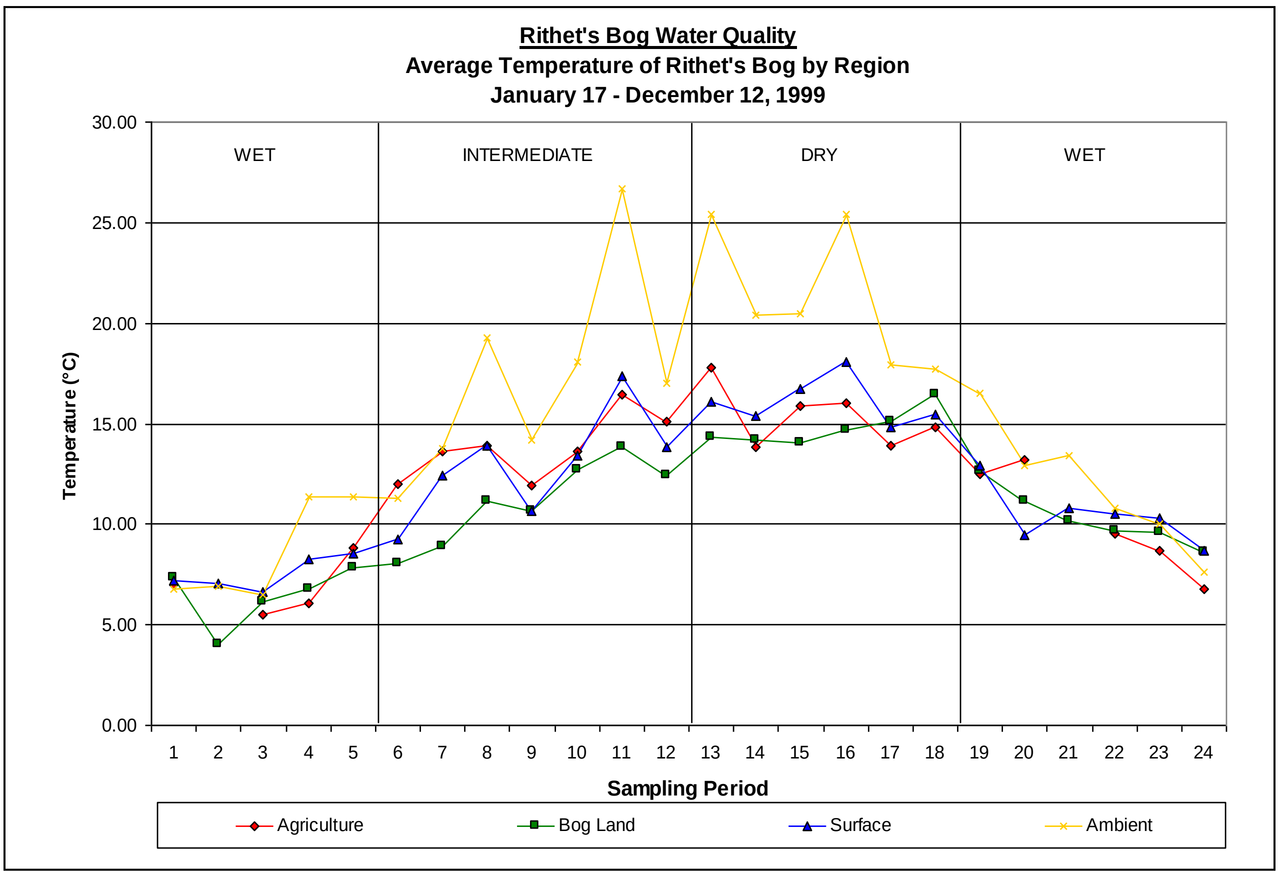


Figure 30: Average Temperature of Rithet's Bog by Region.

10.2 Experiment 2: Off-set Transect Design

Data analysis included a detailed investigation into how the different parameters interacted and influenced each other. Several factors and patterns were identified. The patterns that developed and explanations for them were then utilized to identify key factors that influenced management options.

10.2.1 Water Table, pH and Conductivity

The three most important water characteristics for bog waters are pH, water table and conductivity. When these three parameters are within normal ranges, *Sphagnum* mosses have a competitive advantage over non-bog dependent plant species. There are several interesting ways that these factors interact with each other. An explanation of each factor is necessary before we can look at the way they affect each other.

Conductivity measures the total of all dissolved ions in a solution. Conductivity was measured in µS/cm using the YSI 85. The more ions present, the more electricity the water will conduct and the higher the reading. If the amount of water drops, then the concentration of ions in solution increases and the conductivity measurement increases as well.

The pH parameter measures the total dissolved hydrogen ions, or protons, in a solution. It is the negative logarithm of the concentration of hydrogen ions ($pH = - \log [H+]$). Measuring pH utilizes the same theory as above; however, when the concentration of hydrogen ions increases, the pH should drop. This is due to the negative log function. The concentration of a solution could be increasing with respect to the hydrogen ions, but the pH measurement would decrease. This is an inverse relationship and opposite of conductivity. Water table is a measure of how far below the surface the water level lies. A water table measurement value of zero means that the water table is at the surface and a value of 40 cm means that it is 40 cm below the surface.

Conductivity and pH are then affected, to a degree, by the water table. If the amount of total dissolved ions stays the same and the water table starts to drop, then the concentration of ions will increase. Figure 31 shows the expected relationship. As the water table drops conductivity should increase and pH should fall, both due to a straight dilution factor. The data collected does not display the expected pattern. As the water table starts to drop, the conductivity increases as expected but the pH starts to rise as well (Figure 32).

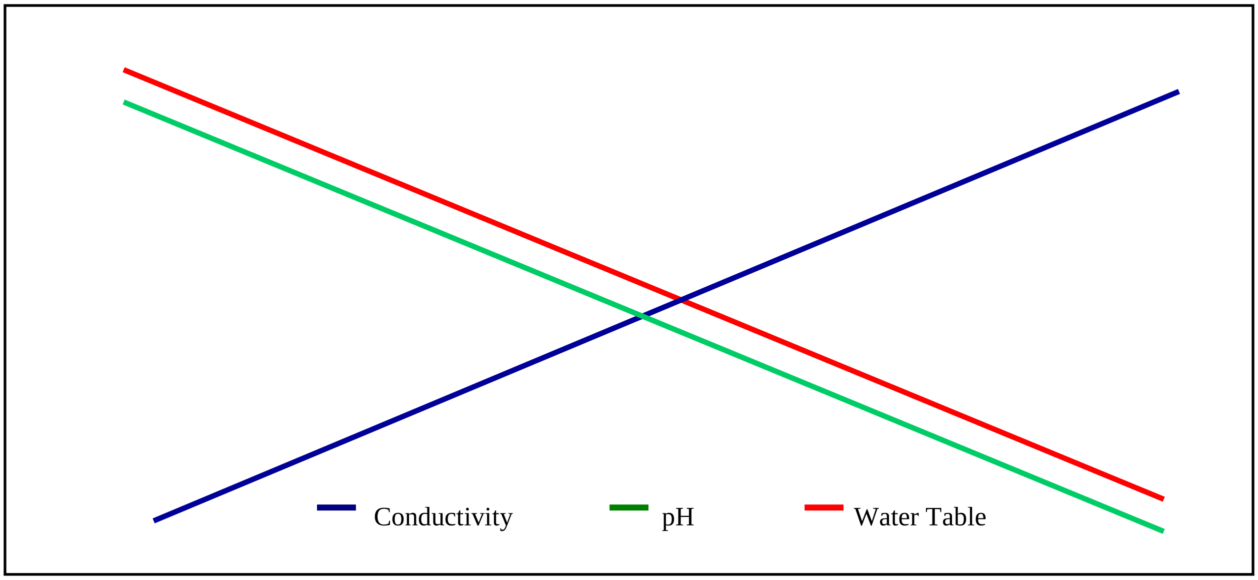


Figure 31: Expected Relationship between Water Table, pH and Conductivity.

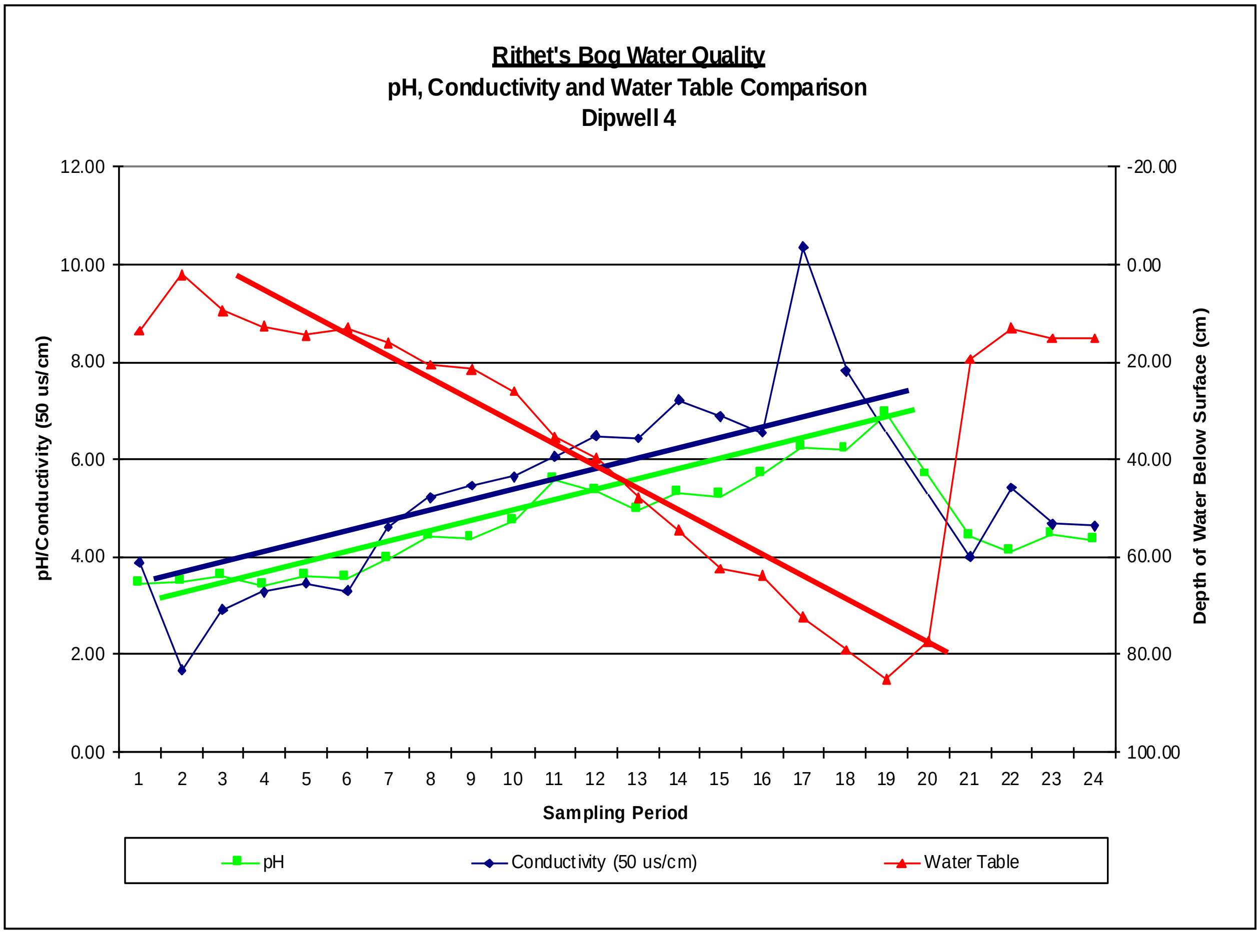


Figure 32: Dipwell 4 pH, Conductivity and Water Table Comparison

During the winter, pH measurements were below 4.5 and the conductivity remained below 200 µS/cm. As the season progressed into summer and the bog started to dry up, pH and conductivity measurements began to rise. It is possible that when the water table drops out of the active layer of peat *Sphagnum* mosses no longer affect the pH with their cation exchange. Whatever the reason for this occurrence, it seems that if the water table could be kept near the surface for the entire year, the pH and conductivity readings would remain within acceptable ranges. Dipwell 5 and 6 display similar patterns (Figures 33 and 34).

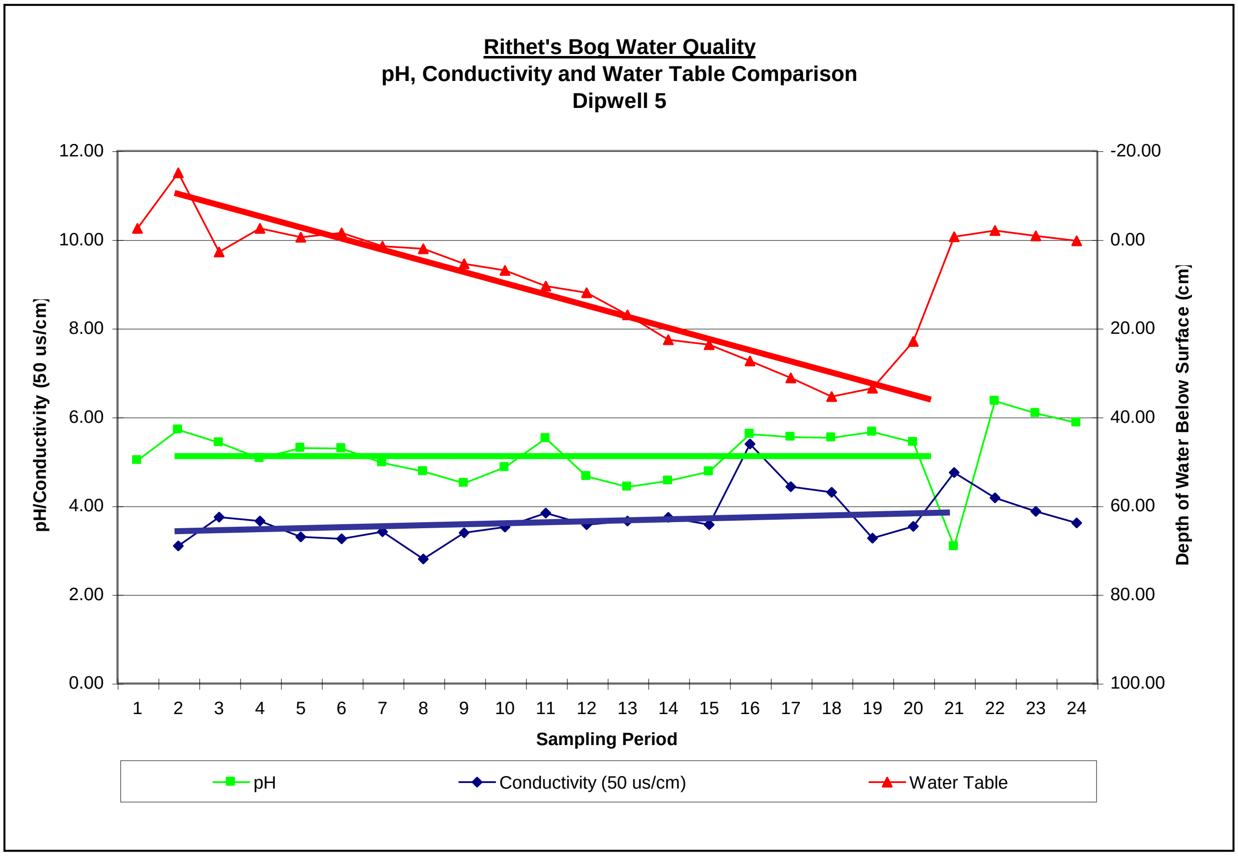


Figure 33: Dipwell 5 pH, Conductivity and Water Table Comparison

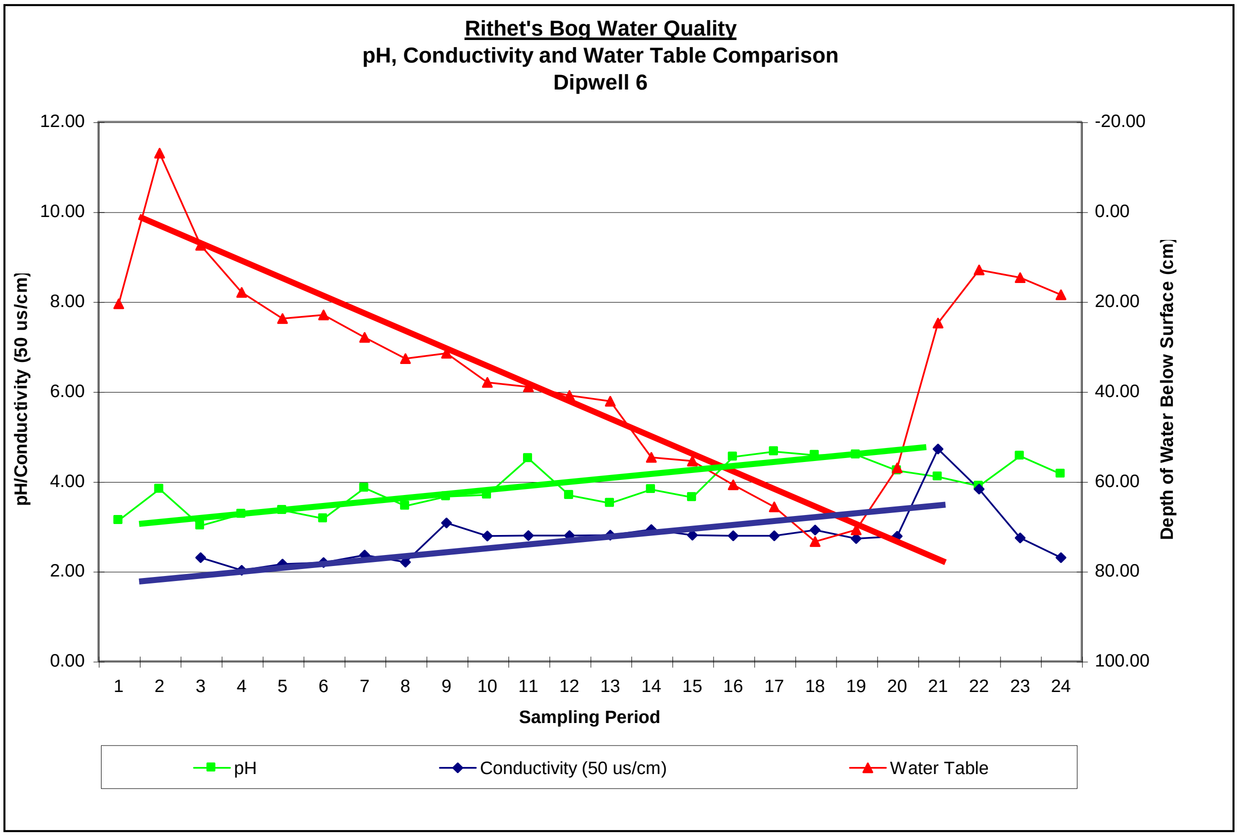


Figure 34: Dipwell 6 pH, Conductivity and Water Table Comparison

10.2.2 Analysis of Effects of North Ditch on Forest Water Table

It has been suggested that the ditch on the north side of the bog forest may be draining the bog and therefore should be filled in. However, our data does not support this conclusion. Table 18 contains data from the two edges of the forest and the nearest well outside the forest. The water table fluctuation realized between dipwell 1, located in the agricultural land, was 120.00 cm and at dipwell 6, in the bog forest it was only 86.40. These two wells are located on either side of the ditch. The fen dipwell had a total fluctuation of 80.00 cm and dipwell 4 had a difference between high and low of 82.8 cm. Even though the area surrounding the fen well was inundated for much of the year, it dried up quickly in the summer.

Table 17: Comparison of the Water Tables from Dipwells on the Edge of the Forest. (cm)

Dipwell	Min. H2O Level	Max. H20 Level	Fluctuation
1	100.0	-20.0	120.0
6	73.4	-13.0	86.4
4	85.0	2.2	82.8
Fen	60.0	-20.0	80.0

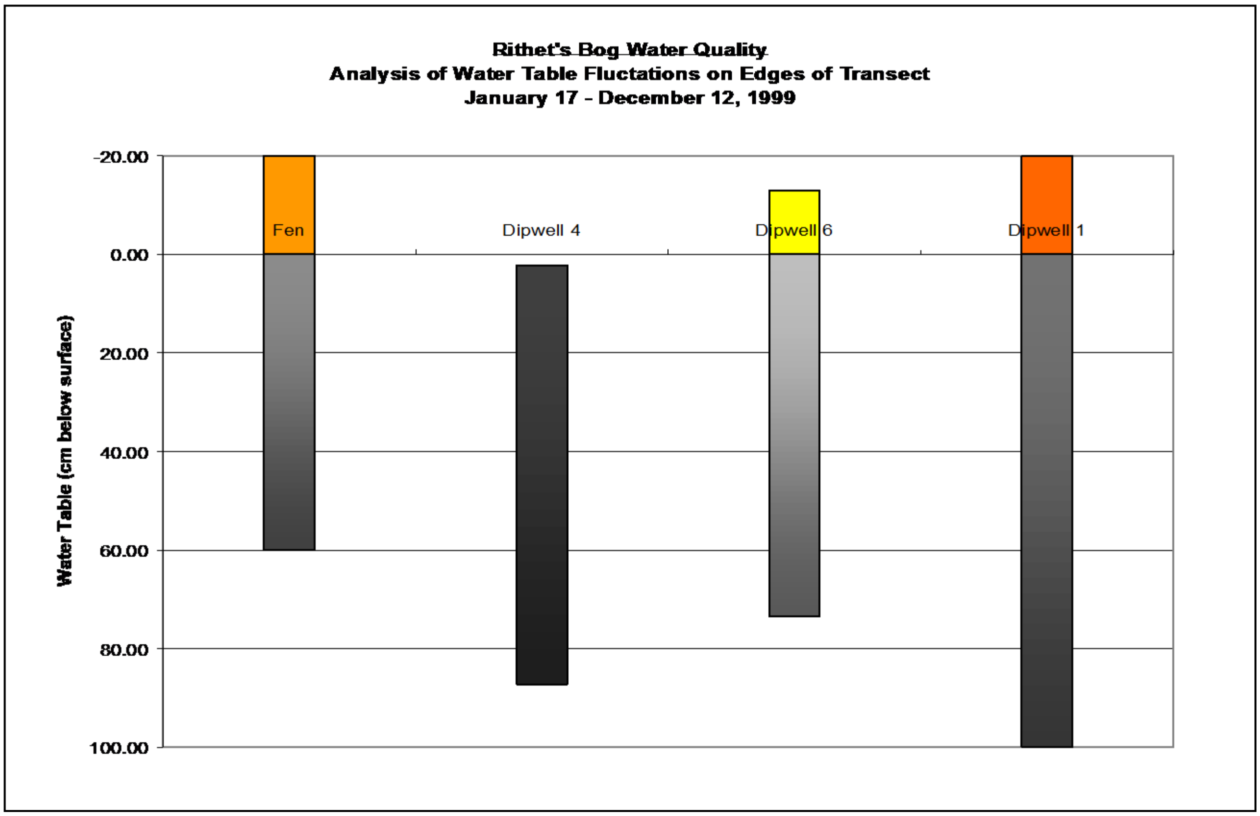


Figure 35: Analysis of water table fluctuation on edges of transect.

When only the total fluctuation is considered it appears that dipwell 4 had a smaller change; however, dipwell 6 ranged from -13.00 to 73.4 cm below the surface while dipwell 4 fell as low as 85.0 cm below the surface. The water table at dipwell 6 stayed higher than dipwell 4 (Figure 35) even though the water table at dipwell 1 fell over a meter below the surface. Dipwell 4 should have had some kind of buffering effect from the fen keeping the water table relatively high because of the inundation. This was not the observed case. These data should be looked at before the ditch is altered as it may actually help to keep the water table higher at dipwell 6 and presumably other edge areas of the forest.

Figure 36 displays water table, pH and conductivity measurement along the transect. Although data analysis failed to identify any areas that meet all the identified requirements for the regeneration of *Sphagnum* mosses, two areas of interest were recognized. First, the water table in the area surrounding dipwell 5 remained above the critical level for the entire year; however, pH and conductivity measurements, at 6.36 and 186.5 respectively, were well out of the acceptable ranges. It is possible that replanting *Sphagnum* moss would self-correct the other two variables. The second area is around dipwell 6. The pH in this area only rose above the critical level for a six-week period at the end of the summer. Conductivity, although still above reasonable levels, was the lowest here of all the forest dipwells. The water table dropped well below the critical level and represents the major hurdle to overcome in this area.

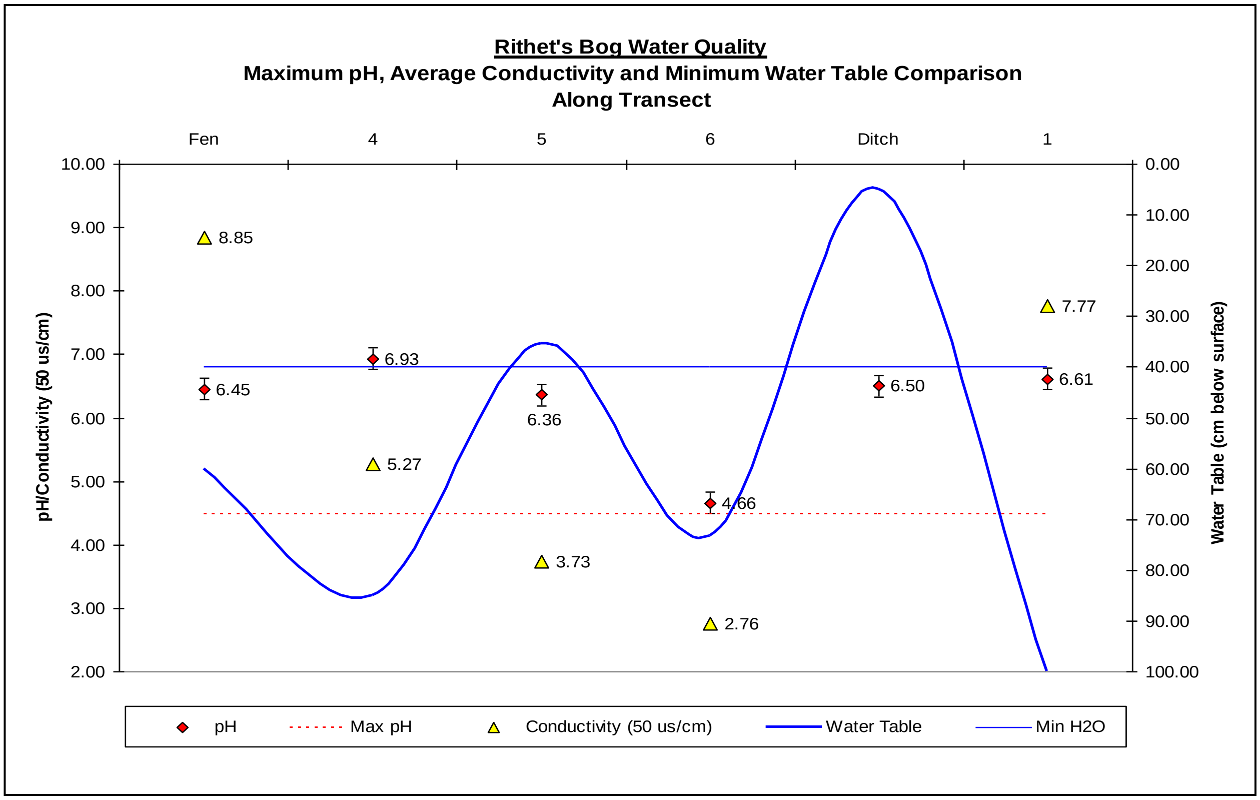


Figure 36: Maximum pH, minimum water table and mean conductivity along transect.

A doming effect is also displayed in Figure 36. The water table is significantly higher in the center of the bog than along the two edges. This further supports the reintroduction of *Sphagnum* mosses in the area surrounding dipwell 5.

11. CONCLUSIONS

11.1 Management Options

J.M. Schouwenaars (1995) identified four specific areas where management options should be focused on for the rewetting of a bog. All of these options are based on controlling the amount of water leaving the bog, but deal with internal and external water management schemes. The four management options are:

1. Construction of Bunds
2. Increase of Area of Open Water
3. Buffer Zones
4. Blocking of Drainage Ditches

11.1.1 Construction of Bunds

Bunds are shallow pits dug as a means of increasing surface inundation in an area. The inundation inhibits growth of vascular plants such as grasses and shrubs and artificially compensates for the loss of water storage capacity in the upper peat layers. This limits the extent to which the water table drops during a dry period.

11.1.2 Increase of Area of Open Water

Another method of increasing inundation in an area is by creating small water holding pools or trenches at regular intervals of about 5-10 m. During the dry season, the water level in these pools will be higher than the water table in the adjacent peat ridges resulting in a net movement of water into the peat. The water table fluctuations; however, are still dependent on the rate of infiltration which is in turn affected by peat permeability and the distance between peat ridges.

11.1.3 Buffer Zones

A buffer zone is an area surrounding a bog in which the water table is kept relatively high providing hydraulic pressure in the strata underlying the peat. The buffer zone lowers the water pressure gradient between the bog and adjacent areas so water does not naturally flow out of the bog remnant. In areas where the underlying strata is sandy (permeable), water tends to flow easily. If the buffer zone is maintained with a high water table, pressure will be exerted on the underlying layers reducing downward water flows.

11.1.4 Blocking of Drainage Ditches

Most altered bogs that require remediation action have been drained to some degree through artificially created ditches. Blocking these ditches appears to be one of the simplest rewetting practices. Whether or not this practice will be sufficient in raising the water table depends to some degree on the strata underlying the peat. Clay will limit water loss, keeping the water table high; however, sandy strata will allow considerable seepage. If the latter condition prevails and is magnified by evaporative losses from invasive vascular vegetation, supplemental actions should be taken.

11.2 Recommendations

Based on the data collected, analysis conducted and the above water management strategies, four recommendations were developed. All focus on decreasing the hydrological gradient between the bog forest and the buffer zone.

11.2.1 Preserve the Existing Buffer Zone

The current lagg area surrounding the bog could be sufficient to serve as a hydrological buffer zone for the bog remnant if improvements were made. Due to the extent of urban development in the catchment area of Rithet's Bog, the lagg area is somewhat small and affected by urban runoff. Improving the quality of the buffer zone can make up for the quantity, which is fixed.

Removal of all invasive non-bog dependent plant species will be necessary to keep the water table high in this zone. The planting of nonvascular water storing plants will aid in increasing the water table. Bunds and other open water storage initiatives should be looked at and included in the buffer zone if feasible. This will help to decrease the hydrological gradient between the bog and the buffer zone.

11.2.2 Removal of Invasive Vegetation

Since agricultural activities ceased in 1994, evapotranspirative water losses are perhaps the main water-losing factor affecting the bog. Whether the plants are in the buffer zone on the surrounding hills, or in the bog forest itself they all contribute to the reduction of available water to the bog. Returning all areas of the park to as natural a state as possible is a necessary step to consider in any rewetting or rehabilitation effort. Without this, vascular plants will continue to decrease the water stored in the bog by natural processes and reduce the effectiveness of all water management options.

11.2.3 Blockage of Drainage Ditches

Ditches, created during agricultural activities may still be draining the bog. Despite the fact that they have been blocked near the outflow, lateral movement of water may still be happening through, around and under these blockages. Blocking the ditches at 50 meter intervals will further reduce the lateral movement of water by reducing the pressure exerted by one large body of water into several smaller bodies of water. This will also increase the water storage capacity of the buffer zone further decreasing the hydrological gradient between the bog and the buffer zone.

11.2.4 Damming of Inflow Channel

The final recommendation is to block or dam the inflow channel near Fir Tree Glen. This will effectively increase the water storage capacity of the buffer zone and store a large amount of water that will be available to keep underlying peat layers saturated through the summer. The peat layers will be kept saturated by the hydraulic pressure exerted by the lake that will be created behind the dam (Figure 37). This dam will also stop nutrient rich water from flowing directly into the center of the bog carrying with it invasive plant species. This should reduce conductivity levels through the bog.

This initiative will have an effect on the entire Colquitz drainage system from the bog, to its outflow into the ocean and must be studied in extensive detail. Wetlands naturally serve as a storm moderator in stream systems, storing and biofiltering water before discharging water into the system. This initiative should positively affect the Colquitz Creek by reducing storm run-off during the winter then, during the summer, flow would be kept higher and cool as stored water slowly returned to the river system.

The lake created behind the dam will also serve as habitat for waterfowl and other birds. This fact, combined with the other bodies that will be created in the buffer zone has interested Ducks Unlimited into looking at these and other options for water management for the bog. Wetlands serve many functions and each area of the park can be created for multi-purposes.

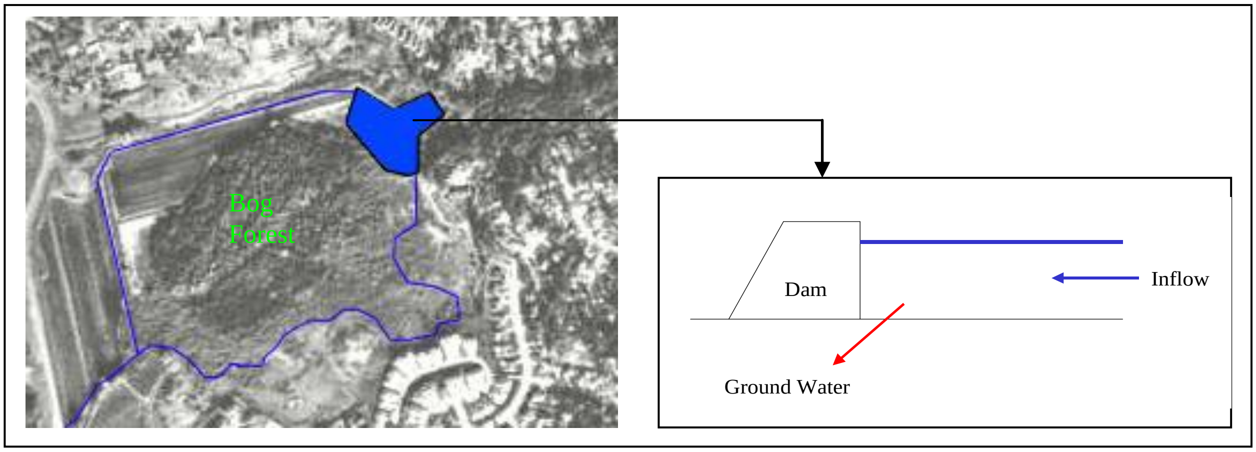


Figure 37: Proposed Dam

11.3 Further Study

One area where future research would be beneficial is the process determining the availability of nitrogen and phosphorus in fens and bogs. In addition, baseline hydrological studies have been identified as a necessity for determining the appropriate management options for a particular bog. The effects of climate change on vegetation and hydrology will probably account for many of future studies.

For Rithet's Bog, a replication of the water quality and hydrological assessment should be performed in the next few years with special attention given to the areas surrounding dipwells 5 and 6. This study would be a good candidate for a Sustainable Research Project for a group of Camosun College Environmental Technology students. It would allow comparisons to be made with past data and, in addition, questions could be answered concerning the extent of area at dipwells 5 and 6 where regeneration of *Sphagnum* moss would be possible. To perform this habitat potential analysis, dipwells will need to be added in the bog forest around these two dipwells. Another area where further study is required is on the effects of the ditch on the north border of the forest and the water levels of dipwells 1 and 6. The replication of the assessment should be in 5 year intervals thereafter in order to conduct a trend analysis on water quality and hydrological factors.

Appendix A

Glossary of Terms

Acrotelm – The uppermost biologically active, aerobic layer of surface peat, usually less than 50 cm deep, consisting of freshly decomposing *Sphagnum* mosses and organic matter derived from other bog vegetation. The lower boundary is defined by the lowest level of the water table over a long period of observation, excluding periods of extreme drought. Water easily infiltrates and drains from the acrotelm, and most changes in water storage occur in this layer.

Aerobic – Characterized by the presence of free oxygen.

Anaerobic – Characterized by the absence of free oxygen.

Anoxic – Lacking oxygen.

Bog – A nutrient-poor, acidic peatland with a poor flora dominated by *Sphagnum* mosses and ericaceous shrubs. A peatland elevated beyond the regional water table that generally receives water and nutrients directly from atmospheric precipitation.

Basin Bog – Occupying the basin of a pond or lake; a lake-fill bog.

Domed Bog – Raised above ground level by a marked convexity, often with a concentric or eccentric pattern of ridges and depressions and/or pools.

Raised Bog – A bog with an ombotrophic centre raised above the minerotrophic lagg and the regional water table; this includes bogs that are domed or plateau-shaped in cross-sectional profile.

Boggin' – The act of trudging through a bog for the purposes of scientific study.

Catotelm – The lower layer of permanently saturated, anaerobic peat in undisturbed raised bogs. The catotelm underlies the acrotelm, and is characterized by negligible water movement and very low biological activity.

Climax Ecosystem – The mature or stabilized stage in a successional series of communities.

Diplotelmic – ‘Two-layered’. In raised bogs, this refers to the typical occurrence of the uppermost ‘active layer’ (the acrotelm) and lower ‘inert layer’ (the catotelm).

Ericaceous – Plants belonging to the Heather family (*Ericaceae*), which includes blueberries, bog cranberry, Labrador tea, bog-laurel and bog rosemary.

Eutrophic – Relatively rich in available nutrients; generally referring to a habitat more nutrient-rich than oligotrophic or mesotrophic habitats.

Evapotranspiration – Combined loss of water from surface evaporation and from transpiration by plants.

Fen – A sedge-dominated peatland often with some shrubs or scattered trees, occurring on minerotrophic sites. In addition to receiving atmospheric precipitation, fens receive water that has flowed through and been enriched by mineral soils. Fens are richer in nutrients and less acidic than bogs.

Fibric - The least decomposed of all organic materials.

Fluvial - Of, relating to, or a living stream or river.

Geomorphology –The study of physical features of the surface of the earth and their relation to its underlying geology.

Ground moraine - A moraine deposited beneath a glacier or glacial drift deposited and overridden by glaciers to form level to gently sloping topography.

Hollow – A microtopographic depression among the hummocks, often covered with *Sphagnum* mosses, liverworts, lichens or bare peat, and with intermittent standing water.

Humic - Highly decomposed organic material.

Hummock – A mound in a peatland, usually <40 cm high, and varying from <1 m^2 to over 10 m^2 in area, usually composed of *Sphagnum* and often colonized by ericaceous shrubs, small trees, other mosses and/or lichens.

Hydrophilic – Having an affinity for water.

Hydrosere – Autogenic terrestrialization of open water.

Infilling or Paludification – Term used to describe the process of bog expansion caused by a gradual rising of the water table as peat accumulation impedes drainage.

Inundation – Flooding or covering by water, usually on a seasonal or periodic basis.

Lagg – The mineral-rich zone surrounding a raised bog, receiving water both from the bog and from surrounding uplands. The lagg is usually colonized by sedge fen vegetation or shrub growth.

Lacustrine Sediments – Sediments of marine origin.

Mesic – Moderately decomposed organic material.

Mesotrophic – Having moderate levels of nutrients, referring to a habitat intermediate in richness between oligotrophic and eutrophic.

Minerotrophic – Areas influenced by water that has been in contact with mineral soils of rock that is therefore richer in mineral-nutrient elements than rainwater.

Oligotrophic – Poor to extremely poor in nutrients and therefore low in productivity. Refers to habitats less nutrient-rich than eutrophic or mesotrophic.

Ombotrophic – Receiving water only directly from atmospheric precipitation.

Peat – Partly decomposed organic matter that accumulates in wet sites under water-saturated conditions.

Peatland – Any type of peat-covered terrain, including fens, bogs, and muskegs. A waterlogged terrestrial ecosystem in which a layer of organic matter (peat) accumulates as a result of continuous saturation and slow rates of decomposition.

Permafrost – A permanently frozen layer at variable depth below the surface in frigid regions of a planet.

Physiognomy – appearance and features that help to describe an aspect of something

Stratigraphy – The vertical sequence of layers of peat and other materials as deposited by vegetation in situ; this sequence records the history of the depositional environment and may be used to trace the history of a peatland.

Succession – The replacement of one community or population by another as a result of changes in the environment.

Temperate – Climates characterized by moderate to high annual levels of precipitation, mild winters and warm summers.

Thalweg – Highest velocity, fasting flowing part of the waterway; usually found over the deepest portion of waterway.

Water Storage Capacity – The total amount of water that can be held in a given volume of soil.

Water Table – the top of the zone of water-saturated ground where all the pore spaces are filled with water, in contrast to the aerated upper zone of peat. The level at which the porewater pressure is equal to atmospheric pressure, forming the junction between saturated and unsaturated conditions.

Xeromorphic – Trees and shrubs adapted to dry conditions.

Appendix B

Quality Assurance/Quality Control Tests

1. Dissolved Oxygen Error

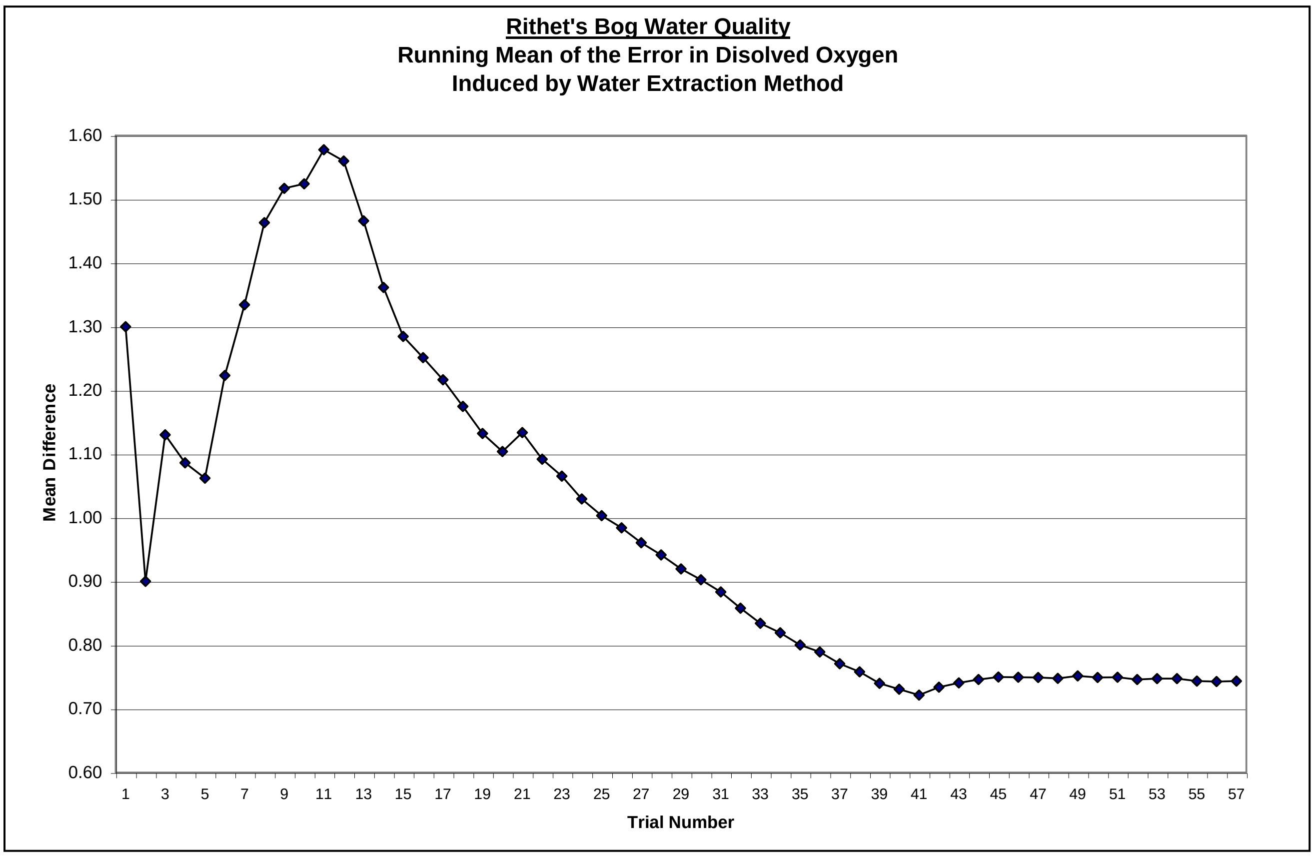
2. pH Error

1. Oxygen Error

The apparatus consisted of a water tank with an electric circulator. Nitrogen was kept flowing into the water through a hose to keep the dissolved oxygen at a low range. A large flask with a small exposed surface area was used as the receiving container as it reduced changes caused by exposure to the atmosphere. The bog equipment used was the pump and YSI Model 85.

The procedure began with turning on and calibrating the YSI 85. With the circulator and nitrogen turned on, the water was pumped out of the tank and into the flask using the same extraction technique as in the bog. The flask was kept above the tank to reduce siphoning and keep results as true as possible. At the moment pumping began, a dissolved oxygen reading was taken from the YSI with the probe in the tank. Another reading was taken at the moment pumping ended. The probe was quickly placed into the flask and after a count to ten another reading was taken. The contents of the flask were emptied back into the tank and the procedure was repeated until the running mean leveled out.

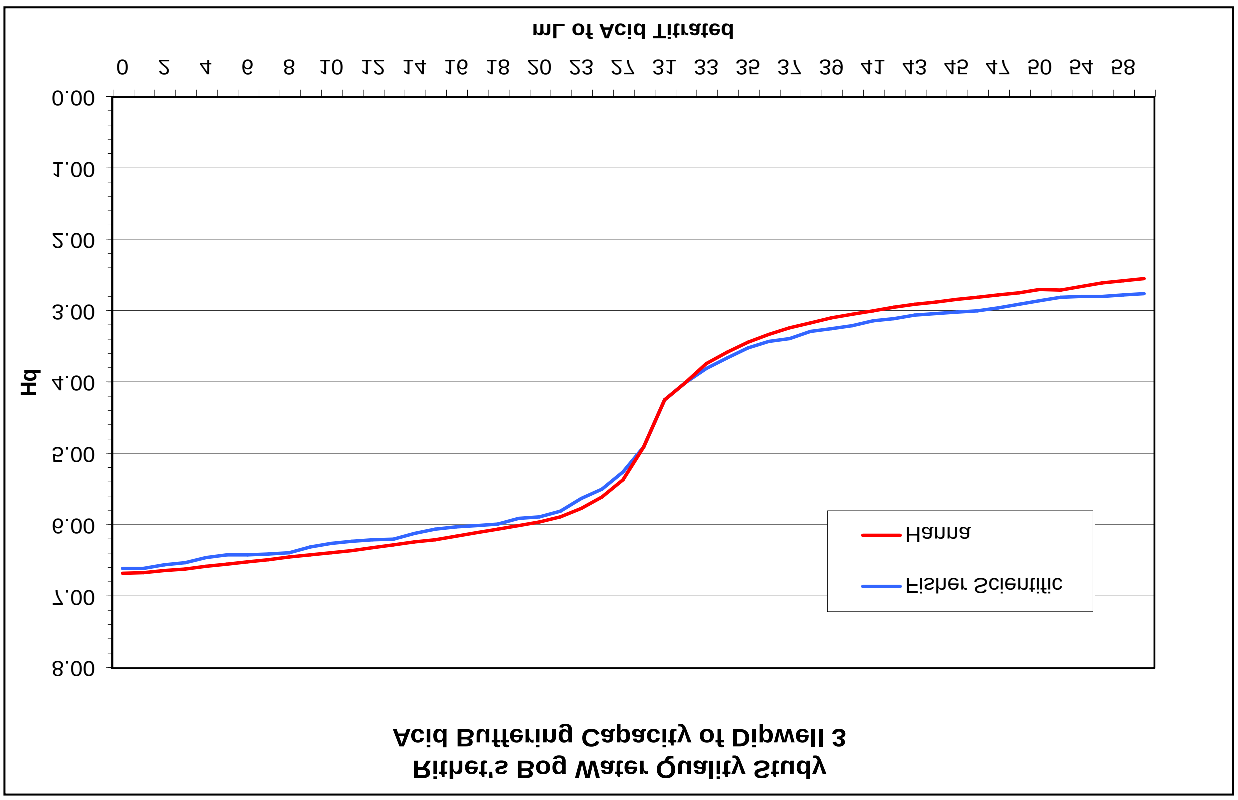
The graph below shows the running mean leveling out at approximately 0.75 mg/L. This shows that the average dissolved oxygen error induced by the water extraction method is +0.75 mg/L.



2. pH Error

To test the accuracy of the Hanna pH meter, a titration was performed using ground water from dipwell 3. The ground water was titrated with the strong hydrochloric acid (HCl). The Hanna pH meter was tested against the Fisher Scientific pH meter by taking measurements of the ground water using both meters after each 1.0 mL aliquot of HCl was added.

By using both pH meters simultaneously it was possible to determine the accuracy of the Hanna pH meter. When graphed, both meters showed approximately the same results as shown in the graph below. The Hanna pH meter gave reasonably accurate field results with an average error of ±0.17.



Appendix C

Outputs From Minitab Statistical Analysis

1. pH
2. Conductivity
3. Dissolved Oxygen
4. Percent Saturation
5. Water Table

pH

Minitab Inputs for pH

pH	Region	Season
4.17	1	1
5.36	1	1
3.83	1	1
4.56	1	2
4.94	1	2
3.72	1	2
5.61	1	3
5.42	1	3
4.12	1	3
5.57	2	1
6.37	2	1
6.29	2	1
5.86	2	2
5.91	2	2
6.01	2	2
5.94	2	3
6.22	2	3
6.27	2	3
7.11	3	1
6.73	3	1
6.95	3	1
7.14	3	2
6.73	3	2
6.74	3	2
7.47	3	3
7.03	3	3
7.04	3	3

Minitab Outputs for the Balanced ANOVA Test

```
Analysis of Variance for pH

Source             DF        SS         MS        F       P
Region              2    25.3207    12.6603   54.82  0.000
Season             2     0.7563     0.3782    1.64  0.222
Region*Sesaon       4     0.2518     0.0630    0.27  0.892
Error              18     4.1573     0.2310
Total              26    30.4862
```

Minitab Outputs for Tukey's Multiple Comparison Test

```
ANALYSIS OF VARIANCE ON pH
SOURCE     DF        SS        MS        F        p
Region      2    25.321    12.660    58.82    0.000
ERROR      24     5.165     0.215
TOTAL      26    30.486

Tukey's pairwise comparisons

    Family error rate = 0.0500
Individual error rate = 0.0198

Critical value = 3.53

Intervals for (column level mean) - (row level mean)

               1         2

     2   -1.9581
         -0.8663

     3   -2.9026   -1.4903
         -1.8108   -0.3986
```

Picture produced by Minitab during Tukey's Multiple Comparison Test

```
INDIVIDUAL 95% CI'S FOR MEAN
                                   BASED ON POOLED STDEV
 LEVEL       N       MEAN     STDEV  -------+---------+---------+---------
     1       9     4.6367    0.7209  (--*---)
     2       9     6.0489    0.2591                (--*---)
     3       9     6.9933    0.2425                          (--*--)
                                     -------+---------+---------+---------
POOLED STDEV =   0.4639                   5.0       6.0       7.0
```

Conductivity

Minitab Outputs for Balanced ANOVA Test

```
Analysis of Variance for Conduct

Source            DF        SS         MS       F      P
Region             2    232496     116248   13.11  0.000
Season             2      4433       2217    0.25  0.782
Region*Season      4     45742      11435    1.29  0.311
Error             18    159661       8870
Total             26    442332
```

Minitab Inputs for Conductivity

Conduct	Region	Season
188.24	1	1
185.01	1	1
142.11	1	1
262.42	1	2
169.89	1	2
129.94	1	2
376.95	1	3
209.12	1	3
141.86	1	3
644.36	2	1
417.88	2	1
399.31	2	1
466.40	2	2
338.62	2	2
421.19	2	2
436.90	2	3
371.52	2	3
344.83	2	3
225.87	3	1
261.81	3	1
298.49	3	1
275.74	3	2
391.64	3	2
389.67	3	2
248.12	3	3
332.37	3	3
576.62	3	3

Minitab Outputs for Tukey's Multiple Comparison Test

```
ANALYSIS OF VARIANCE ON Conduct
SOURCE     DF        SS        MS        F        p
Region      2    232496    116248    13.30    0.000
ERROR      24    209836      8743
TOTAL      26    442332

Tukey's pairwise comparisons

    Family error rate = 0.0500
Individual error rate = 0.0198

Critical value = 3.53

Intervals for (column level mean) - (row level mean)

               1         2

     2    -336.2
          -116.1

     3    -242.8     -16.6
           -22.7     203.4
```

Picture produced by Minitab during Tukey's Multiple Comparison Test

```
INDIVIDUAL 95% CI'S FOR MEAN
                                   BASED ON POOLED STDEV
 LEVEL      N      MEAN     STDEV  -------+---------+---------+---------
     1      9    200.62     77.62   (-----*-----)
     2      9    426.78     91.80                        (------*-----)
     3      9    333.37    108.52                  (-----*------)
                                   -------+---------+---------+---------
POOLED STDEV =    93.50                 200       300       400
```

Dissolved Oxygen

Minitab Inputs for Dissolved Oxygen

Diss O	Region	Season
6.23	1	1
4.34	1	1
5.51	1	1
6.52	1	2
4.17	1	2
5.26	1	2
6.54	1	3
4.13	1	3
6.38	1	3
4.73	2	1
5.33	2	1
3.54	2	1
6.05	2	2
5.18	2	2
3.70	2	2
3.43	2	3
5.70	2	3
3.42	2	3
8.02	3	1
7.66	3	1
8.73	3	1
9.46	3	2
7.39	3	2
7.95	3	2
6.75	3	3
4.36	3	3
2.52	3	3

Minitab Outputs for Balanced ANOVA Test

```
Analysis of Variance for Diss O

Source             DF        SS         MS       F       P
Region              2    26.920     13.460    8.64   0.002
Weather             2    10.203      5.101    3.28   0.061
Region*Weather      4    17.779      4.445    2.85   0.054
Error              18    28.034      1.557
Total              26    82.936
```

Minitab Outputs for Tukey's Multiple Comparison Test

```
ANALYSIS OF VARIANCE ON Diss O
SOURCE     DF        SS        MS        F        p
Region      2     26.92     13.46     5.77    0.009
ERROR      24     56.02      2.33
TOTAL      26     82.94

Tukey's pairwise comparisons

    Family error rate = 0.0500
Individual error rate = 0.0198

Critical value = 3.53

Intervals for (column level mean) - (row level mean)

               1         2

     2    -0.909
           2.687

     3    -3.327    -4.215
```

Picture produced by Minitab during Tukey's Multiple Comparison Test

```
INDIVIDUAL 95% CI'S FOR MEAN
                                   BASED ON POOLED STDEV
 LEVEL      N      MEAN     STDEV  -------+---------+---------+---------
     1      9     5.453     1.028        (------*------)
     2      9     4.564     1.054  (------*------)
     3      9     6.982     2.199                   (------*------)
                                   -------+---------+---------+---------
POOLED STDEV =    1.528                  4.5       6.0       7.5
```

% Saturation

Minitab Inputs for % Saturation

Saturate	Region	Weather
36.98	1	1
22.46	1	1
37.65	1	1
39.21	1	2
18.44	1	2
28.66	1	2
67.20	1	3
18.58	1	3
43.23	1	3
27.10	2	1
39.20	2	1
16.46	2	1
50.52	2	2
33.87	2	2
9.77	2	2
33.20	2	3
36.43	2	3
12.47	2	3
72.09	3	1
54.19	3	1
65.55	3	1
81.47	3	2
63.25	3	2
63.80	3	2
51.47	3	3
30.62	3	3
18.92	3	3

Minitab Outputs for Balanced ANOVA Test

```
Analysis of Variance for Saturate

Source             DF        SS         MS        F       P
Region              2    3603.0     1801.5     8.31   0.003
Weather             2     361.3      180.7     0.83   0.451
Region*Weather      4    2229.7      557.4     2.57   0.073
Error              18    3904.2      216.9
Total              26   10098.3
```

Minitab Outputs for Tukey's Multiple Comparison Test

```
ANALYSIS OF VARIANCE ON Saturate
SOURCE     DF        SS        MS        F        p
Region      2      3603      1802     6.66    0.005
ERROR      24      6495       271
TOTAL      26     10098

Tukey's pairwise comparisons

    Family error rate = 0.0500
Individual error rate = 0.0198

Critical value = 3.53

Intervals for (column level mean) - (row level mean)

               1         2

     2    -13.43
           25.29

     3    -40.35    -46.28
```

Picture produced by Minitab during Tukey's Multiple Comparison Test

```
INDIVIDUAL 95% CI'S FOR MEAN
                                   BASED ON POOLED STDEV
 LEVEL      N      MEAN     STDEV  ---------+---------+---------+-------
     1      9     34.71     15.30       (-------*--------)
     2      9     28.78     13.54   (-------*--------)
     3      9     55.71     19.86                    (-------*--------)
                                   ---------+---------+---------+-------
POOLED STDEV =    16.45                    30        45        60
```

Water Table

Minitab Inputs for Water Table

H2O Tab	Region	Weather
32.50	1	1
10.48	1	1
28.69	1	1
24.63	1	2
5.30	1	2
33.30	1	2
63.40	1	3
26.22	1	3
58.72	1	3
-1.74	2	1
-13.73	2	1
7.92	2	1
9.97	2	2
-1.99	2	2
16.20	2	2
52.70	2	3
16.23	2	3
31.57	2	3

Minitab Outputs for Two Population t-Test

```
TWOSAMPLE T FOR Forest VS Agri
        N      MEAN     STDEV   SE MEAN
Forest  9      31.5      19.3       6.4
Agri    9      13.0      19.8       6.6

95 PCT CI FOR MU Forest - MU Agri: ( -1.1,  38.0)

TTEST MU Forest = MU Agri (VS NE): T= 2.00  P=0.062  DF=  16

POOLED STDEV =       19.5
```

Appendix D

Raw Data

1. pH
2. Conductivity
3. Dissolved Oxygen
4. Percent Saturation
5. Water Table
6. Temperature
7. Weather/Hydrology

pH

Date	Inflow	1	2	3	4	5	6	Ditch 1	Ditch 2	Outflow	Fen
01/27/99	6.88			5.84	3.42	5.02	3.13	6.38	6.77	6.02	
02/03/99	6.32				3.50	5.71	3.83	6.26	6.28	5.83	
02/18/99	6.55	5.52		5.71	3.61	5.42	3.01	6.13	6.26	6.14	
03/08/99	6.85	5.41		5.72	3.39	5.07	3.27	6.55	6.52	6.04	
03/17/99	7.10	5.66		6.15	3.61	5.30	3.36	6.82	7.26	6.80	
03/31/99	6.94	5.55	5.77	6.08	3.55	5.29	3.17	6.79	6.76	6.18	
04/14/99	7.32	5.34	5.84	6.22	3.93	4.97	3.85	6.99	7.00	6.55	
04/29/99	7.15	5.84	5.81	5.98	4.39	4.77	3.45	6.64	6.77	6.35	
05/12/99	7.09	5.77	5.95	5.80	4.36	4.51	3.66	6.82	6.80	6.12	
05/30/99	7.04	5.72	5.79	5.90	4.73	4.87	3.70	6.64	6.88	6.57	
06/12/99	7.55	6.61	6.35	6.40	5.59	5.52	4.51	6.94	7.01	7.02	
06/26/99	6.89	6.21	5.91	5.68	5.35	4.66	3.69	6.29	6.42	6.23	
07/10/99	7.04	5.94	6.35	6.12	4.95	4.43	3.51	6.75	6.53	6.68	5.79
07/29/99	7.17		5.88	5.85	5.30	4.56	3.82	7.20	6.48	6.56	5.61
08/07/99	7.28		5.95	5.98	5.25	4.77	3.64	6.83	6.64	6.57	6.00
08/21/99	7.66		6.40	6.48	5.71	5.62	4.54	7.08	7.00	7.04	6.17
08/31/99	7.72		6.27	6.63	6.25	5.55	4.66	6.92	7.20	7.05	6.24
09/16/99	7.93		6.50	6.59	6.18	5.53	4.58	7.38	7.26	7.12	6.45
10/07/99	6.94		6.11	6.45	6.93	5.66	4.59	6.77	7.10	7.03	6.32
10/16/99	7.85	5.70	6.62	6.58		5.43	4.24	7.50	7.36	7.20	
10/31/99	7.27				4.41	3.08	4.10	6.81	6.87	6.37	
11/12/99	7.47			6.56	4.10	6.36	3.90	6.40	7.30	7.09	
11/28/99	7.38			6.84	4.45	6.08	4.56	7.02	7.30	6.95	
12/10/99	7.58			6.76	4.34	5.87	4.16	7.37	7.36	7.11	

Conductivity (μS)

Date	Inflow	1	2	3	4	5	6	Ditch 1	Ditch 2	Outflow	Fen
01/27/99	294.8				193.4						
02/03/99	229.5				83.1	154.6		263.0	191.2	133.7	
02/18/99	203.2	259.6		476.3	145.7	187.2	115.2	154.6	192.5	182.4	
03/08/99	233.4	345.7		348.7	163.0	182.8	101.1	345.5	446.5	299.2	
03/17/99	253.8	174.7		423.0	173.4	164.9	108.1	346.0	385.1	259.3	
03/31/99	237.4	341.7	283.8	419.6	165.2	162.8	109.6	331.9	306.5	239.7	
04/14/99	286.7	470.6	355.8	507.5	230.6	170.7	118.0	412.4	437.3	362.0	
04/29/99	279.6	641.5	416.8	509.8	260.0	139.9	110.1	422.7	450.7	384.6	
05/12/99	278.7	594.5	319.7	473.0	272.6	169.5	153.8	404.3	425.4	352.1	
05/30/99	285.0	324.6	364.2	348.2	281.7	176.1	139.2	460.3	443.6	412.3	
06/12/99	226.5	450.5	286.6	357.0	303.3	191.7	139.6	404.1	408.4	405.8	
06/26/99	273.7	441.4	343.6	333.4	323.7	178.8	139.6	305.8	255.8	290.2	447.9
07/10/99	276.5	436.9	351.9	318.8	320.8	182.8	140.1	433.5	409.1	422.7	424.4
07/29/99	302.0		310.8	323.7	360.4	186.9	146.4	175.8	697.0	503.0	448.5
08/07/99	119.8		455.1	362.7	344.4	178.8	140.2	352.3	601.0	353.7	454.8
08/21/99	280.5		337.9	346.5	326.8	269.6	139.3	384.0	495.6	385.1	456.9
08/31/99	258.9		402.9	350.1	518.0	221.5	139.5	278.8	539.0	299.0	457.2
09/16/99	251.0		370.7	367.4	391.3	215.2	145.8	369.8	718.0	392.7	497.4
10/07/99	90.5		556.5	349.9		163.5	136.3	85.8	237.2	204.2	353.1
10/16/99	281.4	179.8	279.3	339.9		176.8	139.0	387.1	239.2	351.4	
10/31/99	243.0				200.2	237.3	235.9	192.5	297.4	149.5	
11/12/99	150.4			322.0	270.8	208.8	191.5	158.2	172.7	180.2	
11/28/99	293.6			277.5	232.9	193.7	137.1	356.0	426.4	246.9	
12/10/99	211.0			335.4	231.8	180.7	115.1	329.4	397.1	259.9	

Dissolved Oxygen (mg/L)

Date	Inflow	1	2	3	4	5	6	Ditch 1	Ditch 2	Outflow	Fen
01/27/99											
02/03/99											
02/18/99											
03/08/99	10.02	5.03		5.77	6.61	3.49	5.03	7.58	10.60	6.94	
03/17/99	12.09	2.22		1.89	4.40	4.19	4.31	9.80	13.81	6.45	
03/31/99	11.21	3.35	9.17	4.02	5.65	4.84	5.77	9.60	11.73	8.60	
04/14/99	9.33				5.56	2.83	4.03				
04/29/99	11.25	6.71	1.57	3.16	4.98	2.76	3.60	10.45	7.10	6.92	
05/12/99	9.05	2.95	4.91	3.92	6.67	4.19	5.55	5.99	9.05	6.92	
05/30/99	9.35	7.04	5.30	3.66	6.94	4.37	5.67	5.38	8.20	6.14	
06/12/99	8.57	7.73	4.58	3.00	7.92	4.35	6.55	6.23	4.01	6.69	
06/26/99	7.49	8.53	5.56	4.46	7.94	5.83	5.69	6.66	7.63	3.81	
07/10/99	8.76	3.43	4.69	4.60	8.02	4.93	5.89	3.92	3.70	12.64	4.04
07/29/99	8.16		5.38	1.05	5.34	1.12	4.49	1.32	1.86	1.96	2.34
08/07/99	5.66		4.18	2.62			6.85	1.55	2.00	1.86	2.30
08/21/99	2.81		6.17	3.67	6.67	3.83	7.25	4.55	1.23	3.70	4.09
08/31/99	5.69		6.40	4.89	5.49	6.01	6.14	5.26	3.71	3.65	5.14
09/16/99	9.43		7.36	3.73	7.20	4.77	7.69	9.53	2.60	7.47	
10/07/99	5.58		6.09	2.52		4.67	6.55	6.09	6.20	5.90	4.47
10/16/99	10.85	6.93	4.58	5.12		4.83	7.30	9.31	10.49	8.68	
10/31/99	9.55				6.35	3.15	6.36	5.37	4.96	3.80	
11/12/99	6.04			2.64	6.94	4.20	3.99	9.20	6.50	5.11	
11/28/99	8.54			3.61	6.24	5.05	5.45	6.84	8.50	2.49	
12/10/99	9.50			3.22	6.82	5.12	5.11	7.08	8.79	4.24	

% Saturation O_2

Date	Inflow	1	2	3	4	5	6	Ditch 1	Ditch 2	Outflow	Fen
01/27/99											
02/03/99											
02/18/99											
03/08/99		17.90		15.70	33.00	13.00	25.40	48.90	77.10	61.20	
03/17/99	102.40	9.40		14.30	26.40	23.50	29.20	74.30	109.40	51.80	
03/31/99	91.50	13.90	85.50	17.70	21.70	13.70	20.30	82.90	103.10	71.10	
04/14/99	42.60				30.70	12.20	20.10				
04/29/99	101.80	50.30	5.03	11.80	30.50	18.10	28.10	106.40	74.30	64.70	
05/12/99	80.30	42.40	25.50	7.70	31.60	18.40	29.10	50.90	74.30	46.40	
05/30/99	90.40	50.40	42.40	3.60	36.60	15.20	34.40	73.10	84.40	46.90	
06/12/99	81.50	79.50	18.90	9.00	68.30	16.50	32.00	51.40	32.70	45.40	
06/26/99	82.20	66.60	25.90	8.80	55.10	35.00	36.60	14.80	14.00	34.50	16.40
07/10/99	80.80	33.20	42.80	6.10	67.70	10.50	37.60	18.00	21.30	30.40	20.90
07/29/99	82.30		44.50	8.50	67.50	8.10	46.80	20.70	20.80	22.70	21.40
08/07/99	7.80		20.50	10.70			38.70	5.60	10.80	12.10	13.00
08/21/99	11.70		28.10	10.30	65.80	16.00	43.50	22.60	40.90	21.40	14.10
08/31/99	42.10		27.60	15.40	66.90	21.10	32.20	30.90	10.50	20.20	16.00
09/16/99	84.10		55.10	23.80	68.10	37.20	60.60	85.90	9.20	40.40	59.50
10/07/99	55.20		61.40	35.00		22.20	65.20	44.50	60.20	49.30	59.60
10/16/99	86.40	54.00	17.00	13.80		31.50	59.10	68.00	69.40	56.30	
10/31/99	82.00				69.20	23.40	50.00	55.40	44.90	32.80	
11/12/99	47.30			11.60	34.40	31.60	27.10	55.30	47.00	41.20	
11/28/99	58.00			12.20	29.50	17.50	15.80	42.60	50.20	16.00	
12/10/99	73.30			12.60	29.40	17.00	29.40	44.50	66.20	27.60	

Water Table (cm below surface)

Date	Inflow	1	2	3	4	5	6	Ditch 1	Ditch 2	Outflow	Fen
01/27/99	5.50			7.00	13.70	-2.50	20.50			32.00	-20.00
02/03/99	6.88	-20.00	-20.00	-20.00	2.20	-15.00	-13.00				-20.00
02/18/99	6.49	-12.60	-20.00	3.00	9.50	2.80	7.50			49.00	-20.00
03/08/99	6.05	13.80	-20.00	4.50	12.70	-2.50	18.00			29.50	-20.00
03/17/99	5.39	-8.40	-20.00	10.30	14.50	-0.50	23.80			22.50	-20.00
03/31/99	4.95	-10.50	-12.20	8.00	13.00	-1.50	23.00			20.00	-20.00
04/14/99	3.03	-4.00	-4.30	14.00	16.00	1.50	28.00			12.50	-20.00
04/29/99	5.23	7.20	-1.40	17.70	20.70	2.10	32.70			10.00	-20.00
05/12/99	4.40	9.10	-2.00	16.00	21.50	5.50	31.50			8.00	-20.00
05/30/99	6.05	23.00	5.00	20.00	26.00	7.00	38.00			6.50	-20.00
06/12/99	3.58		2.50	20.00	35.40	10.50	39.00			8.00	-20.00
06/26/99	4.13	35.00	-1.50	17.70	39.80	12.00	40.90			9.00	0.00
07/10/99	4.40	52.70	6.30	22.20	47.90	17.00	42.20			8.60	14.00
07/29/99	2.48		18.10	35.90	54.50	22.60	54.70			7.95	32.60
08/07/99	3.91		17.50	28.80	62.50	23.70	55.50			6.50	33.50
08/21/99	3.47		6.50	27.40	64.00	27.40	60.80			7.40	41.00
08/31/99	3.36		19.70	33.50	72.50	31.20	65.70			7.20	50.50
09/16/99	3.63		29.30	41.60	79.00	35.40	73.40			7.40	60.00
10/07/99	6.00		3.30	26.20	85.00	33.50	70.80			20.00	53.30
10/16/99	3.00	18.50	-5.70	17.50	77.40	23.00	57.00			18.00	-20.00
10/31/99	6.00	-20.00	-20.00	-16.20	19.40	-0.60	24.80			68.00	-20.00
11/12/99	7.00	-20.00	-20.00	-4.00	13.00	-2.00	13.00			58.00	-20.00
11/28/99	6.00	-20.00	-20.00	-4.10	15.10	-0.80	14.70			51.00	-20.00
12/10/99	8.00	-20.00	-20.00	2.90	15.00	0.30	18.50			53.00	-20.00

Temperature (°C)

Date	Inflow	1	2	3	4	5	6	Ditch 1	Ditch 2	Outflow	Fen
01/27/99	7.7			7.0	7.4	7.1	7.5	7.8	6.0	5.0	
02/03/99	8.1				6.5	5.6		7.7	5.5	5.0	
02/18/99	7.6	5.1		6.0	6.3	5.4	6.7	6.7	5.7	6.7	
03/08/99	9.0	6.8		5.5	7.1	6.3	6.9	7.8	7.9	6.9	
03/17/99	8.0	9.5		8.2	8.7	7.1	7.9	8.6	9.1	6.6	
03/31/99	7.8	11.3	15.9	9.0	9.2	7.1	8.0	10.6	9.3	7.3	
04/14/99	10.7	14.1	16.8	10.2	10.4	7.8	8.4	13.6	13.0	11.1	
04/29/99	10.8	13.7	16.5	11.6	12.8	9.9	10.9	15.3	15.6	12.8	
05/12/99	9.3	12.9	12.6	10.2	13.0	9.5	9.6	10.5	12.2	9.6	
05/30/99	11.7	15.2	13.8	11.9	14.5	11.4	12.2	13.7	14.8	12.8	
06/12/99	14.6	18.7	16.2	14.4	17.0	11.5	13.1	18.8	18.7	15.9	
06/26/99	12.4	16.4	16.1	12.8	13.9	11.5	12.0	14.7	14.4	13.4	15.4
07/10/99	14.6	19.5	19.3	14.6	16.2	12.9	13.8	16.9	16.9	16.5	16.5
07/29/99	14.5		14.4	13.4	16.3	12.3	14.0	16.2	15.4	15.7	15.4
08/07/99	17.1		17.1	14.6	15.4	13.9	12.9	16.6	16.5	16.9	16.7
08/21/99	17.1		16.9	15.2	17.1	13.5	13.5	18.0	19.1	16.7	16.6
08/31/99	13.8		14.1	13.7	19.9	12.7	12.8	16.0	14.6	14.6	14.8
09/16/99	14.1		15.6	14.1	20.4	14.2	14.8	16.7	15.5	12.5	17.0
10/07/99	13.0		12.9	12.2		12.2	13.1	13.7	12.0	14.4	
10/16/99	9.5	14.8	13.0	11.9		11.1	11.3	10.8	8.1	7.9	
10/31/99	11.7				11.4	9.1	9.9	8.7	11.9	9.1	
11/12/99	10.3			9.5	9.9	9.4	9.8	11.3	10.0	9.8	
11/28/99	11.4			8.7	10.4	9.2	9.4	10.3	9.2	7.7	
12/10/99	9.5			6.8	9.1	8.4	8.3	9.0	7.6	6.7	

Weather / Hydrology

Date	Weather	Temp. (°C)	Rainfall[1]	Water Level[2] Inflow	Discharge[3] Inflow	Water Level[2] Outflow	Discharge[3] Outflow
01/27/99	Overcast	7.9	0.16	0.06	0.01	0.32	0.44
02/03/99	Overcast	8.3	0.15	0.07	0.03	0.84	0.37
02/18/99	Rain → showers	8.0	0.07	0.06	0.02	0.49	0.42
03/08/99	Rain	12.0	0.15	0.06	0.02	0.30	0.28
03/17/99	Partially cloudy	9.5	0.02	0.05	0.01	0.23	0.31
03/31/99	Sunny	14.0	0.02	0.05	0.01	0.20	0.20
04/14/99	Sunny	12.5	0.01	0.03	0.00	0.13	0.16
04/29/99	Sunny + Hot	18.5	0.01	0.05	0.01	0.10	0.22
05/12/99	Cloudy, sunny breaks, windy	8.5	0.05	0.04	0.01	0.08	0.12
05/30/99	Overcast, humid	12.5	0.02	0.06	0.01	0.07	0.11
06/12/99	Overcast, warm, muggy	22.0	0.01	0.04	0.00	0.08	0.12
06/26/99	Overcast, some precip.	12.0	0.02	0.04	0.01	0.09	0.13
07/10/99	Sunny	19.0	0.02	0.04	0.01	0.09	0.12
07/29/99	Cloudy	19.5	0.00	0.02	-	0.08	0.12
08/07/99	Sunny	18.5	0.01	0.04	-	0.07	0.11
08/21/99	Sunny, warm	23.0	0.01	0.03	-	0.07	0.11
08/31/99	Cloudy with sunny breaks	14.0	0.00	0.03	-	0.07	0.11
09/16/99	Overcast, warm	19.0	0.00	0.04	-	0.07	0.11
10/07/99	Light precipitation	13.0	0.01	0.06	0.01	0.20	0.20
10/16/99	Sunny	10.0	0.03	0.03	-	0.18	0.19
10/31/99	Sunny, windy, cool	13.4	0.10	0.06	0.01	0.68	0.41
11/12/99	Overcast, morning rain	11.0	0.07	0.07	0.01	0.58	0.51
11/28/99	Sunny, partial clouds	11.5	0.07	0.06	0.01	0.51	0.45
12/10/99	Overcast	8.0	0.06	0.08	0.01	0.53	0.32

Appendix E

Buffering Capacity of Rithet's Bog Ground Water

Introduction

The purpose of this lab was to determine the buffering capacity of Rithet's Bog groundwater by titrating a strong acid and strong base with the groundwater from dipwells 3, 4, 5 & 6. It is important to find out the extent to which Rithet's Bog ground water will resist actions intended to change pH. *Sphagnum* moss required a pH of less than 4.5 to regenerate. This lab will hopefully show the likelihood of attaining this pH. By looking at titration curves constructed from the results of the experiment, the buffering capacity of the ground water in each dipwell can be determined.

Methods

Apparatus:

Fisher Scientific pH meter
250ml glass beaker
magnetic stir bar and plate
Volumetric pipettes
50ml Burette

Reagents:

Groundwater from Dipwells 3, 4, 5 & 6
0.1008 M Hydrochloric Acid (HCl)
0.0983 M Sodium Hydroxide (NaCl)

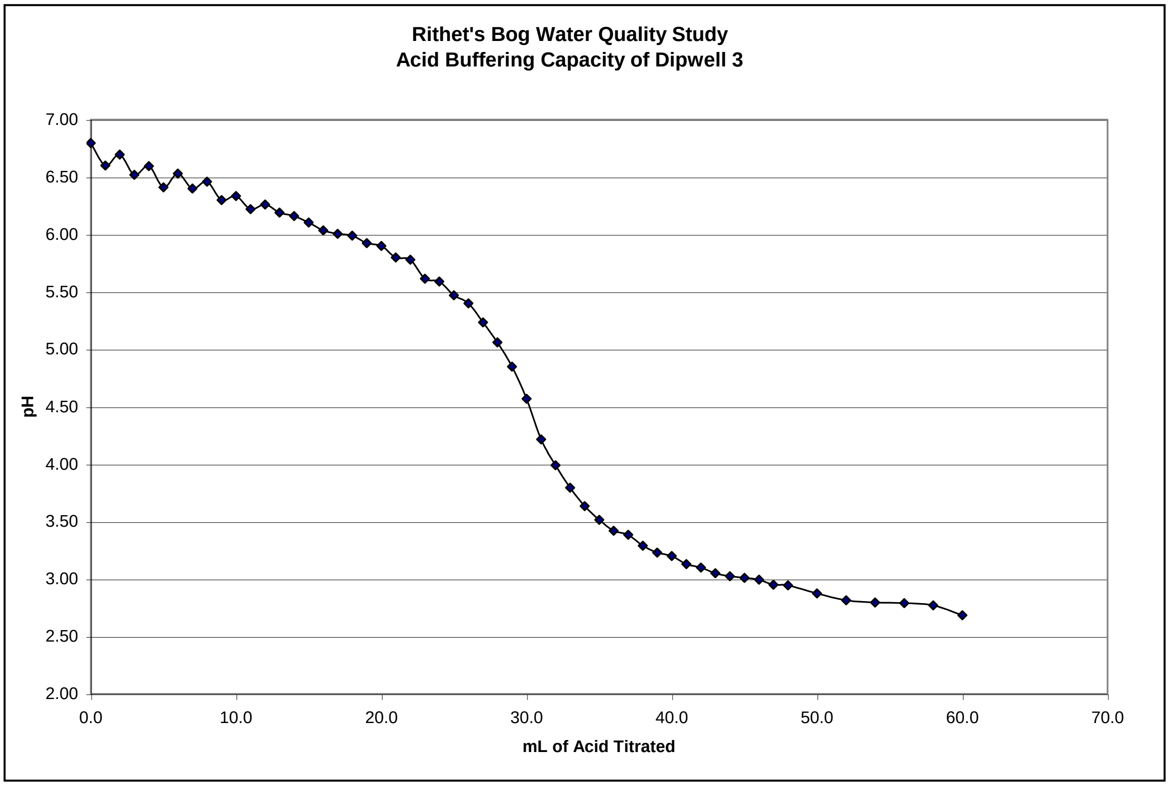
1. Titration Method Using a Strong Acid
   Potentiometric titration curve

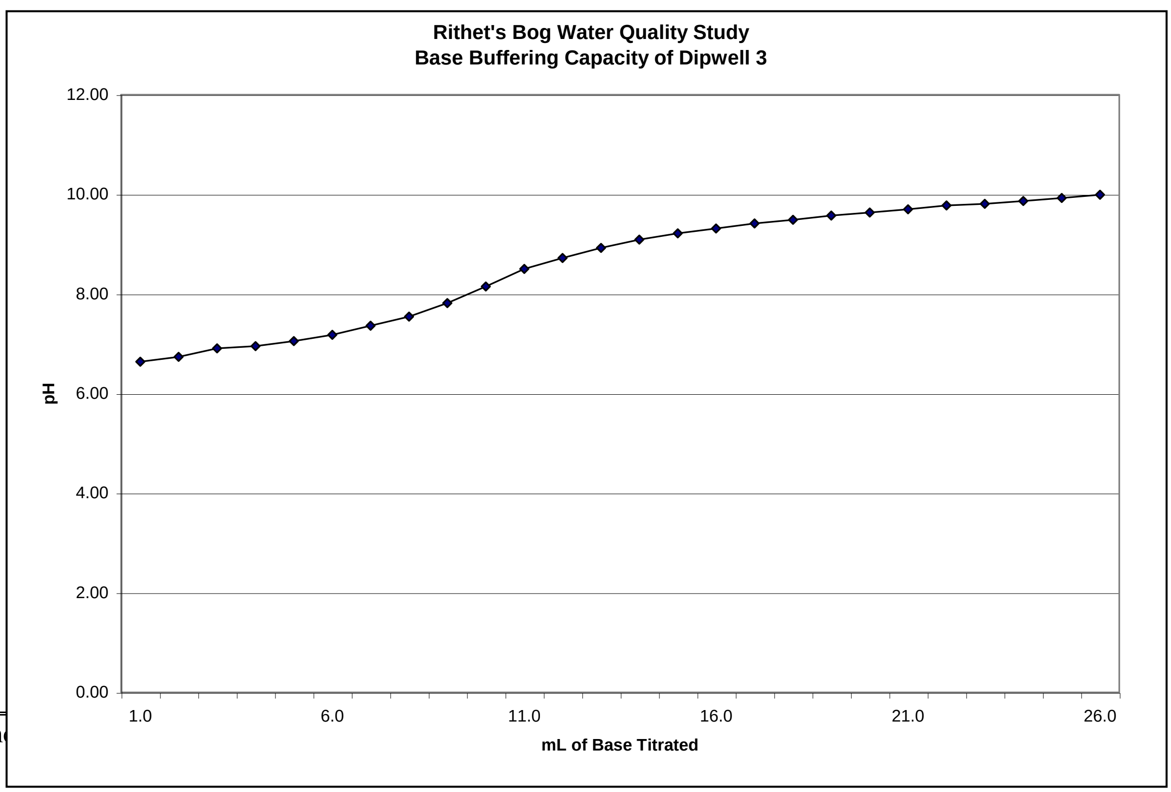
Rinse all glassware with distilled water and drain. Rinse pH probes with distilled water and wipe off excess. Pipette 100 mL of sample into beaker and fill burette with 50 ml 0.10 M HCl. Insert stir bar into beaker so the solution can be stirred constantly. Adjust pH meter probe so sample covers the sensitivity bulb. Measure pH at 0.0 ml and record. Titrate small increments of HCl to the sample such that a pH change of less than 0.2 units occurs per aliquot added. Make sure pH is not still changing when obtaining readings. Continue recording pH until up to 60 ml of titrant has been used. Construct a titration curve by plotting observed pH values against millilitres of acid added.

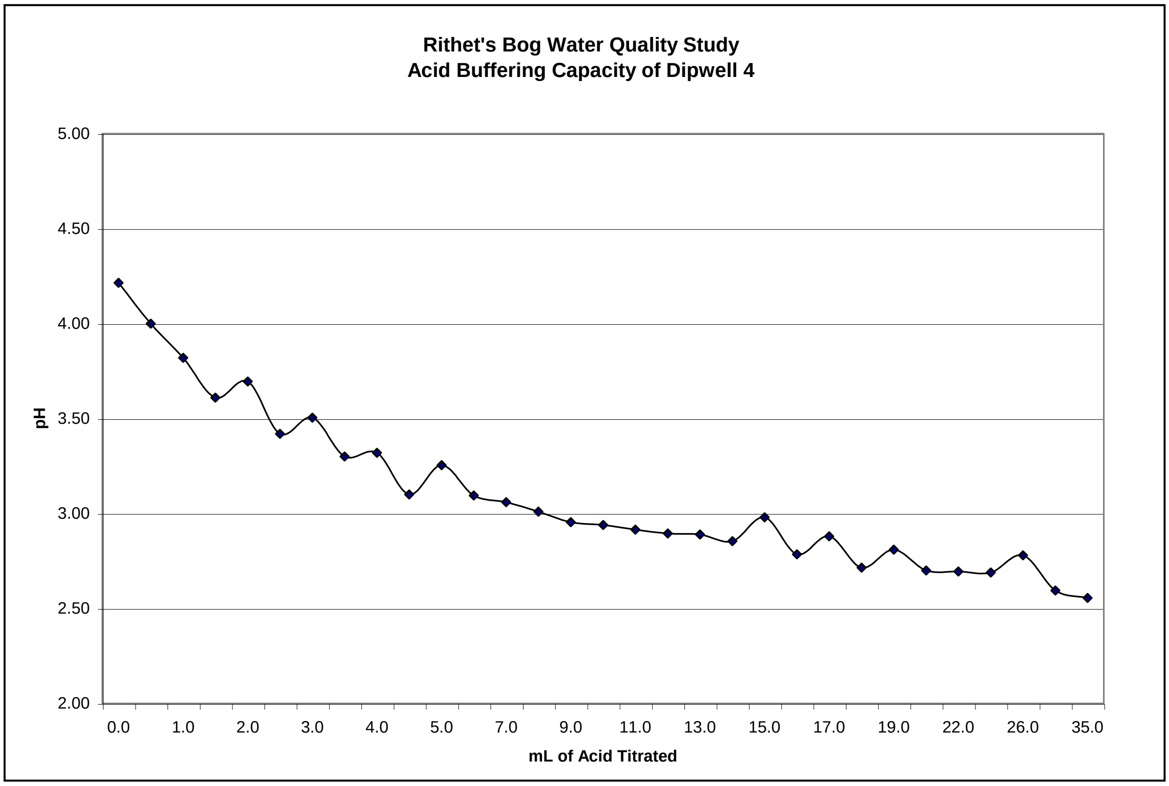
2. Titration Method Using a Strong Base
   Potentiometric titration curve

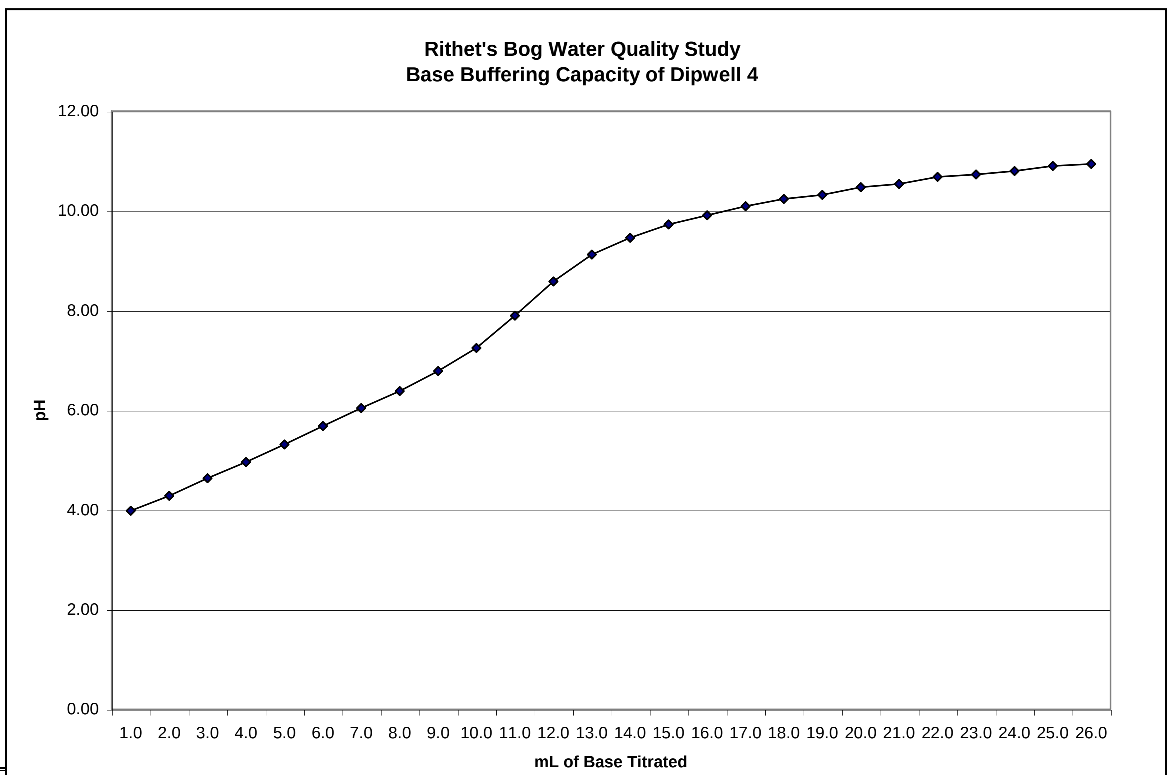
Follow above method. Substitute 0.10 M HCl with 0.01 M sodium hydroxide (NaOH). Construct a titration curve by plotting the observed pH values against millilitres of base used.

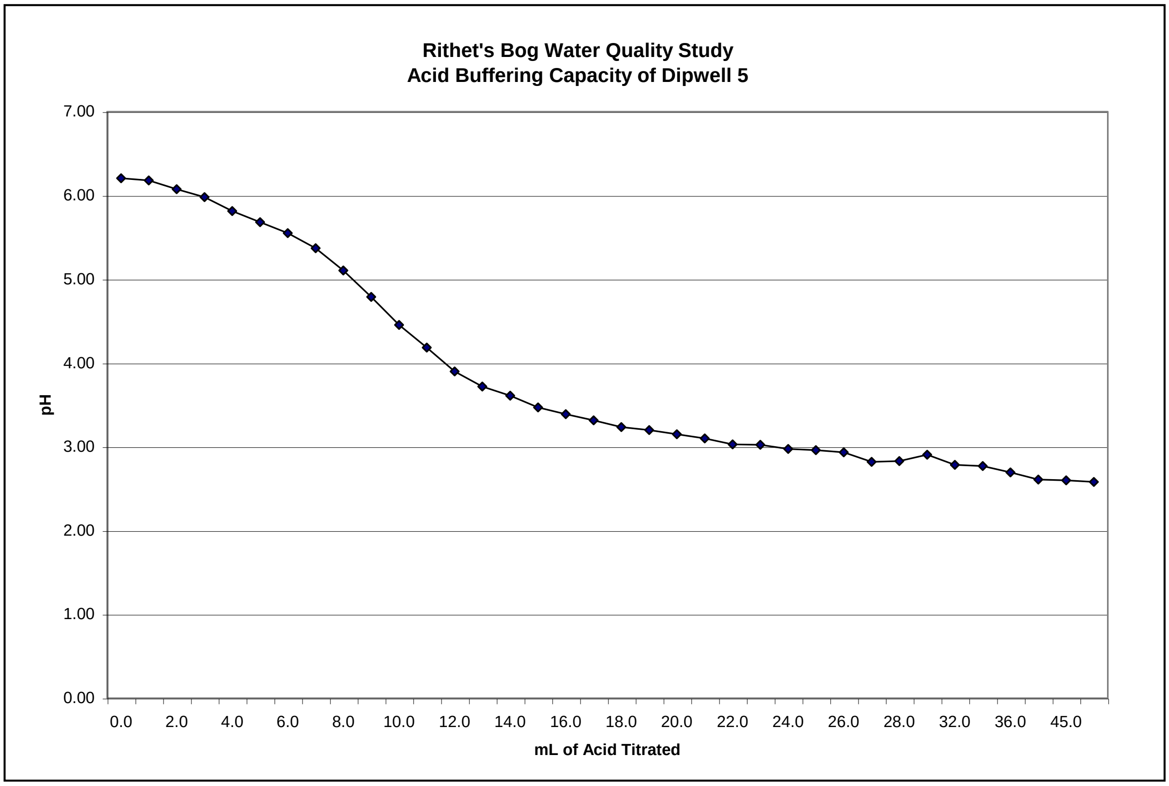
Results

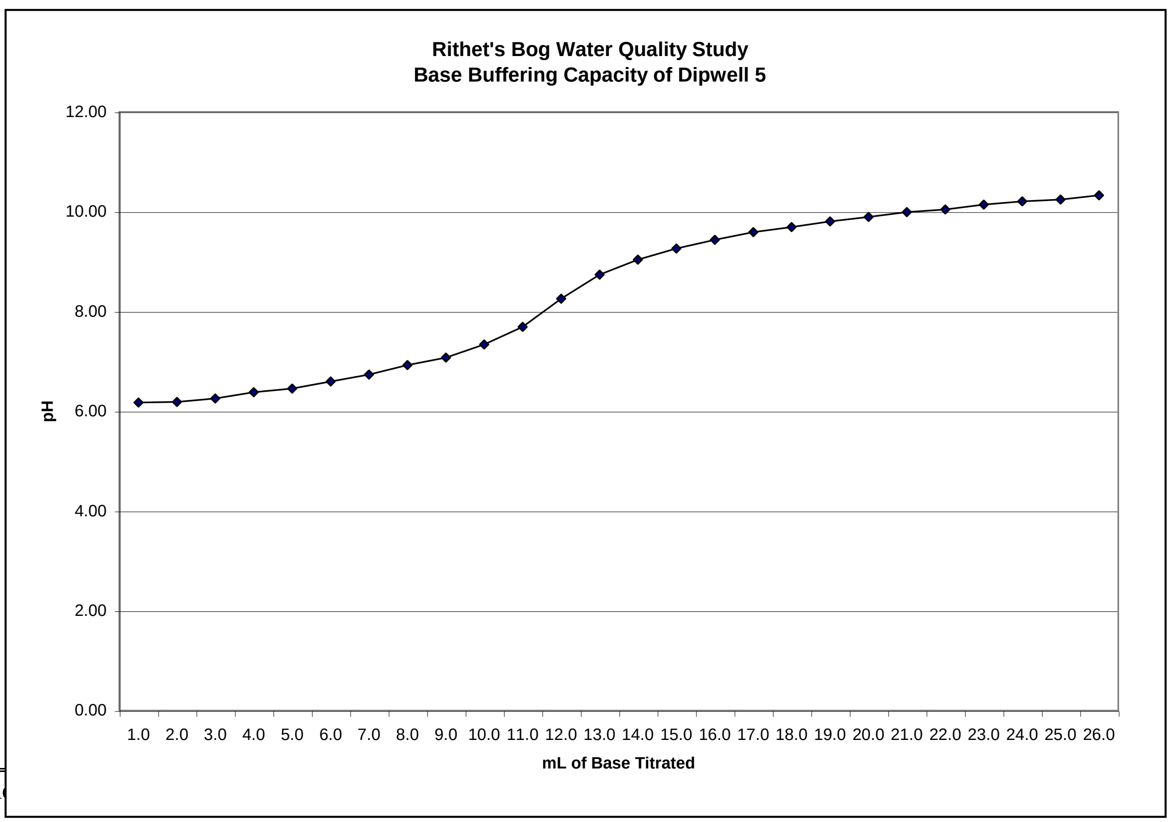

Rithet's Bog Water Quality Study
Acid Buffering Capacity of Dipwell 3
pH
7.00
6.50
6.00
5.50
5.00
4.50
4.00
3.50
3.00
2.50
2.00
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
mL of Acid Titrated

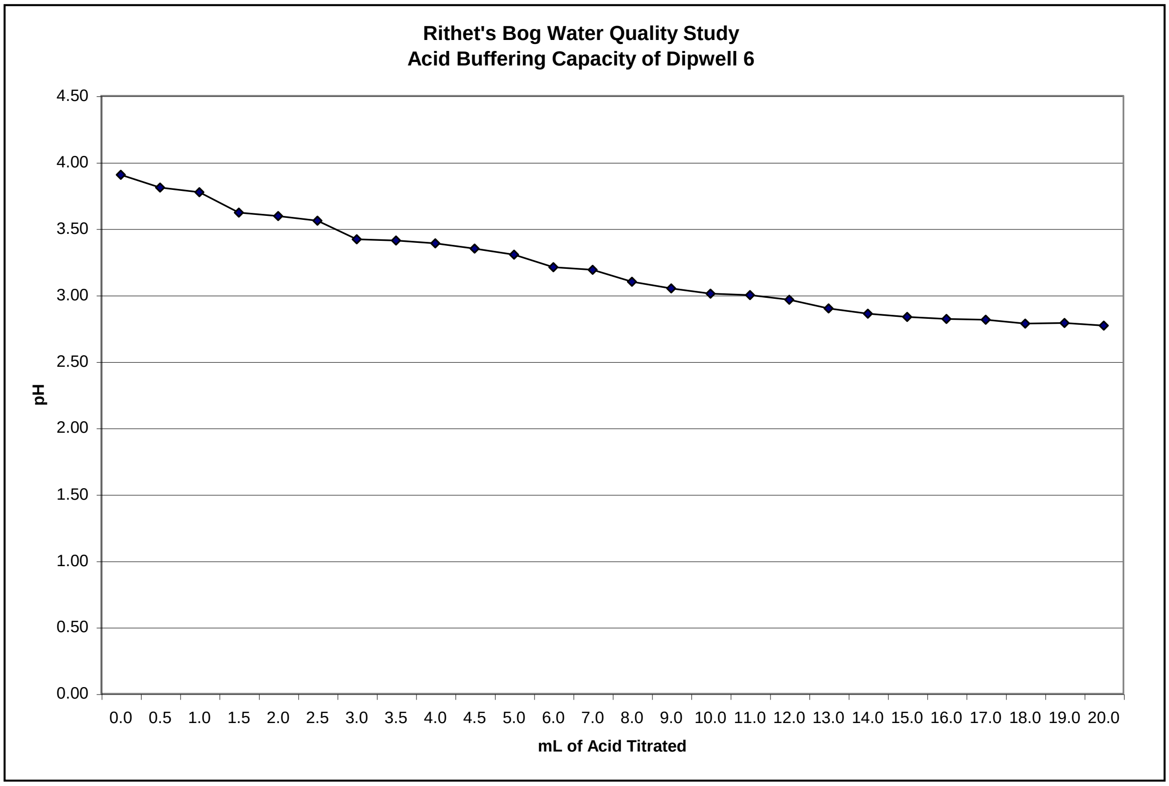

Rithet's Bog Water Quality Study
Base Buffering Capacity of Dipwell 3
pH
12.00
10.00
8.00
6.00
4.00
2.00
0.00
1.0
6.0
11.0
16.0
21.0
26.0
mL of Base Titrated

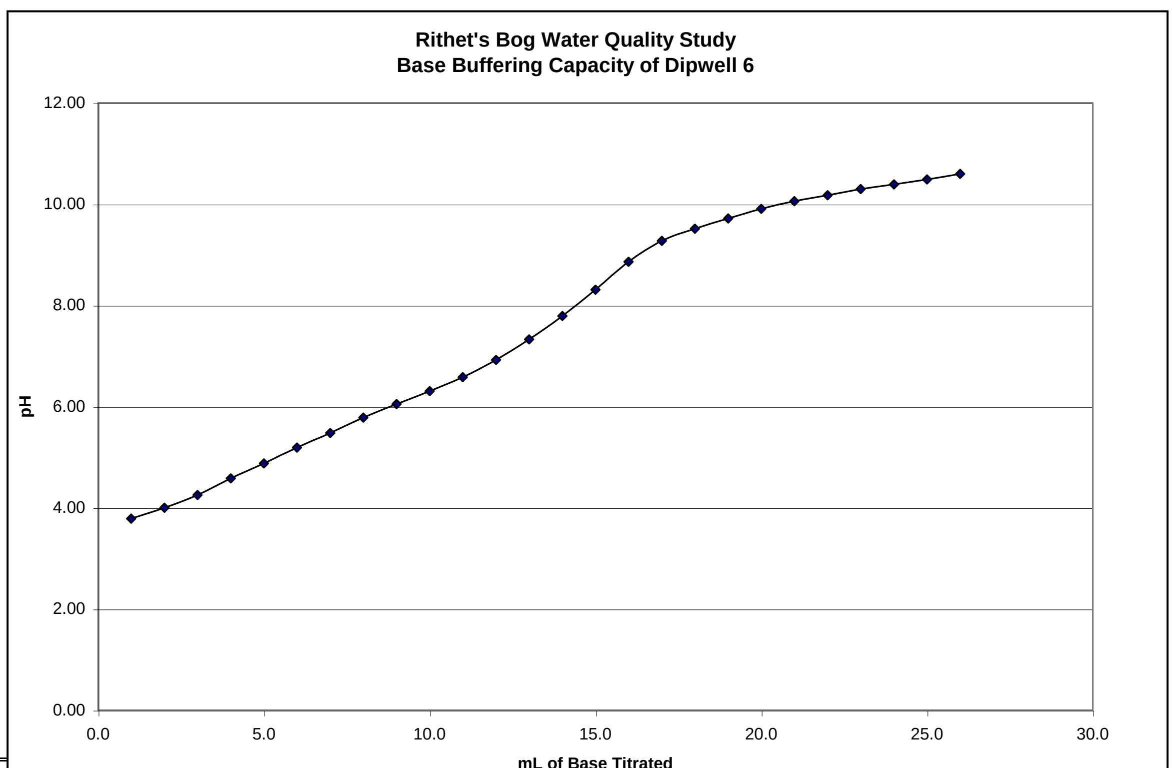

Rithet's Bog Water Quality Study
Acid Buffering Capacity of Dipwell 4
pH
5.00
4.50
4.00
3.50
3.00
2.50
2.00
0.0
1.0
2.0
3.0
4.0
5.0
7.0
9.0
11.0
13.0
15.0
17.0
19.0
22.0
26.0
35.0
mL of Acid Titrated


Rithet's Bog Water Quality Study
Base Buffering Capacity of Dipwell 4
pH
12.00
10.00
8.00
6.00
4.00
2.00
0.00
1.0 2.0 3.0 4.0 5.0 6.0 7.0 8.0 9.0 10.0 11.0 12.0 13.0 14.0 15.0 16.0 17.0 18.0 19.0 20.0 21.0 22.0 23.0 24.0 25.0 26.0
mL of Base Titrated


Rithet's Bog Water Quality Study
Acid Buffering Capacity of Dipwell 5
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
pH
0.0 2.0 4.0 6.0 8.0 10.0 12.0 14.0 16.0 18.0 20.0 22.0 24.0 26.0 28.0 32.0 36.0 45.0
mL of Acid Titrated


Rithet's Bog Water Quality Study
Base Buffering Capacity of Dipwell 5
12.00
10.00
8.00
6.00
4.00
2.00
0.00
pH
1.0 2.0 3.0 4.0 5.0 6.0 7.0 8.0 9.0 10.0 11.0 12.0 13.0 14.0 15.0 16.0 17.0 18.0 19.0 20.0 21.0 22.0 23.0 24.0 25.0 26.0
mL of Base Titrated


Rithet's Bog Water Quality Study
Acid Buffering Capacity of Dipwell 6
pH
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 5.0 6.0 7.0 8.0 9.0 10.0 11.0 12.0 13.0 14.0 15.0 16.0 17.0 18.0 19.0 20.0
mL of Acid Titrated


Rithet's Bog Water Quality Study
Base Buffering Capacity of Dipwell 6
pH
12.00
10.00
8.00
6.00
4.00
2.00
0.00
0.0
5.0
10.0
15.0
20.0
25.0
30.0
mL of Base Titrated

Conclusions

<u>Acid Buffering Capacity</u>

Dipwells 3 and 5 show a reasonable potentiometric curve for which the inflection point is approximately 4.5. Dipwells 4 and 5 both started at a pH lower than 4.5 and show only the lower part of the curve after the inflection point. From these results it was determined that the acid buffering capacity of Rithet's Bog was approximately 4.5. The current characteristics of the ground water in Rithet's Bog oppose a change in pH below 4.5. These conditions will not take place naturally unless there is an extreme ecosystem change and enough *Sphagnum* moss to keep the environment constant.

<u>Base Buffering Capacity</u>

All four dipwells (3, 4, 5 &6) show a potentiometric curve in which the inflection point is approximately 8. This shows that the current ground water conditions oppose a change that raises the pH above 8. The base buffering capacity test was done for interests sake as undisturbed bogs have an acidic pH.

Appendix F

Inflow/Outflow Measurements and Calculations

1. Inflow
2. Outflow
3. Comparison

Inflow Calculations

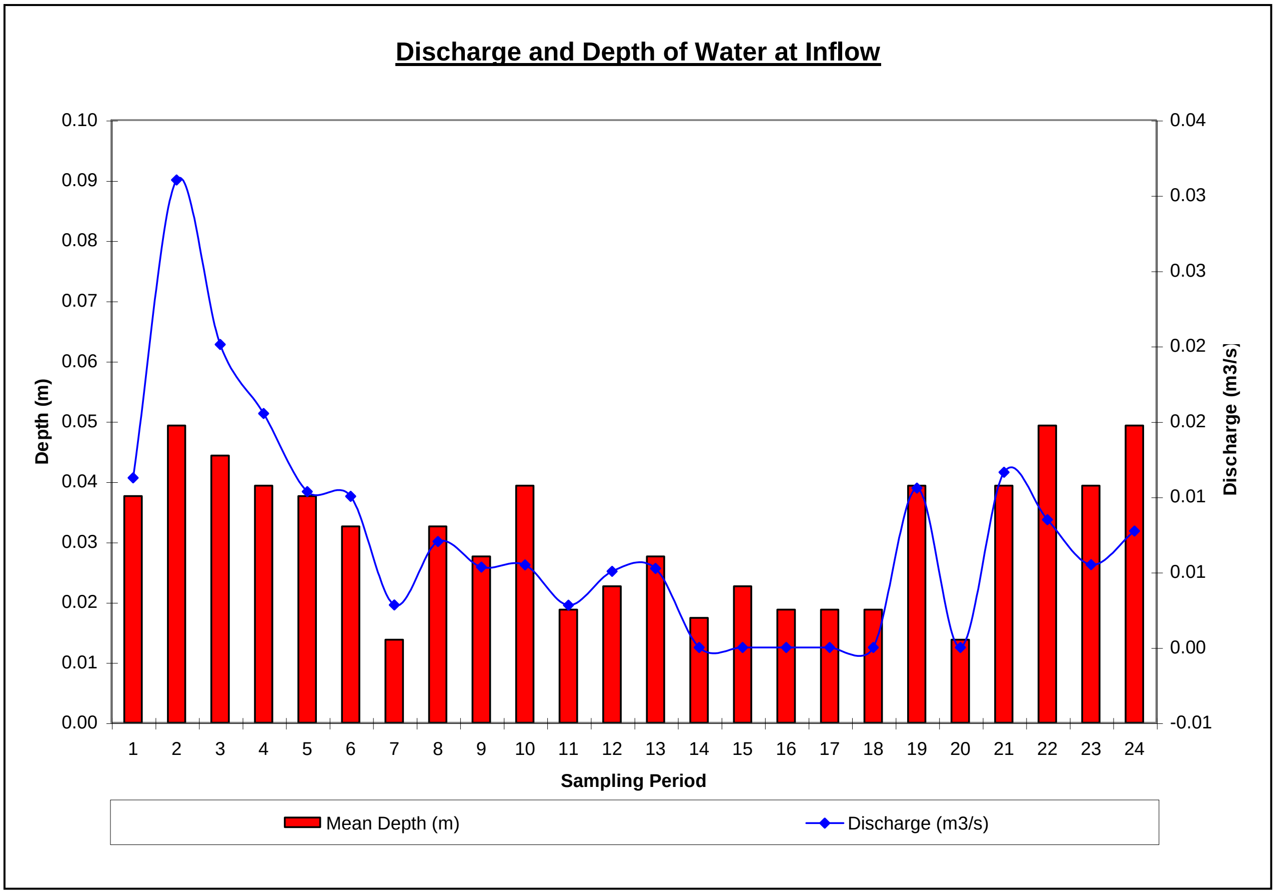
Discharge = 0.75 x Velocity x Wetted Width x Mean Depth

$$\text{Velocity} = \frac{\text{Distance (m)}}{\text{Time (s)}}$$

Date	Distance (m)	Time (s)	Velocity (m/s)	Wetted Width (m)	Mean Depth (m)	Discharge (m^3/s)
01/27/99	10.00	27.45	0.36	1.10	0.04	0.01
02/03/99	10.00	13.95	0.72	1.17	0.05	0.03
02/18/99	10.00	18.94	0.53	1.15	0.04	0.02
03/08/99	10.00	21.27	0.47	1.12	0.04	0.02
03/17/99	10.00	29.88	0.33	1.10	0.04	0.01
03/31/99	10.00	26.08	0.38	1.07	0.03	0.01
04/14/99	10.00	34.40	0.29	0.94	0.01	0.00
04/29/99	10.00	37.23	0.27	1.07	0.03	0.01
05/12/99	10.00	40.76	0.25	1.05	0.03	0.01
05/30/99	10.00	60.32	0.17	1.12	0.04	0.01
06/12/99	9.25	45.75	0.20	0.99	0.02	0.00
06/26/99	6.00	20.79	0.29	1.03	0.02	0.01
07/10/99	5.50	22.83	0.24	1.05	0.03	0.01
07/29/99	7.00	-	-	0.83	0.02	-
08/07/99	7.00	-	-	1.03	0.02	-
08/21/99	7.00	-	-	0.99	0.02	-
08/31/99	7.00	-	-	0.99	0.02	-
09/16/99	7.00	-	-	0.99	0.02	-
10/07/99	7.00	21.87	0.32	1.12	0.04	0.01
10/16/99	7.00	-	-	0.94	0.01	-
10/31/99	7.00	19.89	0.35	1.12	0.04	0.01
11/12/99	7.00	35.74	0.20	1.17	0.05	0.01
11/28/99	7.00	42.15	0.17	1.12	0.04	0.01
12/10/99	7.00	39.20	0.18	1.17	0.05	0.01

Floating object method: Discharge Calculations.

Sandford, H. (1998). Envr. 203: Streams Module. Camosun College Print Shop. Victoria, BC


Discharge and Depth of Water at Inflow
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
Depth (m)
0.04
0.03
0.03
0.02
0.02
0.01
0.01
0.00
-0.01
Discharge (m3/s)
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Sampling Period
Mean Depth (m)
Discharge (m3/s)

Outflow Calculations

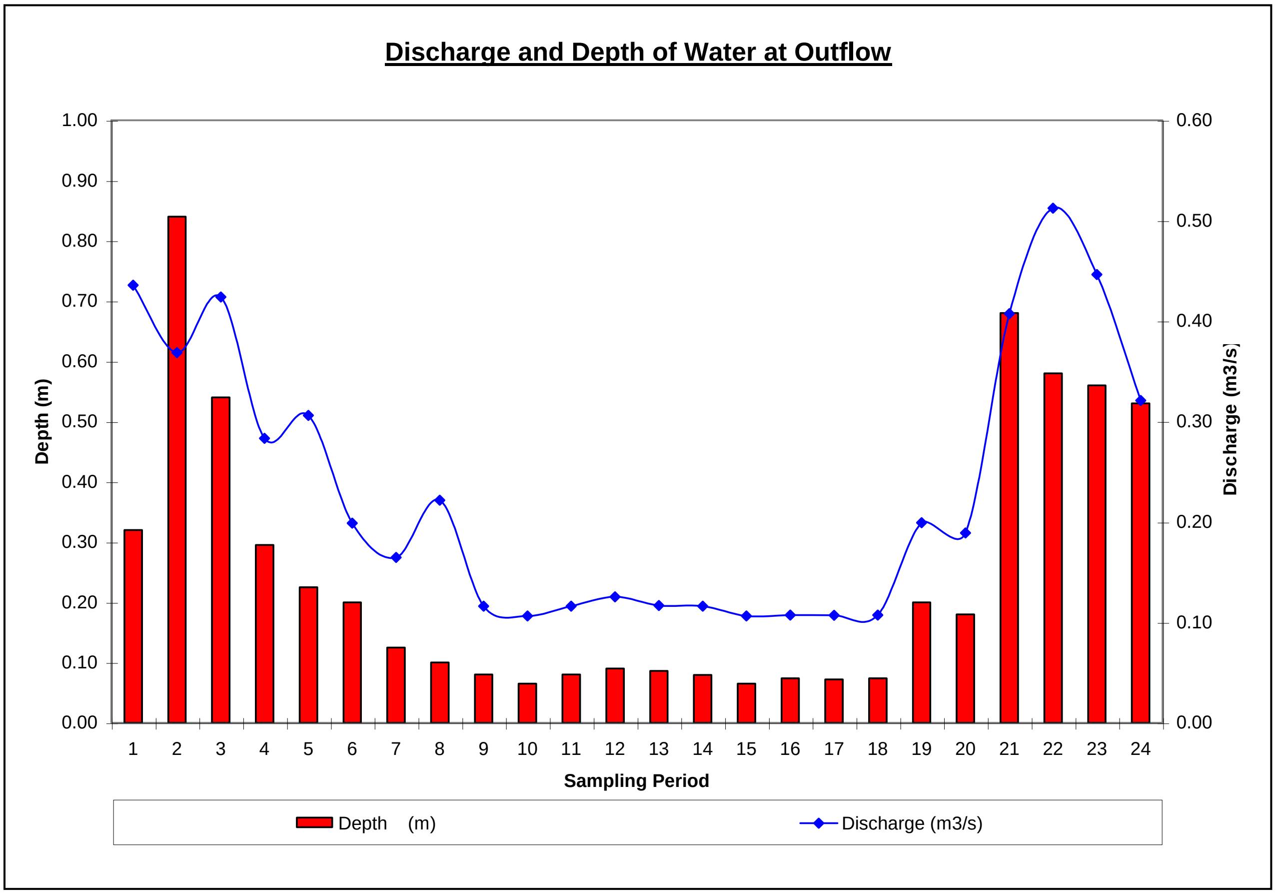
$$\text{Velocity} = \frac{\text{Distance (m)}}{\text{Time (s)}}$$

$$\text{Distance} = \frac{\text{Counts x 26873}}{999999}$$

Date	Trial1	Trial 2	Counts	Distance (m)	Velocity (m/s)	Depth (m)	Height (h)	Cross Section (m^2)	Discharge (m^3/s)
01/27/99	1289	1347	1318	35	0.59	0.32	0.29	0.74	0.44
02/03/99	1050	1258	1154	31	0.52	0.84	0.23	0.71	0.37
02/18/99	1483	1540	1512	41	0.68	0.54	0.07	0.63	0.42
03/08/99	866	827	847	23	0.38	0.30	0.32	0.75	0.28
03/17/99	968	821	894	24	0.40	0.23	0.39	0.76	0.31
03/31/99	545	612	579	16	0.26	0.20	0.41	0.77	0.20
04/14/99	471	496	484	13	0.22	0.13	0.49	0.76	0.16
04/29/99	705	611	658	18	0.29	0.10	0.51	0.75	0.22
05/12/99	345	354	350	9	0.16	0.08	0.53	0.74	0.12
05/30/99	0	0	325	9	0.15	0.07	0.55	0.73	0.11
06/12/99	0	0	350	9	0.16	0.08	0.53	0.74	0.12
06/26/99	0	0	375	10	0.17	0.09	0.52	0.75	0.13
07/10/99	0	0	350	9	0.16	0.09	0.52	0.74	0.12
07/29/99	0	0	350	9	0.16	0.08	0.53	0.74	0.12
08/07/99	0	0	325	9	0.15	0.07	0.55	0.73	0.11
08/21/99	0	0	325	9	0.15	0.07	0.54	0.74	0.11
08/31/99	0	0	325	9	0.15	0.07	0.54	0.74	0.11
09/16/99	0	0	325	9	0.15	0.07	0.54	0.74	0.11
10/07/99	0	0	580	16	0.26	0.20	0.41	0.77	0.20
10/16/99	0	0	550	15	0.25	0.18	0.43	0.77	0.19
10/31/99	1427	1476	1452	39	0.65	0.68	0.07	0.63	0.41
11/12/99	1864	1934	1899	51	0.85	0.58	0.03	0.60	0.51
11/28/99	1576	1668	1622	44	0.73	0.56	0.05	0.61	0.45
12/10/99	1128	1139	1134	30	0.51	0.53	0.08	0.63	0.32

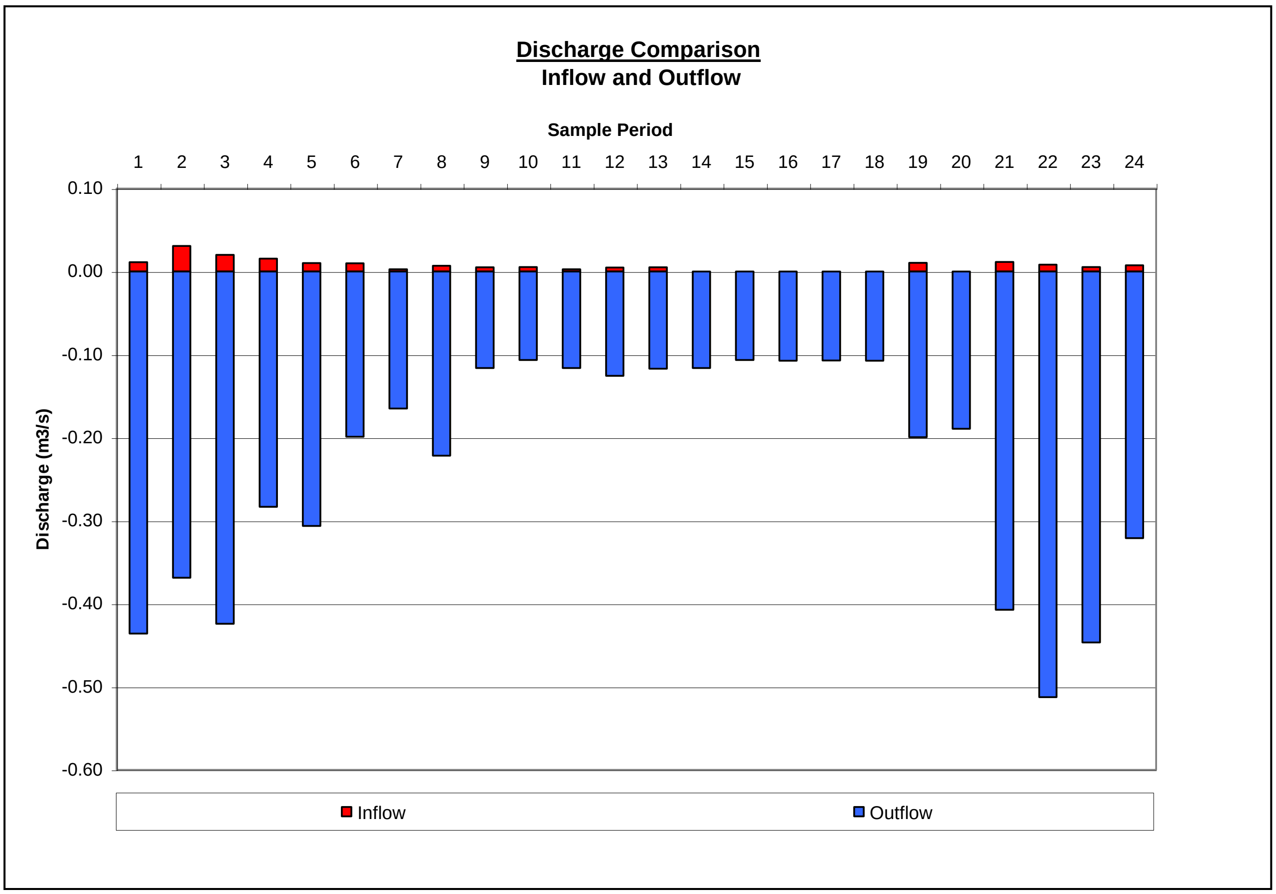
Current meter method: Discharge Calculations.

Sandford, H. (1998). Envr. 203: Streams Module. Camosun College Print Shop. Victoria, BC


Discharge and Depth of Water at Outflow
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Depth (m)
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Discharge (m3/s)
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Sampling Period
Depth (m)
Discharge (m3/s)

Comparison Calculations

Date	Inflow	Outflow	Inflow	Outflow	Difference
01/27/99	0.01	0.44	0.01	-0.44	0.45
02/03/99	0.03	0.37	0.03	-0.37	0.40
02/18/99	0.02	0.42	0.02	-0.42	0.44
03/08/99	0.02	0.28	0.02	-0.28	0.30
03/17/99	0.01	0.31	0.01	-0.31	0.32
03/31/99	0.01	0.20	0.01	-0.20	0.21
04/14/99	0.00	0.16	0.00	-0.16	0.17
04/29/99	0.01	0.22	0.01	-0.22	0.23
05/12/99	0.01	0.12	0.01	-0.12	0.12
05/30/99	0.01	0.11	0.01	-0.11	0.11
06/12/99	0.00	0.12	0.00	-0.12	0.12
06/26/99	0.01	0.13	0.01	-0.13	0.13
07/10/99	0.01	0.12	0.01	-0.12	0.12
07/29/99	-	0.12	0.00	-0.12	0.12
08/07/99	-	0.11	0.00	-0.11	0.11
08/21/99	-	0.11	0.00	-0.11	0.11
08/31/99	-	0.11	0.00	-0.11	0.11
09/16/99	-	0.11	0.00	-0.11	0.11
10/07/99	0.01	0.20	0.01	-0.20	0.21
10/16/99	-	0.19	0.00	-0.19	0.19
10/31/99	0.01	0.41	0.01	-0.41	0.42
11/12/99	0.01	0.51	0.01	-0.51	0.52
11/28/99	0.01	0.45	0.01	-0.45	0.45
12/10/99	0.01	0.32	0.01	-0.32	0.33



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