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Sustainable phosphorus management of horse paddocks at Julmyra

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Cover: Horse paddocks at Julmyra Horse Center, 2012. Photo by author.

Abstract

Horse keeping is gaining an increasing interest in Sweden. During 2004 to 2010 the number of horses increased with 10 - 20 %, and was estimated to be 362 700 in 2010. Julmyra Horse Center (JHC), situated in Heby municipality, is a gated community for people sharing a large interest for horses and a vision of a sustainable horse management has been formulated. This study evaluates how the horse keeping of today at JHC, and how an expansion of the horse keeping may affect the risk of enhanced phosphorus load to the nearby lake system Vansjön – Nordsjön. The risks associated with outdoor horse keeping are an accumulation of phosphorus in the soil profile caused by dung deposition and roughage residues, and treading damages, that might contribute to eutrophication. The soils in the area are mainly lowland soils with high humus content. The mineral fractions are dominated by sand, sandy loam and moraine. There are no regulations regarding livestock densities for outdoor horse keeping in Sweden, but maximum 2-10 horses/hectare is recommended in order to retain a vegetation cover in paddocks. The livestock density at JHC today is 17.5 horses per hectare, causing treading damages in most paddocks. The paddocks receive approximately a yearly input of 38 – 53 kg P/hectare with the current horse density. The soil phosphorus status in most of the paddocks (P-AL) was low to moderate, 4.2 – 7.9 mg/100 g soil. However, in areas where an accumulation of phosphorus by dung deposition had occurred over a long period of time, and for a loose housing system the P-AL values were higher (17.7 and 16.3 mg/100 g soil). In these areas, the values of phosphorus sorption capacity in the soil were low or moderate (1.1 and 4.5) and the degree of soil phosphorus saturation quite high (up to 22.0 %). It was concluded that there is a continuous accumulation of phosphorus in the horse paddocks which is not sustainable in the long-term. In order to make the paddock management at JHC sustainable suggested countermeasures are increased paddock areas, cleaning of dung and roughage residues and establishment of grass vegetated buffer strips between paddocks and the watercourse.

Keywords: Julmyra Horse Center, phosphorus losses, phosphorus accumulation, eutrophication, horse paddock, outdoor horse keeping, horse manure management

Sammanfattning

Julmyra Horse Center (JHC) är ett hästsportsamhälle i Heby kommun, Uppsala län, som omfattar 250 hektar mark. På JHC finns hästsportanläggningar i form av stall, travbana, ridhus m.m. och också boendemöjligheter. Julmyra Horse Center har en vision om en hållbar hästhållning. I dagsläget finns det 105 hästar på området men det finns planer på att utöka till 500 hästar. I samband med en utökad hästverksamhet planeras även utökad byggnation med konceptet ”gård på gården”, som innebär avstyckning av mark på 2-5 hektar där bostadshus samt stall kan uppföras.

Ett stort antal hästar samlat på en begränsad yta kan komma att påverka miljön på ett negativt sätt om hästhållningen inte är hållbar. Det som främst kan orsaka problem är gödselhantering, av både stallgödsel och gödsel i rasthagar. I detta fall ligger hästanläggningen uppströms sjösystemet Vansjön- Nordsjön som är påverkat av övergödning. Övergödning i sjöar orsakas av tillförsel av växtnäring, framförallt fosfor, och oro finns för att en utökad hästverksamhet kan komma att påverka sjösystemets ekologiska status. Främst är det fosforläckage från rasthagarna som utgör en risk. När det gäller hantering av gödsel i stallen har JHC redan en fungerande stallgödselhantering i form av containersystem.

Av områdets 250 hektar utgör ca 6 hektar rasthagar till de 105 hästarna, vilket ger ett djurtryck på 17,5 hästar per hektar. Det är ett djurtryck som ligger högt över Jordbruksverkets rekommendationer. Ett för högt antal hästar leder till att marken i rasthagarna blir upptrampad och att det då inte finns ett sammanhängande växttäcke som kan ta upp växtnäringen från hästgödseln och skydda mot jorderosion. Genom att hagarna ligger längs bäcken som går genom området finns därmed en direkt risk för belastning av växtnäring och jordpartiklar. I arbetet gjordes en fosforbalans och fosforbelastningen på hagarna uppskattades. Jordprover togs för att undersöka markens fosforinnehåll och förmåga att binda fosfor som tillförs med gödseln. Beräkningarna indikerar en hög fosforbelastning som kan innebära ökad risk för förluster av fosfor. Samtidigt visar jordprovtagningen att marken, förutom i två identifierade riskområden, har relativt låg fosformättnadsgrad och förmåga att binda fosfor. Där utgör dagens tillförsel av fosfor ingen större läckagerisk, men kan på sikt leda till problem. Riskområdena, där fosforinnehållet i marken var högt, och förmågan att binda ytterligare fosfor nedsatt, var platser med stor belastning av gödsel under lång tid. De åtgärder som rekommenderas för att JHC ska uppfylla sin vision om en hållbar hästhållning är att mocka ut gödsel och foderrester från rasthagarna, samt att utöka antalet rasthagar för att minska djurtrycket. Detta för att fosforbelastningen inte ska bli ett problem i form av ökat läckage i framtiden. Dessutom behövs etablering av skyddszoner mot bäcken för att förhindra ytavrinning från hagarna under perioder med regn eller snösmältning.

Table of contents

1 Introduction

The number of horses in Sweden is increasing. In 2010, the number of horses was estimated to 362 700, which corresponds to an increase of 10 - 20 % since 2004 (SBA a, 2011). Approximately 500 000 people in Sweden are active in the horse businesses for reasons such as exercise, recreation, horse breeding and/or sports of different kind.

Sweden has assigned environmental objectives with the overall goal to solve our major environmental problems and to reach ecologically sustainable development. Environmental objectives that are related to horse keeping, and therefore of importance in this context, are *A varied agricultural landscape*, *Zero eutrophication* and *Flourishing lakes and streams* (SEPA, 2012). Keeping an open landscape is important for the biodiversity, and a varied agricultural landscape with a sustainable outdoor horse keeping can provide positive effects for those purposes since horse keeping has become more and more important, as the grazing cattle is decreasing. Zero Eutrophication is an environmental objective including that lakes and streams should meet the requirements of nutrient levels for a good ecological status within the year of 2015, as defined in the Water Framework Directive (Directive 2000/60/EC). Flourishing lakes and streams is another environmental objective concerning a sustainable ecology and preservation of the variety of habitats. This means that surface water bodies should achieve good water surface status no later than 2015 with respect of the biodiversity and the chemical and physical conditions, as defined in the Water Framework Directive (Directive 2000/60/EC).

Julmyra Horse Center (JHC), situated in Julmyra in Heby municipality, is a gated community for people sharing a large interest for horses and a vision of a sustainable horse management (JHC, 2012). Julmyra Horse Center is organised as a private company, Julmyra Horse Center AB, equally owned by Julmyra Förvaltning AB and Sala Sparbank. Julmyra Horse Center provides different kind of horse facilities such as a racecourse, stables, racetracks, drill-halls, riding trails etc. In the activities of today, Julmyra facilitates 105 horses but intends to expand in a near future. The landscape surrounding Julmyra is mostly hilly forest areas and patches with arable land, marshland and small lakes. The lake system Vansjön-Nordsjön (EU_CD: SE665056-156386) is the final recipient in the sub-drainage area for the watercourse Julmyrabäcken, which runs through the JHC area. The ecological status for Vansjön-Nordsjön is modest; meaning that the lakes are affected by eutrophication. Limnological investigations of Vansjön-Nordsjön have been conducted at three occasions (Olevall & Vesterberg 1998, Carlsson, 1999). In the case of Vansjön – Nordsjön the County Administrative Board has stated that it is technically impossible to reach the goal of good environmental status within the year of 2015 and a respite has been given until 2021 (VISS, 2009).

Land use in the catchment for Vansjön-Nordsjön that may pose a risk of nutrient losses to the water environment leading to eutrophication are emissions related to sewage from households in the area, nutrient losses from arable land including horse keeping and leaching from deforestation (Ridderstople, 2008). *Vansjön-Nordsjöns Väl* is an organization founded by residents around Vansjön-Nordsjön, with the aim to protect and preserve the lake system (www.vnval.se). Their concern is that an increased horse population at JHC may have negative effects on the ecological status of the lakes, where the phosphorus load poses a major risk. The potential sources of phosphorus leakage from horse keeping are the outdoor keeping and manure management.

2 Objectives

This study evaluates how the horse keeping of today affects, and how an expanding horse keeping at Julmyra Horse Center (JHC) may affect, the risk of increased eutrophication of nearby lakes. The main objective is to contribute to development of strategies for how to reduce the risk of negative environmental impact from the planned expansion of JHC. This study will also be included as a part of the development of an overall environmental plan for a sustainable horse management at JHC.

3 Literature review

3.1 Horse keeping and manure management

3.1.1 Legal frameworks

The manure storage capacity demanded according to legal frameworks depends on the number of horses and on the location (SBA, 2011). Julmyra is not located in a nitrate sensitive area, and follows therefore the general regulations for Sweden, the regulations for the minimum storage capacity are shown in Table 1. Stables with up to ten horses are not concerned with the regulations, nevertheless the manure storage has to be constructed to prevent nutrient leaching to surface and subsoil water that may harm the environment or human health.

The regulation for spreading horse manure is the same as for other types of solid manures. The legislation for spreading of manure on arable land is 22 kg P/ha/year as an average during a five year period (SBA, 2011).

Information of removed and received manure have to be documented and kept for at least six years, the documentation must contain date, amount, type of manure, provider and receiver, the amount of phosphorus in the manure or the number of animals the manure correspond to (SBA, 2011). With less than ten horses on a yearly basis the provider have no obligation to document removal of manure however the receiver have to document when receiving manure.

Table 1. *Time regulations for required storage of manure in non-nitrate sensitive areas of Sweden (SBA, 2011)*

Number of horses	**Storage capacity (months)**
0 to 2	No general regulations
> 2 to 10	No general regulations
> 10 to 100	6
> 100	8

3.1.2 Nutrient content in horse manure

Table 2. *Standard values for the amount of phosphorus excreted yearly in horse manure (SBA, 2011)*

Type of horse	Secreted amount of P per year (kg)
Horse	8.9
Pony (300 kg)	6.4

Nutrient content in horse manure depends mainly on three factors; feeding plan, training intensity of the horse and the horses age. Full grown horses excrete the same amount of nutrients that is taken up by the fodder. Young horses take up more nutrients as they are growing and lactating mares take up as much as the milk contains. A 500 kg horse produces approximately 8-10 tons of manure per year, giving a daily manure production of 20-30 kg. A small horse produces from 8 tons down to only a few. The heterogeneity of horse manure makes it difficult to obtain a representative sample, and therefore the nutrient content is best calculated from the feeding plan. (Steineck et al. 2000). However the Swedish Board of Agriculture has standard values that can be used for estimations of phosphorus amount in horse manure (Table 2) and a study by Caselles et al. (2002) found that the average value of total phosphorus content was 7.6 (6.1 - 9.3) g kg-1 dry weight of manure.

3.1.3 Risks associated with horse keeping

In Swedish outdoor horse management, horses are often kept in small fenced-off areas near the stables (Parvage et al. 2011). The risk associated with outdoor horse keeping is partly due to the accumulation of phosphorus in the soil profile caused by dung deposition and roughage residues, and partly due to treading damages. Accumulation of phosphorus increases the potential risk for losses to drainage water (Sharpley et al. 1997). Sanderson et al. (2010) found that areas with high livestock densities are likely to be point sources of nutrient pollution and degradation of soil and vegetation. Intensive treading causes plant damage and decreased vegetation cover and increases the risk for surface runoff of particle bound phosphorus to surface waters. Treading may also cause soil compaction and loss of soil structure that can lead to decreased infiltration capacity and an increase of surface runoff of water, nutrients and faecal coliforms. The result is decreased water quality in the catchment area (Singleton el al. 2000; Taddese et al. 2002). Surrounding vegetation may however buffer the effect of treading damages and high nutrient deposition and function as a filter for surface runoff if not directly connected to a watercourse (Sanderson et al. 2010).

In a study of 30 outdoor areas in southern and western Sweden (Dahlin & Johansson, 2008) the effect of animal pressure varied depending on the type of sub-area, where feeding areas and dung areas had a strong increase in soil mineral nitrogen content. The increased phosphorus accumulation could be prevented with dung clearing. The positive effect of dung clearance on phosphorus is due to that the dung contains most of the phosphorus, whereas the major part of the nitrogen is present in the urine. The extent of the outdoor feeding showed significant correlation with nitrogen and phosphorus amounts in the soil. However this effect was not limited to the feeding areas but in general, horses consume fodder and deposit it in other sub-areas of the paddock. The soil nutrient content was highest in general for paddocks and in loose housing systems. In another study by Airaksinen et al. (2007) where the runoff water from a cleaned paddock and an uncleaned paddock was analysed after seven months, the runoff from the uncleaned feeding area had phosphorus contents that were fifty times higher than the starting values. Other areas of the paddock had values ten times higher than from the start. And the uncleaned feeding area in the paddock had phosphorus contents three times higher than the in the cleaned paddock. Parvage et al. (2011) compared paddock soils with arable land and found that the concentration of extractable phosphorus was higher in the paddocks than in arable land, and that the degree of phosphorus saturation was also higher for the paddocks. Paddocks that were located close to the stable had higher phosphorus and organic carbon content than paddocks located further away. For practical reasons, horses are often held in paddocks close to the stable and therefore these areas receive larger amounts of dung that can explain the higher values. This might also be due to a very long history of livestock keeping on the farm.

Deposition of dung on wet soil may result in a rapid transport of phosphorus on the soil surface and/or downwards, especially if precipitation occurs (McGechan et al. 2005). Generally, phosphorus losses from dung deposition are low during relatively dry soil conditions. The losses during very wet conditions are often dominated by particle-bound phosphorus which is mainly lost through preferential flow when the macropores are water filled. During dry soil conditions colloid sorbed phosphorus are most likely to become trapped due to that only the micropores are water filled. Phosphorus has low solubility and high sorbability, and therefore soluble phosphorus losses tend to be low. The environmentally harmful quantities of phosphorus losses transported from livestock catchment to water systems seem therefore to be colloid or particle sorbed phosphorus through macropore flow.

3.1.4 Outdoor feeding of roughage

There is a lack of knowledge about feeding racks adopted for horses. The horse is a grazing herbivore that can graze continuously for several hours. In the wild, or with free access to roughage, the horse is using 12 - 14 hours per day for grazing (Johansson, 2007). The natural grazing position for a horse is with one foreleg in front of the other, and the horse grazes near this leg. A feeding rack can obstruct this natural position, if not properly constructed (Ventorp & Michanek, 2001). Feeding on the ground enables the horse to graze in the natural position but increases the risk for hygienic quality problems due to contamination of the roughage by soil, manure, urine and parasites (Johansson, 2007). An experiment of feed racks for horses by Johansson (2007) concluded that today none of the feeding racks are adopted for outdoor feeding of roughage to horses.

3.1.5 Recommendations for horse paddock management

The Swedish Board of Agriculture have recommendations for paddock size with respect to production of fodder and for reduction of treading damages, since a vegetation cover can bind the soil and prevent losses of soluble nutrients and erosion of soil particles (SBA, 2013). The recommended area vary depending on grass production and the utilization of the paddocks, 0.3 to 1.5 ha of pasture is needed for feeding of a horse during the summer period. If the horse is not feed with extra roughage during pasture, all the nutrients taken up by the horse will be returned in the manure. There will be a concentration of nutrients in small areas but the vegetation can utilize most of the nutrients, resulting in a good nutrient recirculation. A paddock without vegetation cover cannot prevent nutrient loss in the same way. The manure in such paddocks should therefore regularly be taken away to manure piles. The size required for a paddock to maintain the vegetation cover depends on soil characteristics, time of ground frost and how the paddocks are utilized. A rule of thumb is 0.1-0.5 ha per horse (SBA, 2006). Pasture rotation is important for the recovery of vegetation cover and for preventing parasites. A rotation of outdoor fodder areas in the paddock is also important due to nutrient losses from fodder and that the vegetation cover needs to recover. Another option is surface reinforcements where manure and fodder can be taken away. In natural pastures there should be no extra feeding for the protection of the biological diversity.

3.2 Phosphorus in the soil

3.2.1 Phosphorus forms and sorption-desorption processes

The natural occurring phosphorus content of a soil depends on the soil parent material and the degree of weathering (Smeck, 1985; Börling, 2003). The primary mineral apatite is the major source of soil phosphorus and through weathering primary phosphates are released into the soluble phosphorus pool. The soluble phosphorus is then either transformed into inorganic or organic phosphorus forms. The inorganic forms consist of secondary phosphorus minerals, the labile phosphorus pool and dissolved phosphorus in the soil solution. The organic phosphorus is formed by production of biomass through plant uptake. Parts of the biomass is annually degraded and either immobilized or mineralized by the microorganisms. The degradation results in accumulation of organic material and organic phosphorus. Organic phosphorus consists in many forms in the soil and all of them are not known. The most common of the identified forms are mono- and diesters of orthophosphate. The most common esters are inositol phosphate, phospholipids and nucleic acids. The mineralized phosphorus is returned to the soluble phosphorus pool. Soil is a dynamic system in a continuous state of transformations. Reactions from secondary phosphorus minerals to soluble phosphorus are slow and an equilibrium state is rarely reached. An equilibrium state is more rapidly established between the labile phosphorus pool and the soluble phosphorus.

The main part of soil phosphorus occurs in the non-labile forms of primary and secondary minerals, occluded phosphorus and stabilized organic phosphorus which is unavailable for plant uptake. The non-labile forms are only made available through dissolution or mineralization. The secondary minerals include minerals with phosphorus chemisorbed to their surfaces, commonly with iron (Fe) and aluminium (Al) oxides and carbonates. When secondary phosphorus minerals are formed, the pH-status of the soil influences what kind of minerals that are being formed. In acid soils mainly minerals of Al- and Fe-phosphates are formed and in neutral to alkaline soils, calcium (Ca) phosphates are dominating (Smeck, 1985; Börling, 2003; SEPA, 2005). Occluded phosphorus is secondary phosphorus minerals that are encapsulated by Fe- and Al-oxides or by other minerals. There is a geological timeframe for the transformation of primary phosphorus minerals to occluded phosphorus (Smeck, 1985).

The labile phosphorus pool is smaller than the non-labile pool (Smeck, 1985; Börling, 2003). It consists of phosphorus sorbed to the surface of oxides, hydroxides and clay particles and to some extent also of organically bound phosphorus. The labile phosphorus pool and dissolved phosphorus in the soil solution is in equilibrium. The dissolved phosphorus in the soil solution is the minor phosphorus pool and the only pool directly available for plant uptake. In the soil solution the dissolved phosphorus consists mainly of HPO42- and H2PO4- in the pH range 4 -10. As the dissolved phosphorus content in the soil solution decreases either due to plant uptake, immobilization of microorganisms or through leakage during the season it needs to be refilled with phosphorus from the labile phosphorus pool. When the soluble and labile phosphorus pools becomes undersaturated they will continuously be refilled with phosphorus originating from primary and/or secondary phosphorus minerals. Weathering of soils due to decreasing pH favours formations of Fe- and Al-phosphorus minerals as their solubility decreases, resulting in decreasing pools of soluble and labile phosphorus pools.

3.2.2 Paths of phosphorus losses

The key factor for phosphorus losses is the soil hydrology. In the movement of phosphorus from soil to water a number of processes are involved (SEPA, 2005). The driving force in the transport of plant nutrients is the precipitation surplus. The infiltration capacity of a soil depends on the soil material and structure (Eriksson et al. 2005). The transport occurs partly through the soil profile to drainage systems or to ground water and partly as surface runoff to ditches or streams. Surface runoff occurs when the rain intensity exceeds the infiltration capacity of the soil or when the soil water storage is full and water cannot infiltrate (SBA, 2008). In an unsaturated soil, the micropores are water filled while the macropores are air filled. In a saturated soil, also the macropores are water filled and surface runoff can emerge (Eriksson et al. 2005). The movement of water in the soil depends partly on the hydraulic conductivity of the soil which differs for different soils. The drainage of a coarse-textured soil is faster than of a fine-textured soil (SBA, 2008). On the other hand, clay and loam soils often have a structure with macropores which may provide fast transport pathways for phosphorus. Therefore, soils dominated by clay or silt have high risk of phosphorus losses (Ulén & Jakobsson, 2005).

Phosphorus in the soil solution can occur in dissolved form (organic or inorganic) or bound to particles, and the transformation processes can be biological, physical or chemical. Knowledge about the various phosphorus forms and how they transform are important for understanding the relationship between land management and its environmental effects on water (SEPA, 2005). If the inputs of phosphorus exceed the output of phosphorus by plant uptake, harvests, grazing and losses to water, phosphorus will accumulate gradually on sorption sites in the soil and will gradually decrease the adsorption capacity of the soil. The amount of dissolved phosphorus in the soil solution will consequently increase as well as the risk of losses through surface runoff or subsurface flows.

In risk assessment of phosphorus losses the entire soil profile should be included together with landscape position and connectivity to surface waters to include all processes involved in phosphorus mobilization and transport (Ulén & Jakobsson, 2005). To be able to identify high risk soils for phosphorus losses it is important to understand and quantify hydrological pathways within the soil and those related to topography, e.g. slopes.

3.3 Methods for examination of soil phosphorus

3.3.1 Phosphorus sorption index (PSI)

A soils phosphorus sorption capacity is affected by the chemical properties of the soil, the phosphorus content, previous phosphorus fertilizations and land use. The amorphous aluminium oxides content is an important factor for the sorption capacity (Bloom, 1981; Borggaard et al. 1990; Börling et al. 2001). The phosphate adsorption can indirectly be affected by organic matter due to decreasing aluminium oxide crystallinity, and thereby increase the reactivity and phosphorus sorption capacity of the soil (Borggaard et al. 1990). The adsorption capacity of phosphorus increases with increasing concentrations of Al, Fe or clay. The pH value also affects the adsorption ability, which increases at very low (sorption to Fe- and Al hydroxides) or very high pH (sorption to Ca oxides) values. In Swedish soils, Al is defined as the factor with the largest impact of phosphorus adsorption. Accumulation of phosphorus in a soil with low adsorption capacity will increase the amount of phosphorus in the labile pool that may lead to an increased loss of phosphate phosphorus to the environment. As sorption sites becomes phosphorus saturated the phosphorus desorption increases (SEPA, 2005). Phosphorus sorption index (PSI) is a way to quantify the phosphorus sorption capacity of a soil. In this method, an excessive amount of phosphorus is added to a soil sample which is mixed with water. After an equilibrium is reached the adsorption is measured, i.e. the reduction of phosphorus concentration in the solution. This is a quick method to evaluate if the soil is approaching phosphorus saturation. Adsorption index (PSI) can be expressed as the amount of adsorbed phosphorus divided with the logarithm for equilibrium concentration, PSI = X/log C (mmol kg-1 soil) (Bache & Williams, 1971; Börling et al. 2001).

3.3.2 Degree of phosphorus saturation (DPS)

The degree of phosphorus saturation (DPS) can be explained as the percentage of a soil´s phosphorus adsorption capacity already occupied by phosphorus. Since the amount of Fe and Al hydroxides are important factors for the soil phosphorus sorption the DPS is calculated as the ratio between P-AL and Al-AL and Fe-AL on a molar basis (Ulén, 2006). The critical saturation threshold is the DPS value that indicates an increased loss of phosphorus. Different critical thresholds have been reported and for example 25 % in the Netherlands and 30 % in Belgium. However, it is not completely appropriate to use these thresholds for other soil types (Beauchemin & Simard, 1999; Liu et al. 2012), but it might give an indication.

3.3.3 P-AL method

Since the beginning of the 1960ies the method generally used in Sweden to evaluate the more or less soluble phosphorus is based on the extraction method with ammonium lactate (P-AL). There are several ways to evaluate the bioavailable part of soil phosphorus. Common for the different methods is that the soil is treated with a more or less strong chemical adapted for the soil pH conditions. The extraction solution used with the P-AL method has a pH of 3.75 and this has shown to work well for most of the Swedish soils. Soils are classified regarding the P-AL value based on agronomic crop requirements (Table 3). It is generally accepted that phosphorus is most bioavailable within the pH range of 6 to 7. The fertilizing effects of amended phosphorus decreases with a rising P-AL value and at P-AL values over 8 mg/100 g soil the obtained effects is small (Mattsson et al. 2002). In phosphorus leaching assessment, soil extraction with the AL method is commonly used as an indicator since P-AL contents have been found to be positively related to the phosphorus concentrations in drainage water (Ulén, 2006).

Table 3. *Classification of extractable phosphorus based on the P-AL method (Eriksson et al. 2010)*

Phosphorus class	P-AL (mg/100 g soil)
I	< 2.0
II	2.0 – 4.0
III	4.1 – 6.0
III	6.1 – 8.0
IVA	8.1 – 12.0
IVB	12.1 – 16.0
V	> 16.0

3.4 Measures to prevent losses of phosphorus

The most important measure for preventing phosphorus losses is to minimize the source of leakage. The source of phosphorus losses in horse paddocks are mainly dung and roughage, but can also be due to loss of soil particles when the soil surface is damaged. When minimizing the source is not sufficient, other measures close to the source need to be taken.

3.4.1 Custom rations

The amount of nutrients in the manure is related to the nutrient intake by feeding and therefore a well-planned ration is important in order to avoid excessive feeding (SBA, 2008).

3.4.2 Cleaning of paddocks

Manure is one of the phosphorus sources in horse paddocks and therefore should the dung should be cleared away in high pressure areas as was suggested by e.g. Dahlin & Johansson (2008). The cleaning can be performed traditionally by hand or by for example a muck-truck. The muck-truck paddock vacuum cleaner (www.wiklundtrading.com) is constructed for cleaning of horse paddocks. A hose vacuum transports the manure to a container with a capacity of 350 litres. The manure vacuum attachment can also be used for collecting leaves, water or waste materials.

3.4.3 High pressure areas

Potential high pressure areas are the areas surrounding outdoor feeding places, water points and narrow passages where the vegetation cover can be destroyed by treading damage even at moderate animal density. By placing roughages and water points at upland areas and on trampling resistant ground and/or to move them around is a measure to prevent the risk of trampling damage. If these measures are not feasible, surface reinforcement of high pressure area can be an option (Lindgren & Lindahl, 2007).

3.4.4 Surface reinforcement

The purpose with surface reinforcement is to stabilize the soil surface, and stabilization can be achieved in several ways, either permanently or irreversibly. The types of permanent reinforcement can be constructions with cement boards or to change the topsoil material to a footing material such as gravel or wood chips, where the latter is not to recommend for feeding areas. In order to increase the percolation of water through the soil a tile drainage system can be constructed. Another option, which is more or less irreversible, is soil stabilization with different types of plastic mesh like grass reinforcement.

A survey of different grass reinforcements constructed in high animal density areas was conducted by the Swedish Institute of Agricultural and Environmental Engineering (Lindgren & Lindahl, 2007). The purpose of the survey was to evaluate if the reinforcements could tolerate treading by horses and/or cattle. The products Grass reinforcement and Hit Grid was used by farmers, while EquiTerr and TexWay two other reinforcement products not yet used by farmers in Sweden.

Grass reinforcement can be designed as meshes, carpets or sheets. The grass reinforcement carpet sold by Agronaut (www.agronaut.se) is a strong plastic mesh that is attached to the ground by shackles of iron. The grass can grow through the carpet and the surface remains stable while the natural drainage is maintained. The carpet is best placed on dry soil where there is no surface water. If placed where the vegetation is sparse soil particles can crawl up through the reinforcement and undermine the underlying layer. To obtain a robust area a geotextile should be placed beneath the reinforcement. This type of reinforcements can manage heavy load from both vehicles and animals. In the survey, the grass reinforcement carpet had a good durability if constructed and managed according to recommendations. The Grass reinforcement carpet was used in one of the horse farms in the study, placed by the inlet to a loose housing system without recommended preparation, however it seemed to have managed treading by horses.

Hit Grid is developed for horse paddocks, and is a coarse plastic raster that is recommended to be placed on a ten centimetre drainage layer and cover by a thin layer of gravel. The raster is 2 m2 squares and can be locked together. Hit Grid placed on a ground with poor bearing capacity the squares can accidently be detached. The Hit Grid is sold by Gimmex (www.gimmex.se). The Hit Grid was placed on another horse farm, and gave a good and stable surface that managed treading by horses.

EquiTerr is used in Sweden for parking lots and have not yet been used by farmers. Horse facilities in Germany and USA have reinforced areas with EquiTerr. The EquiTerr is panels (50*39*4,5) made of HD-polyeten plastic that is attached when placed. The construction demands a proper pre-work and is therefore an alternative for a more permanent installation. The EquiTerr withstand loads of 156 ton/m2.

TexWay (www.texway.se) is a synthetic carpet with rubber filling that is intended to be placed on a bearing cover of gravel to receive a curved surface with water runoff.

3.4.5 Phosphorus filter

Phosphorus filter is a countermeasure where a material with high affinity for phosphorus is applied to particularly absorb dissolved phosphorus transported with water (Ahlgren et al. 2011). Filter material can be applied directly to the fields by incorporation in the soil surface or applied in connection to ditches and drainage systems. For ditch application is it more common to apply the filter in the soil above tile drainage, application to open ditches is possible but more problematic. The active constituents of phosphorus adsorption filters are Ca/Mg and Fe/Al, their characteristics differs and filters with Fe/Al is more effective than Ca/Mg and are therefore a better alternative for systems with high phosphorus levels. The effectiveness of the active constituents is also dependent on the surrounding conditions and the soil pH is an important factor to consider.

3.4.6 Buffer strips

Buffer strips grown with grass or bushes along watercourses and lakes can catch particle bound phosphorus in surface runoff which otherwise could have been lost through surface runoff or erosion. The vegetation in the buffer strip decreases the rate of water flow and facilitates water infiltration and retention of particle-bound and dissolved phosphorus. The recommended size of a buffer strip can vary from 5 – 15 m depending on the topography and precipitation intensity of the location. However to obtain subsides the buffer strip sizes have to be 6 – 20 m wide (SBA, 2013). It is important that the vegetation of the strip has a ground cover during the whole year. Perennial grasses seem to be more effective than a mixture of herbs, trees and bushes (SBA, 2008; Ahlgren et al. 2011). Vegetative buffer zones have been reported to have a positive effective of both reducing phosphate phosphorus and total phosphorus in runoff from agricultural land (Patty el al. 1997) and grazing areas (Webber et al. 2010). However, the soil in the buffer zone will eventually become saturated with phosphorus and the buffer strips should therefore be harvested to permanently remove phosphorus. A problem with harvesting is that it may lead to destabilization of the buffer zone, which can lead to erosion, and harvesting should therefore not be conducted close to the water course bank (Wenger, 1999).

3.4.7 Infiltration ditch (Skåldike)

An infiltration ditch (Skåldike) is a developed form of a riparian strip for areas with high surface runoff, where infiltration of water as facilitated in a constructed ditch. This is a method which is often discussed for treatment of urban storm water. It should be dimensioned to catch a certain amount of runoff water that can infiltrate the ground during high intensity precipitation or snowmelt. The construction of the ditch edges should be flat and the ditch bottom built of infiltrating soil materials (Owenius, 2011 b).

3.4.8 Two-stage ditch

The design of a two-stage ditch consist of a mainstream enclosed with extended ditch edges at a higher level, like a plateau on both sides instead of the usual steep slopes (SBA, 2013). Two-stage ditches become more stable due the vegetation cover that function as soil reinforcement on the plateaus that should decrease the risk for erosion from the ditch walls. The ditch also functions at higher water flows without flooding, and the deeper part is narrower than in an usual ditch, which decreases the risk that the ditch dries out during summer time. The two-stage ditch is however a relatively unproven concept, and most research have been conducted in the USA and more research for Swedish conditions are required.

3.4.9 Phosphorus ponds

A phosphorus pond is often constructed in an already existing watercourse to slow down the water flow rate and thus enable sedimentation of particles. The sedimentation rate of a particle depends on the size and weight, for a small particle the sedimentation can take from days to weeks. The sedimentation trap should be rather deep to increase the water volume and thereby the turnover rate and also to decrease the risk of sediment washout. The design of a sedimentation pound is usually a deep hole by the inlet where the large particles sediment relatively fast, thereafter a more shallow area with a vegetation filter (SBA, 2008; Ahlgren et al. 2011). The purpose of the vegetation filter is to slow down the water flow rate and thereby increase the sedimentation, the vegetation also functions as a reinforcement by binding the sediment by their roots. Construction of a sedimentation pound demands permission from the County administrative board.

3.4.10 Wetlands

Wetlands can be constructed for several purposes like phosphorus and nitrogen retention as well as for increasing biodiversity (SBA, 2008). The formation and location of the wetland will be different depending on the purpose. Wetlands for phosphorus retention should be located close to the source and constructed as a phosphorus pond with a succeeding vegetation filter part.

4 Case study

4.1 Julmyra Horse Center

Julmyra is situated in Heby municipality in the county of Uppland. Julmyra Horse Center AB is owned by Julmyra Förvaltning AB and Sala Sparbank and is a gated community for people with a mutual interest in horses for racing and riding, either on a hobby or a professional level. The on-going expansion of Julmyra Horse Center (JHC) is divided in sub-area 1 and sub-area 2 with a total area of 250 hectares. In sub-area 1, the horse center provides facilities such as a horse racecourse, racetracks, drill-hall and riding trails. The area also includes a plan of a residential area for establishment of several apartment buildings. Sub-area 2 is a forested area which is planned to be divided in to 35 larger plots of two to five hectares per unit, according to a concept called "farm on the farm". In each individual "farm on the farm"-unit there are opportunities for private stables and paddocks. Today JHC accommodates 105 horses, but with the future plan of expansion the numbers may increase with up to 500 horses.

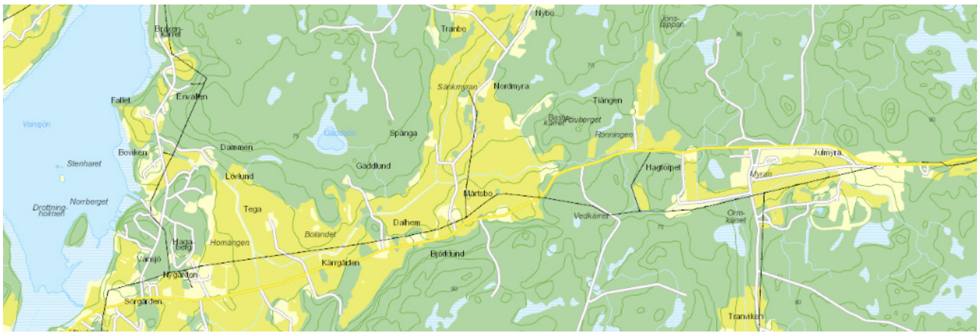

Figure 1. Overview of the JHC area and Vansjön - Nordsjön (VISS, 2009)

The JHC area is located upstream from the lakes Vansjön-Nordsjön (Figure 1). They are eutrophicated, which means that water conservation efforts need to be taken to prevent further load from the developing JHC area. An Environmental & Technology working team at JHC has therefore been established. One of their main aims is that the expansion and development of Julmyra shall be managed with the highest possible consideration for the nearby soil and water environment. The working team is developing strategies of how to minimize the negative environmental impact from the planned activities within the whole area. A cursory investigation concerning the nutrient load for the planned expansion area was made in 2007 by UVAT AB (UVAT, 2007). The investigation concluded that the increased nutrient impact will mainly originate from private wastewater facilities and as diffuse emissions from the horse management. In 2011, a self-monitoring program was started, which includes sampling of water in the streams running through the JHC area towards lake Vansjön-Nordsjön, for analysis of nitrogen and phosphorus concentrations (Table 1) (Owenius, 2011a). In 2012, an investigation identifying the main risk areas and suggestions of possible countermeasures was started (Owenius, 2012).

4.2 Hydrogeology and land use

The landscape surrounding Julmyra consists mostly of hilly forest areas and some arable land, marsh land and small lakes. There are areas with mountain outcrop and a subgrade of moraine. In the low land areas and marsh land the top layer consists of organic materials usually peat, and the subsurface of sediment of clay or silt (Heby Municipality, 2011). The JHC area is drained by the narrow water course Julmyrabäcken, which originally is a dug ditch. Downstream Julmyra, the watercourse connects with the somewhat larger Fallbäcken, which has its outflow in Vansjön-Nordsjön. Fallbäcken is the drainage recipient of 75 % of the total catchment for Vansjön-Nordsjön. The upper parts of the Julmyra area is dominated by forest land (Figure 2), while arable land becomes more predominant further down-stream, closer to the lakes (UVAT, 2007).

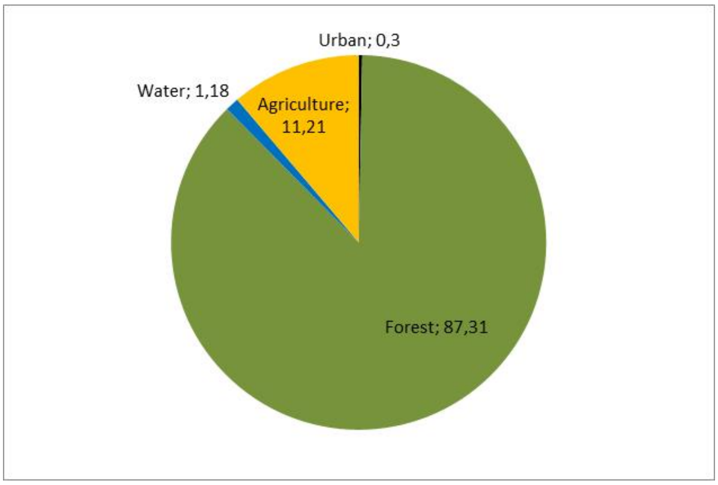

Figure 2. Land use in percentage, in the sub-catchment area with a total area of 39.2 km2 (SMHI, 2012).

4.3 Vansjön – Nordsjön

Vansjön and Nordsjön are connected lakes in the forest-dominated catchment area of Örsundaån, with Lake Mälaren as the final recipient. Until the 18th century, the lakes were used as water power reservoirs for mill activities in the area. In the end of the 18th century, after the mill was shut down, the water level of the lakes was lowered to create more suitable conditions in the surrounding area for agricultural production. Today, the lakes are therefore relatively shallow with depths varying from 1-2 meters, and a total area of 2,33 km^2. Limnological investigations of the lakes have been conducted three times over the years. The first was made by Gunnar Lohammar in 1933/35 and the second in

1975/76 by Maud Wallsten. The latest investigation was conducted in 1997 by Isabelle Olevall and Susanne Vesterberg at the department of limnology, University of Uppsala. In this investigation Vansjön was classified as an eutrophic lake. The total phosphorus content varied between 0.031 and 0.065 mg/l and the total nitrogen content from 0.67 to 1.2 mg/l (Olevall et al.,1998). According to Carlsson (1999), who used source apportionment modelling for estimations of the different sources of nitrogen and phosphorus transported to the lakes during 1989 to 1999, the main source was forest and thereafter agriculture. Fallbäcken, the watercourse which Julmyrabäcken connects with downstream Julmyra, was estimated to have a transport load of 200 kg of phosphorus per year to the lakes.

The lowering of the water level in the lakes changed the flora and fauna to be more characteristic for eutrophic water bodies. During summer periods there is a dense vegetation due to the water level and a nutrient rich sediments. The organisation "Vansjön Nordsjöns Väl" (www.vnval.se) was formed in 1996 with the aim to reduce the eutrophication effects on the lakes (Carlsson, 1999). In 2005, WRS, a consulting company in water management, made an investigation of construction and restoration of wetlands as nutrient traps in the catchment area of Vansjön-Nordsjön on behalf of "Vansjön Nordsjöns Väl". A wetland was suggested to be located in the JHC area to retain nutrients from horse paddocks and waste water from households (Andersson & Eriksson, 2005).

The total catchment area of Vansjön-Nordsjön is 55.4 km^2 and approximately 80 % is covered by forest and 12 % by arable land (Carlsson, 1999), the sub-catchment area where JHC is located is 39.2 km^2 (Figure 3). More recent investigations of the ecological status made by the County Administrative Board in 2009 which also indicate that the Vansjön-Nordsjön system is affected by eutrophication, giving the lakes a modest ecological status (yellow in the status classification colour map). The eutrophication is caused by agriculture activities and wastewater from private households within the catchment area (VISS, 2009). Within the Julmyra sub-catchment area, there are 189 private sewages (SMHI, 2012). The ecological status includes biological, physical- chemical and hydrological quality factors for surface water. The aim is that all surface waters should reach good ecological status until 2015. However the time limit to reach good ecological status for Vansjön-Nordsjön is extended to 2021 due to the measures that needs to be taken until 2015 is not economically defendable nor technically possible (VISS, 2009).

4.4 Eutrophication

In aquatic ecosystems eutrophication is a condition where high nutrient concentrations, mainly of phosphorus and nitrogen, stimulate the growth of algae. One consequence of eutrophication is intensive algal growth which is followed by degradation of the organic matter, oxygen depletion and death of organisms living in the benthic zone (Walls, 2006).

For fresh water bodies, phosphorus is the main limiting nutrient (Schindler, 1977). Diffuse phosphorus losses from agricultural production may effect water quality in streams, rivers and lakes and increase the eutrophication, which can present problems for the ecological status and recreational use (Haygarth, 2005; Ulén & Jakobsson, 2005). Of the net phosphorus load on inland lakes and watercourses caused by human activities, 44 % of 1390 ton/year, comes from agriculture (SS, 2012). Diffuse phosphorus losses from agriculture land has become a problem in all European countries due to the contribution to eutrophication (Ulén & Jakobsson, 2005). The potential phosphorus loss from the soil to water increases with increasing soil phosphorus content (Sharpley et al.1997). The transport of phosphorus in soil and water can occur in soluble forms as well as colloid-associated (Haygarth, 2005).

The Swedish Environmental Protection Agency (SEPA) has published a report on lakes and watercourses which provides a basis for assessing the status of aquatic areas in terms of several physical and chemical parameters, where one concerns nutrients (SEPA, 1999). For both total phosphorus and total nitrogen there is a scale of 1 – 5 (Table 4).

According to the first results from the JHC monitoring programme, the amounts of total phosphorus and nitrogen in the watercourse varies between 0.02 – 0.045mg/l and 0.82 – 1.5 mg/l respectively (Table 5). According to the Swedish Environmental Protection Agency's criteria for environmental quality for lakes and streams (Table 4) the level of total phosphorus in the watercourse equals moderate to high levels and the level of nitrogen equals high to very high levels.

Table 4. *Environmental Quality Criteria of total phosphorus and total nitrogen levels for lakes and streams (SEPA, 1999)*

Scale	Tot-P conc. (mg/l)	Tot-N conc. (mg/l)	Designation
Scale 1	0.0125	0.300	low
Scale 2	0.0125 – 0.025	0.300 – 0.625	moderate
Scale 3	0.025 – 0.050	0.625 – 1.250	high
Scale 4	0.051 - 0.10	1.251 – 5.000	very high
Scale 5	> 0.10	> 5.000	extremely high

Table 5. *Monitoring results of nutrient concentrations in water at the outflow from Julmyrabäcken in JHC self-monitoring program*

Date	Phosphate-P (mg/l)	Total-P (mg/l)	Total-N (mg/l)
Apr 4 2011	0.015	0.041	1.5
May 5 2011	0.005	0.02	0.88
Jun 17 2011	0.017	0.045	1.1
Dec 01 2011	0.01	0.027	1.4
Apr 27 2012	0.005	0.029	1.2
Oct 26 2012	0.005	0.039	0.82

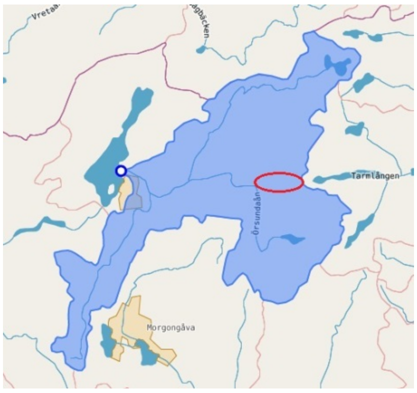

Figure 3. Sub-catchment area for Vansjön – Nordsjön where the JHC area is marked in red (SMHI, 2012).

5 Material and methods

5.1 Description of horse paddocks

Julmyra Horse Center comprises 250 hectares, of which approximately 6 hectares are used as paddock area for, in all, 105 horses (Figure 4). The paddocks are in use all year round, but the horses also spend time on pastures, during 2 - 4 weeks/year. The oldest paddocks have been managed for about 20 years, and the area for horse paddocks has expanded continuously as the number of horses has increased. The livestock density today is 17.5 horses per hectare. The horses are fed with roughage in the paddocks every day. The roughage residues and dung are left in the paddocks. Drainage water from the paddocks is drained to the watercourse Julmyrabäcken.

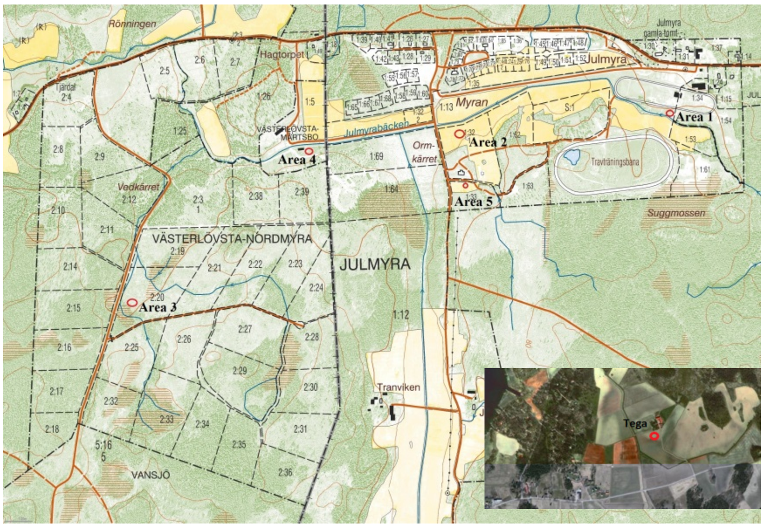

Figure 4. Overview of Julmyra Horse Center (Lantmäteriet). The soil sampling areas (sample numbers within parentheses) are included in the figure; Area 1 (1,2), Area 2 (3,4), Area 3 (5, 6, 7), Area 4 (8,9,10,11), Area 5 (12), Area 6 (13). Further information in Table 6.

5.2 Management at JHC

The information about paddock management practices, indoor and outdoor feeding, number of horses and paddock area was obtained from conversation with Geir Pedersen at JHC. In case of lack of information, data has been supplemented with standard values from literature and other.

5.3 Water sampling

Water sampling of Julmyrabäcken was conducted on two occasions, 7th of September and 26th of October 2012, at four sites both upstream and downstream JHC and at relative low flow conditions. The first sampling site was upstream Julmyra, the second at the outflow of Julmyrabäcken, the third at Mårtsbo and the fourth by the outlet to Vansjön (Figure 5). The selection of sample sites was chosen to investigate and compare the impact of horses with sewage from households and other agriculture activities. An additional water sample was collected on the 3rd of May 2012 of drainage water from a paddock in area 1:26 (Figure 4) as the drainage pipe was directly connected to the watercourse. The water samples were collected in glass bottles and were kept at a temperature slightly above 0 °C before analysis which took place within four days after sampling.

5.3.1 Water analysis

The water samples were analysed at the facilities of SLU for total phosphorus, phosphate phosphorus and total nitrogen according to the colorimetric methods of International Standard Organization (ISO 2003). The concentrations of total phosphorus were determined on unfiltered samples and analysed after oxidation with sulphuric acid (H2SO4) and potassium persulphate (K2S2O8) as oxidizing reagents. The phosphate phosphorus concentrations were determined on filtered samples without oxidation. The total nitrogen concentration was determined by a combustion catalytic oxidation method where all nitrogen was converted to nitrous oxide before analysis (Shimadzu TOC-VCPH +TNM -1) according to European Standard (SS-EN 12260-1).

5.4 Soil sampling

Soil sampling was conducted to investigate the soil phosphorus status in the paddocks in sub-area 1 and in the forest soil in sub-area 2 for future expansion. The sampling areas were selected in order to represent paddocks with low to high pressure and reference areas (Figure 4, Table 6). The soil samples were collected on two occasions, either 3rd of May or 7th of September. Soil was collected from the top-soil (0-20 cm depth) with a soil auger. Approximately 1 kg of soil was collected in a bucket, mixed and put into plastic bags to prepare for analysis.

Table 6. *Description of areas for soil sampling*

High pressure paddock	**Low pressure paddock**	**Reference area**
Farm centre (Area 1)	Area 2	Lawn (Area 5)
Loose housing (Area 4)		Forest (Area 3)
		Arable field (Area 6)

5.4.1 Soil analysis

All soil samples were pre-treated by drying in 40˚C until dry, ground and sieved through a 2 mm sieve, at the laboratory facilities of SLU.

The analysis of phosphorus (P), iron (Fe), aluminium (Al), calcium (Ca), organic and total carbon (Tot-C), total nitrogen (Tot-N) and pH were performed by Agrilab AB in Uppsala. For analysis of bioavailable phosphorus, aluminium (Al), iron (Fe) and calcium (Ca) the extraction method used was with ammonium lactate; ammonium lactate 0.1M and acetic acid 0.4M at pH 3.75 and a soil/solution ratio of 1:20 (Egnér et al. 1960). The extracts was then analysed with inductively coupled plasma (ICP) spectrometry. The organic and total carbon was determined after dry combustion according to Swedish Standard (SS-ISO 10694). The total nitrogen content was determined by dry combustion according to Swedish Standard (SS-ISO 13878). The determination of soil pH was according to Swedish Standard (SS-ISO 10390).

The Phosphorus Sorption Index (PSI), determined by the colorimetric method (molybdophosphoric blue colour method) was used as an indicator of the ability for phosphorus sorption in the soils. Triplicates from each soil sample were analysed giving a total of 39 samples. Two grams of air-dried soil samples were placed in 50 ml plastic centrifuge tubes and 20 mL of 0.01 M CaCl2 with a KH2PO4 at a concentration of 10 mmol kg-1 soil was added. The samples were placed in a shaker for 20 h (at moderate rate). The suspension was then centrifuged at 3000 rpm for 20 min. The supernatant was collected and filtered through a 0.45 µm membrane filter. Thereafter 0.5 – 5 ml of the supernatant was added to a 50 ml volumetric flask to which 8 ml of reagent was also added. The flasks were then filled with distilled water to a volume of 50 ml. The concentrations of the solutions were then measured in a photo spectrometer at the wavelength 904 nm. The sorbed equilibrium concentration (CP µmol/l), which is the difference between the phosphorus first added and the final concentration, was calculated. The PSI values was calculated as described by Bache & Williams (1971) and Börling et al. (2001) using the equation PSI= X/log CP, where X represents the amount of phosphorus adsorbed by the soil (mmol/kg soil) and CP the phosphorus concentration in the solution (µmol/l).

The degree of phosphorus saturation (DPS) for ammonium lactate was calculated on a molar basis. The equation was as follow: DPS = (P-AL/Fe-AL + Al-AL)*100 (Ulén, 2006).

5.4.2 Soil classification

Soil textures were classified based on a simple roll test and the organic carbon content as described by Eriksson et al. (2011). The organic matter content was determined from carbon content according to Ekström (1927).

5.5 Phosphorus load in paddocks

The import of phosphorus with feedingstuffs was used for estimations of the phosphorus input to the paddocks. It was assumed that all phosphorus which passes through the horses will be found in urine and faeces, and an estimation was made of how much of the excreted phosphorus would end up on the paddock area. For calculations of manure allocation, the time spent outdoors was used. There was also a comparisons made with the expected amounts of phosphorus excreted in horse manure from standard values according to the Swedish Board of Agriculture. The losses of phosphorus from paddocks through leaching and erosion was assumed to be very low in comparison to the content in manure, and was not included in the calculations.

Finally, scenario calculations were made in order to find out how an increased amount of horses would affect the phosphorus load on JHC.

5.6 Statistical analysis

In order to determine significance of the correlation between different characteristics regression analysis was performed in Sigmaplot. A significance level of 5% ($P < 0.05$) was used.

6 Results

6.1 Nutrient content in stream water

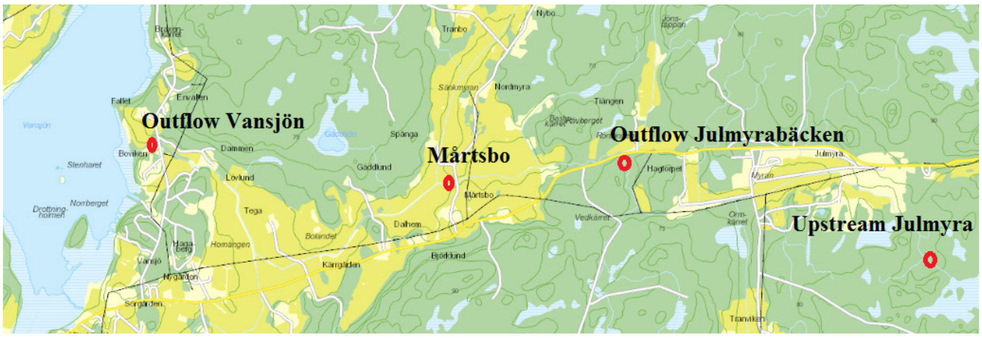

Figure 5. Water samples were taken upstream and downstream JHC (VISS, 2011).

The four sampling sites for stream water from upstream Julmyra and down to Vansjön are shown in Figure 5 and measured values in Table 7. Nutrient concentrations along the watercourse increased downstream at both sampling occasions. The concentrations of phosphate phosphorus, i.e. the dissolved form of phosphorus which is bioavailable, fluctuated between 0.004 to 0.011 mg/l and the concentrations of total phosphorus from 0.012 to 0.047 mg/l. The total nitrogen concentrations were higher in September (0.95 – 1.4 mg/l) than in October (0.52 – 0.87 mg /l). By using the "Environmental Quality Criteria" for assessing the status of the watercourse, total phosphorus was found to be in scale 1 – 3 (low to high) and total nitrogen in scale 2 – 3 (moderate to high).

During field work, a drainage pipe was found that drained the water directly out into the watercourse. Analysis of the drainage water revealed higher concentrations of phosphate phosphorus and total phosphorus (Table 8) than analysis of the samples from the watercourse (Table 7).

Table 7. *Phosphorus and nitrogen concentrations of water sampled from the water course*

Date	Sampling site	Phosphate-P (mg/l)	Total-P (mg/l)	Total-N (mg/l)
070912	Upstream Julmyra area	0.004	0.017	0.95
070912	Outflow Julmyrabäcken	0.005	0.028	1.12
070912	Mårtsbo	0.005	0.030	1.14
070912	Outflow Vansjön	0.010	0.047	1.40
261012	Upstream Julmyra area	0.005	0.012	0.52
261012	Outflow Julmyrabäcken	0.006	0.024	0.75
261012	Mårtsbo	0.007	0.024	0.75
261012	Outflow Vansjön	0.011	0.033	0.87

Table 8. *Phosphorus and nitrogen concentrations of drainage water from a paddock with direct connection to Julmyrabäck-en*

Date	Sampling site	Phosphate-P (mg/l)	Total-P (mg/l)	Total-N (mg/l)
030512	Drainage pipe paddock	0.021	0.042	1.08

6.2 Soil physical and chemical properties

Table 9. *Humus content determined by calculating from carbon content (Ekström, 1927) and soil classification according to Eriksson et al. (2011). Area number is equal with the map area number in Figure 4*

Soil (Sample number)	Tot_C (% of DM)	Humus content	Soil texture	Swedish soil texture class
High pressure paddock: Area 1 (1)	1.65	2.8	Sand	mr Sa
High pressure paddock: Area 1 (2)	4.02	6.8	Sand	mr Sa
High pressure paddock: Area 4 (8)	13.0	22.1	Sandy peat	sa M
High pressure paddock: Area 4 (9)	21.5	36.6	Sandy peat	sa M
High pressure paddock: Area 4 (10)	6.0	10.2	Sandy loam	mr LL
High pressure paddock: Area 4 (11)	21.1	35.9	Sandy peat	sa M
Low pressure paddock: Area 2 (3)	17.1	29.0	Sandy peat	sa M
Low pressure paddock: Area 2 (4)	18.5	31.5	Sandy peat	Sa M
Reference: Area 5 (12)	2.1	3.6	Sandy loam	mmh LL
Reference: Area 6 (13)	1.9	3.2	Sandy loam	mmh LL
Forest: Area 3 (5)	26.3	44.7	Sandy peat	sa M
Forest: Area 3 (6)	18.0	30.6	Sandy peat	sa M
Forest: Area 3 (7)	7.0	12.0	Moraine	mr Mä

Table 10. Soil characteristics of horse paddocks and reference areas. For PSI, standard derivation (s.d) of the three samples at each location are presented

Sample site (Sample number)	Site description	pH	P-AL (mg/100 g)	Class	Ca-AL (mg/100 g)	Al-AL (mg/100 g)	Fe-AL (mg/100 g)	Tot_P (mg/kg DM)	Tot_C (% of DR)	Tot_N (% of DM)	DPS (%)	PSI (Mean value)	PSI (s.d)
High pressure paddock: Area 1 (1)	Farm centre (gate)	6.4	17.7	V	38	33	78	573	1.65	0.25	22.0	1.15	±0.12
High pressure paddock: Area 1 (2)	Farm centre (path)	6.3	9.9	IVA	134	38	117	514	4.02	0.38	9.08	3.75	±0.22
High pressure paddock: Area 4 (8)	Loose housing (path)	5.7	7.9	III	357	97	123	704	13.0	0.68	4.37	7.85	±0.24
High pressure paddock: Area 4 (9)	Loose housing (path)	5.9	5.9	III	398	190	113	810	21.5	1.02	2.10	13.50	±0.85
High pressure paddock: Area 4 (10)	Loose housing (defecation area)	6.5	16.3	V	229	50	130	730	6.0	0.37	12.7	4.67	±0.02
High pressure paddock: Area 4 (11)	Loose housing	5.8	7.0	III	366	168	97	781	21.1	0.98	2.83	10.96	±0.04
Low pressure paddock: Area 2 (3)	Paddock	5.9	3.7	II	409	130	80	571	17.1	0.78	1.89	8.71	±0.14
Low pressure paddock: Area 2 (4)	Between paddocks	6.0	4.2	III	422	153	86	640	18.5	0.93	1.90	9.23	±0.84
Reference: Area 5 (12)	Lawn	5.8	1.4	I	183	25	68	710	2.1	0.31	2.15	4.62	±0.68
Reference: Area 6 (13)	Arable field	6.2	2.8	II	189	23	26	647	1.9	0.25	6.86	2.79	±0.58
Forest: Area 3 (5)	Forest (hill)	4.7	5.2	III	218	57	64	531	26.3	1.05	5.19	5.00	±0.14
Forest: Area 3 (6)	Forest (marsh)	5.5	3.8	II	299	124	93	640	18.0	0.89	1.98	8.10	±0.06
Forest: Area 3 (7)	Forest (till)	4.0	2.2	II	11	42	19	49	7.0	0.26	3.73	1.01	±0.45

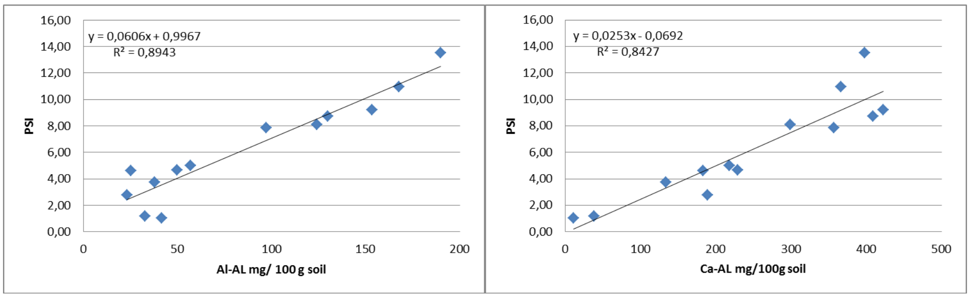

Figure 6. Regression plots for phosphorus sorption index (PSI) versus extractable aluminium (Al) and calcium (Ca).

The soils in the area are rich in humus (Figure 4) and the mineral fractions are dominated by sand, sandy loam and moraine (Table 9).

In the topsoil, P-AL was not significantly correlated with neither of the minerals associated with soil phosphorus binding; Al-AL, Fe-AL, Ca-AL or with soil C content (Table 10). However the phosphorus sorption index (PSI) showed a highly positive correlation with the amount of aluminium (Al) ($r = 0.96$, $p < 0.0001$) and the amount of calcium (Ca) ($r = 0.92$, $p < 0.0001$) (Figure 6) but no significant correlation with iron (Fe). Parvage et al. (2011) also found Al to have the strongest correlation with extractable phosphorus, and Al is often described as being the parameter more strongly correlated with phosphorus sorption than Fe.

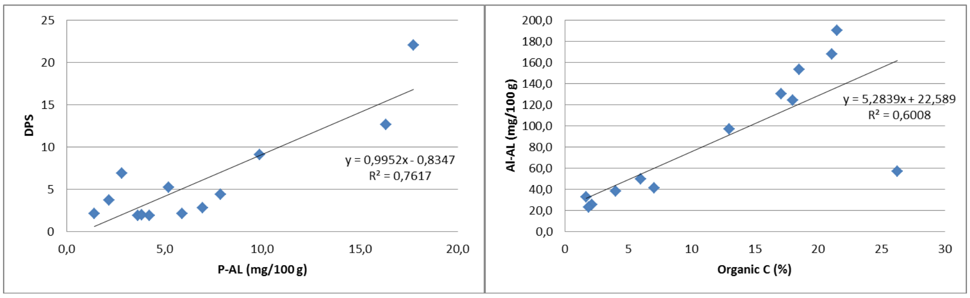

Figure 7. Regression plots for soil parameters; degree of phosphorus saturation (DPS) versus extractable phosphorus (P-AL), extractable aluminium (Al) versus organic C (%).

The degree of phosphorus saturation in the soil (DPS) can be estimated using different measured soil parameters. In this study the following was used: DPS = P-AL/Fe-AL + Al-AL on a molar basis (Ulén, 2006) due to it had the best significant correlation with P-AL contents ($r = 0.87$ $p < 0.0001$).

Al-AL showed a positive significant correlation with soil carbon content ($r = 0.7751$ $p = 0.0019$). Al-AL increasing with soil carbon content is consistent with that Al is strongly associated with organic matter (Börling et al. 2001).

6.2.1 Soil phosphorus status of paddocks

The lowest values for PSI were found in one of the forest areas but the lowest values for sampled paddock areas were (1.15 and 4.67) and the highest DPS (22.0 and 12.7 %) as well as the highest content of P-AL (17.7 and 16.3) were found in Area 1 “Farm centre” and in Area 4 “Loose housing, defecation area” (Table 10). That phosphorus addition in form of manure decreases the phosphorus sorption maximum due to increased saturation of the soil was reported by Siddique & Robinsson (2003). The other sampled areas in Area 4 “Loose housing”, with lower loads of horse manure, had higher PSI values and lower DPS and P-AL values than the “defecation area”.

The P-AL content in the rest of the sampled paddocks varied between 4.2 – 7.9 mg/100 g soil, and according to the agricultural P-AL classification system they varied between class II and III, whereas the highest values in Area 1 and Area 4 were in the highest, class V. The arable field had a lower P-AL content than all of the paddocks as well as a low PSI and DPS values.

Parvage et al. (2011) found that the horses are often kept close to the stable and that the carbon contents in the paddocks nearer the stable were higher than those further away. There are no such results in this study and instead the lowest carbon contents were found in the paddock that had been used for the longest period time. Here, the area is a former marsh land and the soils had high carbon content for natural reasons.

6.2.2 Soil phosphorus status of forest soil

Three samples were collected from the forest soil in sub-area 2 in three different types of areas, on a hill, in a marsh land and in a till soil (Table 4). The lowest PSI values of all sampled areas were found in the forest till (1.01). The extractable amounts of aluminium (Al), iron (Fe) and especially calcium (Ca) were low and can therefore explain the low phosphorus adsorption capacity. The marsh land had higher PSI (8.10) and very low degree of phosphorus saturation (1.98%) due to higher amounts of Al, Fe and Ca that play a major role in binding soil phosphorus. The hill area had a PSI of 5.0 (moderate high) and a DPS of 5.19 % (low).

6.3 Phosphorus load on paddocks

6.3.1 Estimations of today

A rough estimation, with the ambition to reflect the import of phosphorus via feedingstuffs at JHC, was made, where the rations for both horses and ponies were calculated on a yearly basis (Table 11). The content of phosphorus in the feedingstuffs is represented in Table 12.

The estimated total amount of imported phosphorus via feedingstuffs was about 1268 kg P/year (Table 13). With 105 horses divided on 6 hectares the livestock density today is 17.5 horses per hectare. The horses are outdoor 6 hours per day which means that approximately 25 % of the dung is deposited in the paddocks, containing 317 kg P/year, giving a yearly deposition of 53 kg P/ha. Horses tend to defecate in certain areas of a paddock and the dung are therefore heterogeneously distributed which increases the risk for phosphorus accumulation in certain areas.

In Table 13, the phosphorus load on the paddocks is calculated from standard values of phosphorus excreted in horse manure (SBA, 2011). The amount of phosphorus deposited in paddocks based on the standard values would be 38 kg P/ha. The calculated amounts of phosphorus differ by 15 kg P/ha, where the values estimated from rations is higher than the standard values.

Table 11. *Number of horses, stable days and rations expressed in kg/stable day and in kg/year based on information from Geir Pedersen, JHC*

	Number of horses/pony	Number of stable days/year	Roughage kg/day *kg/year*	Concentrate kg/day *kg/year*
Horse	100	344	10	5
			344000	*172000*
Pony	5	344	5	
			8600	
Total			**352600 kg/year**	**172000 kg/year**

Table 102. *Feedingstuffs total content of phosphorus (P) expressed in g/kg*

Feedingstuff	Tot-P
Roughage*	1.4
Concentrate**	4.5

*Average value from analysis results of roughages conducted by Eurofins.

**Data from Svenska Foder.

Table 113. *Yearly import of phosphorus today and for scenario calculations based on rations, and excreted amount of phosphorus based on standard values for today and scenario calculations*

	Yearly import of phosphorus via feedingstuffs			Excreted phosphorus based on standard values (SBA, 2011 b)	
Today	Roughage (kg)	Concentrate (kg)	Total import of P (kg)	Secreted P kg/horse year	Total amount of P kg/year
Horse	482	774	1256	8.9	890
Pony	12		12	6.4	32
Total	**494**	**774**	**1268**		**922**
Scenario calculations					
Horse	2288	3677	5965	8.9	4228
Pony	60		60	6.4	160
Total	**2348**	**3677**	**6025**		**4388**

6.3.2 Scenario calculations

According to the future plan of expansion the number of horses will increase to 500. The scenario calculation is based on the same rations as in Table 11 and on the phosphorus content in Table 12. Today, ponies represent approximately 5 % of the total number of horses and in the scenario calculations they represent the same frequency. The total amount of imported phosphorus to JHC with an increase to 500 horses could be 6025 kg P/year (Table 13). Scenario calculations based on standard values for horse manure (SBA, 2011), gives a total amount of 4388 kg P/year (Table 13).

7 Discussion

There is a complex combination of factors that determines the nutrient content in drainage and runoff water from horse paddocks; land use in previous years, vegetation cover during the year, amount and intensity of precipitation, soil profile characteristics, drainage system, topography, paddock size, livestock density and barriers in the landscape. Specific for phosphorus is the binding ability in the soil profile.

7.1 Stream water monitoring

Eutrophication is one of the major threats for the water quality of the Swedish fresh waters. Therefore, environmental monitoring is important to be able to identify if, and to what extent, countermeasures are needed. In this study watercourse sampling was only conducted at two occasions. This is not enough to see a trend, but gives us momentary status of the phosphorus and nitrogen concentrations in the water course. However, the results of the water analysis is consistent with the results from the JHC monitoring program that began in 2011, which includes measurements of the nitrogen and phosphorus concentrations at four occasions per year at three sites along in the JHC area (Owenius, 2011 a). The sampling sites in this study were selected to be able to compare the impact of the horses at JHC with wastewater from households and from agriculture activities. The concentrations of phosphate and total phosphorus increase downstream. According to the "Environmental Quality Criteria" the status of the watercourse for total phosphorus was classified as low at the outflow from Julmyra and high by the inlet to Vansjön-Nordsjön and from moderate to high for nitrogen. The increased concentrations of nutrients downstream are partly due to agriculture activities and wastewater from private household, but the main source are likely to be the forest, as 87 % of the sub-catchment area is covered by forest.

7.2 Soil phosphorus characteristics of the paddocks

The obtained results for calculations of the relationship between PSI and AL-extractable Al, Fe and Ca in the soil showed that the relationship was strongest for Al. Aluminium is often described as being the parameter more strongly correlated with phosphorus sorption than Fe (Börling et al. 2001). The Al-AL in the soils increased with soil organic carbon. Borggaard et al. (1990) found that organic matter has no direct influence on adsorption of phosphate in Danish sandy soils and no correlation was found in this study either. The adsorption capacity for phosphate changes with the amount of extractable amount aluminium and iron, irrespective of the organic matter content. The paddocks classified as high pressure paddocks were identified as the paddocks with the highest amount of extractable phosphorus. Motavalli & Miles (2002) found that long-term application of animal manure generally resulted in increased phosphorus pools. Two of the high pressure paddock had more enriched soil phosphorus pools than the others; the “farm centre” (Area 1) and the “defecation area” in the loose housing paddock (Area 4), and the soil P-AL is usually related to the concentrations of dissolved phosphorus in drainage water (Ulén et al. 2000) which make these high risk areas. With high P-AL values, high DPS and low PSI, these areas are presumed to be affected by previous dung deposition, as phosphorus previously added blocks parts of the sorption sites (Börling, 2003; Liu et al 2012). This indicates that when a soils affinity for phosphorus decreases, with rising DPS, more phosphorus can be released to the soil solution and thereby increase the risk for higher phosphorus losses. Therefore additional applications of manure on soils like this should be avoided (Liu et al. 2012). The paddock at the “farm centre” has been used as pasture for other animals during a long period of time and became a horse paddock in 1990, therefore the high phosphorus content is probably not a result of the horse management alone but an accumulation over a longer period of time.

The critical threshold of soil phosphorus saturation was first introduced in the Netherlands as a part of their environmental and manure management, and the critical saturation threshold was set to 25 %. This critical threshold of 25 % have been applied on other soil types and if that is appropriate can be discussed (Beauchemin & Simard, 1999). In this study the critical threshold have not been investigated, however conclusions can be drawn from the “farm center” with a P-AL of 17.7 mg/100g soil, a PSI of 1.15 and a DPS of 22 % are approaching a degree of phosphorus saturation that could be the critical threshold for this soil.

According to Djodjic et al. (2004) a risk assessment should include adsorption and release of phosphorus from both top-soil and sub-soil and the water transport mechanism through the soil profile. In this study the top-soil was analysed, but for further investigations and analysis of the sub-soil should be conducted.

7.3 Horse density

The recommendations regarding horse densities, in order to retain a vegetation cover in the paddocks, are 1 horse/1000-5000 m^2 (2-10 horses/hectare) according to a report from the Swedish Board of Agriculture (SBA, 2006). However, the recommendations were recently somewhat modified and is now more focused on adaption to the existing soil conditions to prevent treading damages (SBA, 2013), instead of general recommendations. With the horse density recommendations from SBA (2006) the 105 horses at JHC, would require 10.5 – 52.5 ha of paddocks, instead of the current 6 ha that gives a horse density of 17.5 horses per hectare. The high horse density at JHC causes treading damages in the paddocks by the lack of, or very poor, vegetation cover and in some areas of standing water. Treading damages may reduce the infiltration capacity of a soil, but it can be recovered after about a year, depending on the soil type, if allowed to rest (Tian et al. 2005). It is important to prevent treading damages for both animal health and for environmental purposes (Singleton et al. 2000; Taddese et al. 2002) and therefore the horse density in the paddocks should be reduced and a paddock rotation needs to be implemented.

7.4 Protection of the water course

Numerous of the paddocks on the slope are located adjacent to the water course. Surface runoff from these paddocks runs likely directly into the water course and therefore a buffer zone should be implemented. Vegetative buffer zones, with grass, have been reported to have a positive effective of reducing phosphate phosphorus and total phosphorus in runoff from agricultural land (Patty el al. 1997) and grazing areas (Webber et al. 2010). However the soil in the buffer zone will eventually become saturated with phosphorus, and the vegetation of buffer strips should preferably therefore be harvested to permanently remove phosphorus. A problem with harvesting is that it may lead to destabilization of the buffer zone which can lead to erosion, harvesting should therefore not be conducted close to the watercourse bank (Wenger, 1999).

7.5 Forest area

To minimize the environmental impact of horse paddocks at the exploitation of the forest, sub-area 2, soil sampling may be conducted as a help to find the most suitable location in regard of soil phosphorus sorption capacity. The forest moraine soil had low DPS but also low PSI and low amounts of Al, Fe and Ca indicating that this soil have a low phosphorus sorption capacity. The other two sampled areas had better phosphorus sorption capacities and higher contents of Al, Fe and Ca, which make these soils more buffering against phosphorus leaching related to phosphorus loading. Moraine soils have however a good infiltration capacity that would prevent surface runoff and treading damages due to saturated soils, therefore with a paddock management that includes dung and roughage residues cleaning these areas could be suitable paddock areas.

7.6 Phosphorus load

With a horse density of 17.5 per hectare, the annual input of phosphorus from dung deposition was estimated to be 53 kg P/ha when calculated from rations, if calculated with standard values of phosphorus excreted in horse manure (SBA, 2011) the deposition was 38 kg P/ha. The variation in phosphorus deposition can partly be due to when calculating with rations the assumption is taken that all phosphorus in the feedingstuffs is excreted in the manure, and also that most of the horses at JHC are trotting horses and have probably therefore more nutritious rations than what is included in the standard values. The actual amount of phosphorus deposited is likely in between these values, either way the amount of phosphorus in the paddocks exceeds the plant uptake, especially since most of the paddocks have poor vegetation cover. In comparison, the annual amounts of phosphorus application with manure spreading to arable land are restricted to 22 kg/ha and year as a mean value for a five year period and the fertilizing recommendations for grazing fields on arable land is 15 kg P/ha for soils with P-AL class I and 5 kg P/ha for class II. Even though the soil P-AL values in most of the paddocks are desirable or even too low in regard of agricultural crop needs, the lack of vegetation and the high depositions of phosphorus results in excessive soil phosphorus content that is not sustainable in the long-term.

7.7 Countermeasures

A wetland was suggested to be constructed to trap the nutrients leaching from the JHC area, in an investigation where possible nutrient traps were evaluated in the catchment area of Vansjön-Nordsjön. The suggestion was a wetland located before Julmyrabäcken connects with Fallbäcken, the watercourse that drains the catchment. From the results of this study the situation today do not require this measure, however if the paddock management do not improve and the number of horses increases, a constructed wetland would be a necessary countermeasure. Measures that however needs to be taken today are increased paddock areas and cleaning of dung and roughage residues and establish grass vegetated buffer strips between the paddocks and watercourse.

8 Conclusions

Even though the phosphorus status in most of the paddocks was at moderate levels, the paddock management at JHC is not sustainable. In the management today the horses are fed with roughages in the paddocks, and the residues and dung are not taken away. Moreover, the ground is affected by treading damages due to high density of horses. If the same management remains, phosphorus will slowly accumulate and, eventually, this will probably lead to increased phosphorus losses and increased surface runoff. The degree of phosphorus saturation of the soils is quite low which implies that applied phosphorus can accumulate, but in the long-term an increased phosphorus content will cause an increased risk of losses from the soil. A sustainable horse management would be to regularly clean out the dung and roughage residues, reduce the horse density and implement paddock rotation for both environmental and horse health purposes.

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